Basic impacts of anthropogenic climate change

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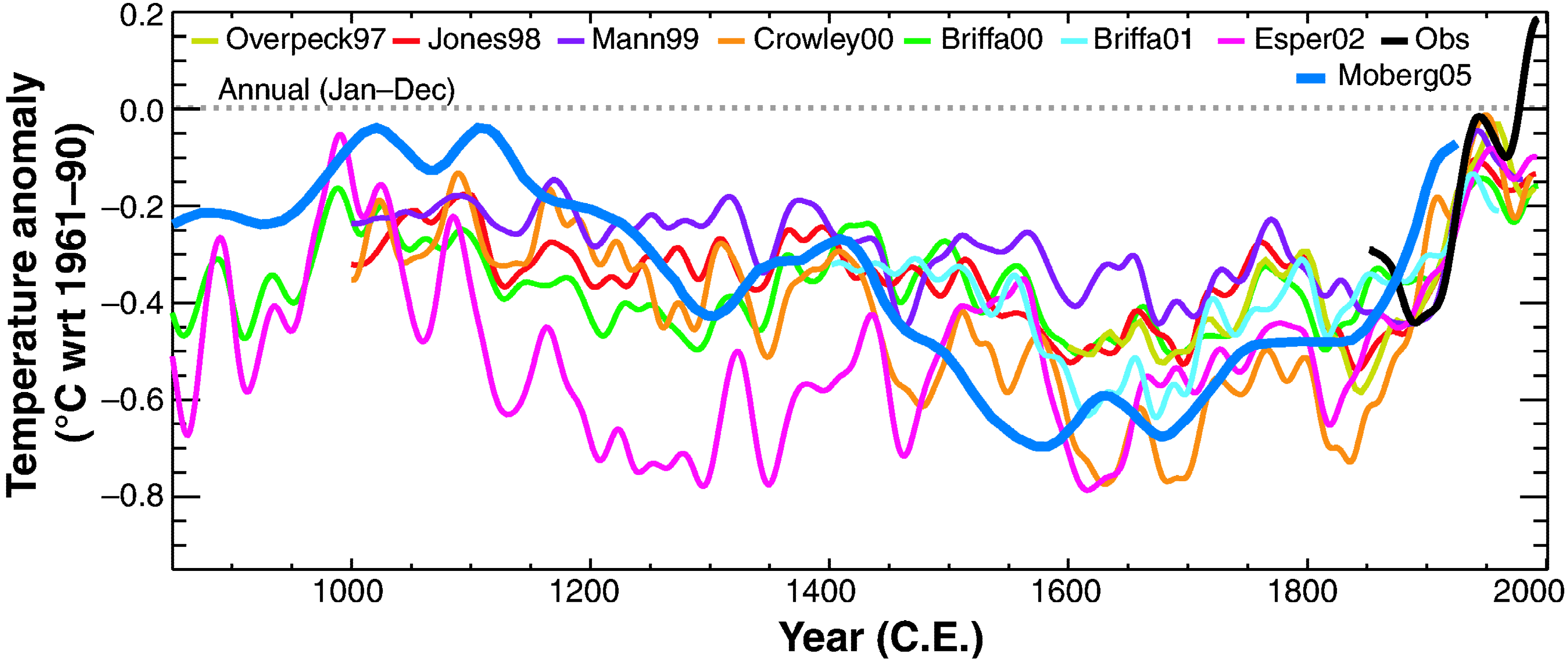
PIK

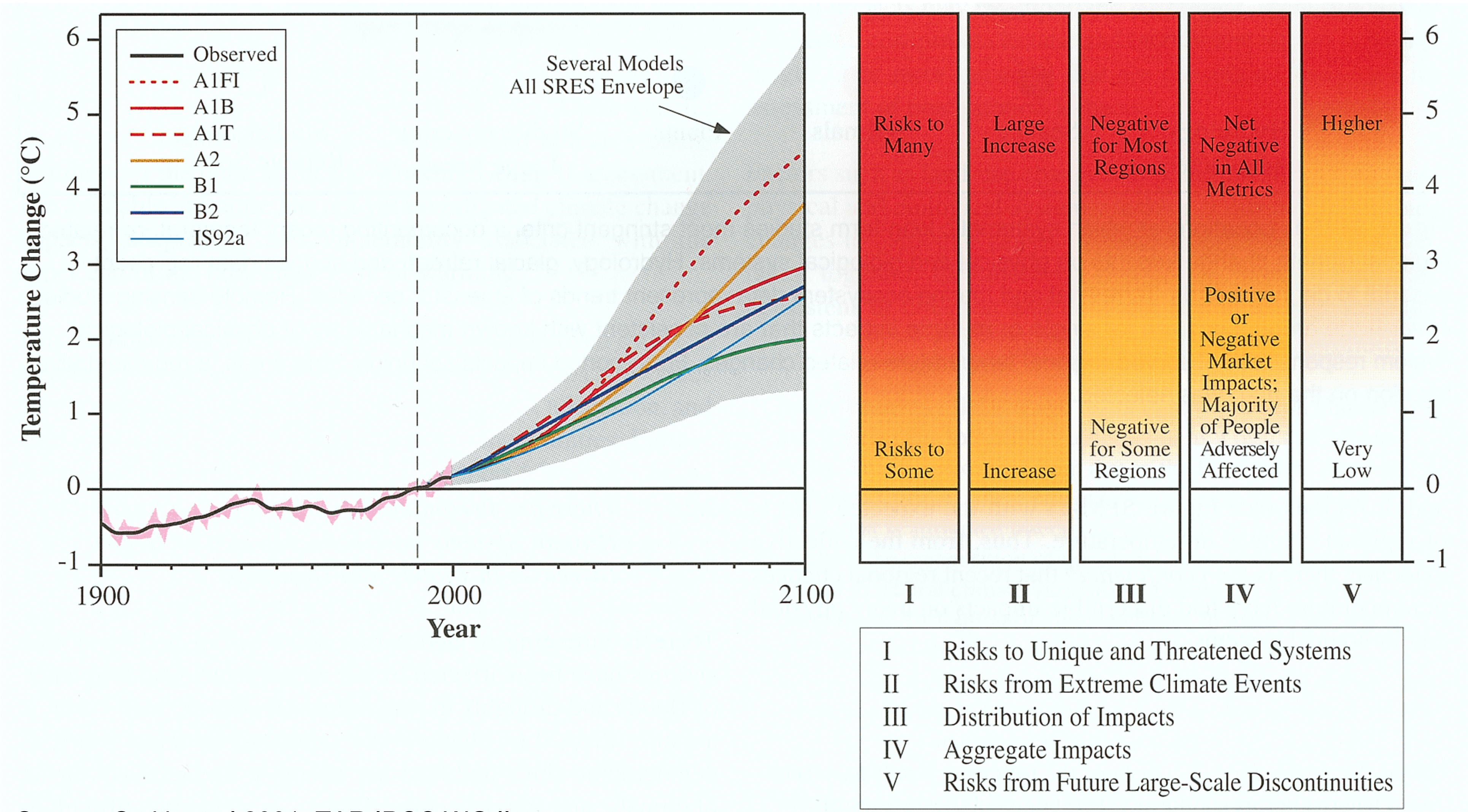
with contributions
from Alberte Bondeau,
Hermann Lotze-Campen,
Wolfgang Lucht and others



Still no equal. Temperature records recovered from tree rings and other proxies broadly agree that no time in the past millennium has been as warm as recent decades (black).

Kerr, Science 2005

“Reasons for concern”



Source: Smith et al 2001, TAR IPCC WG II

Main questions

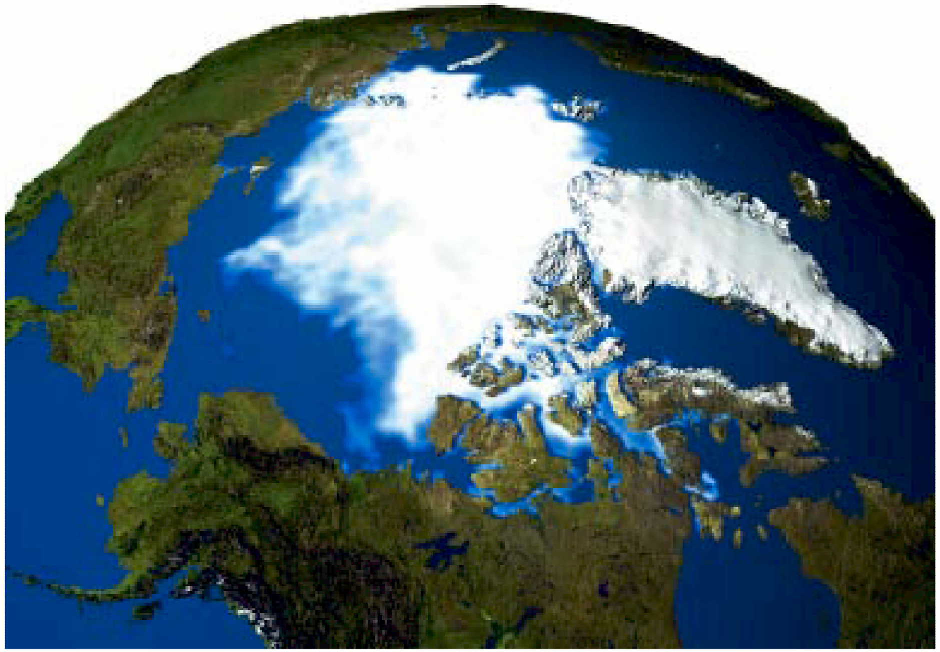
1. Is there any evidence for impacts of anthropogenic climate change that have already occurred?
2. Are future impacts of anthropogenic climate change to be expected?

Question #1

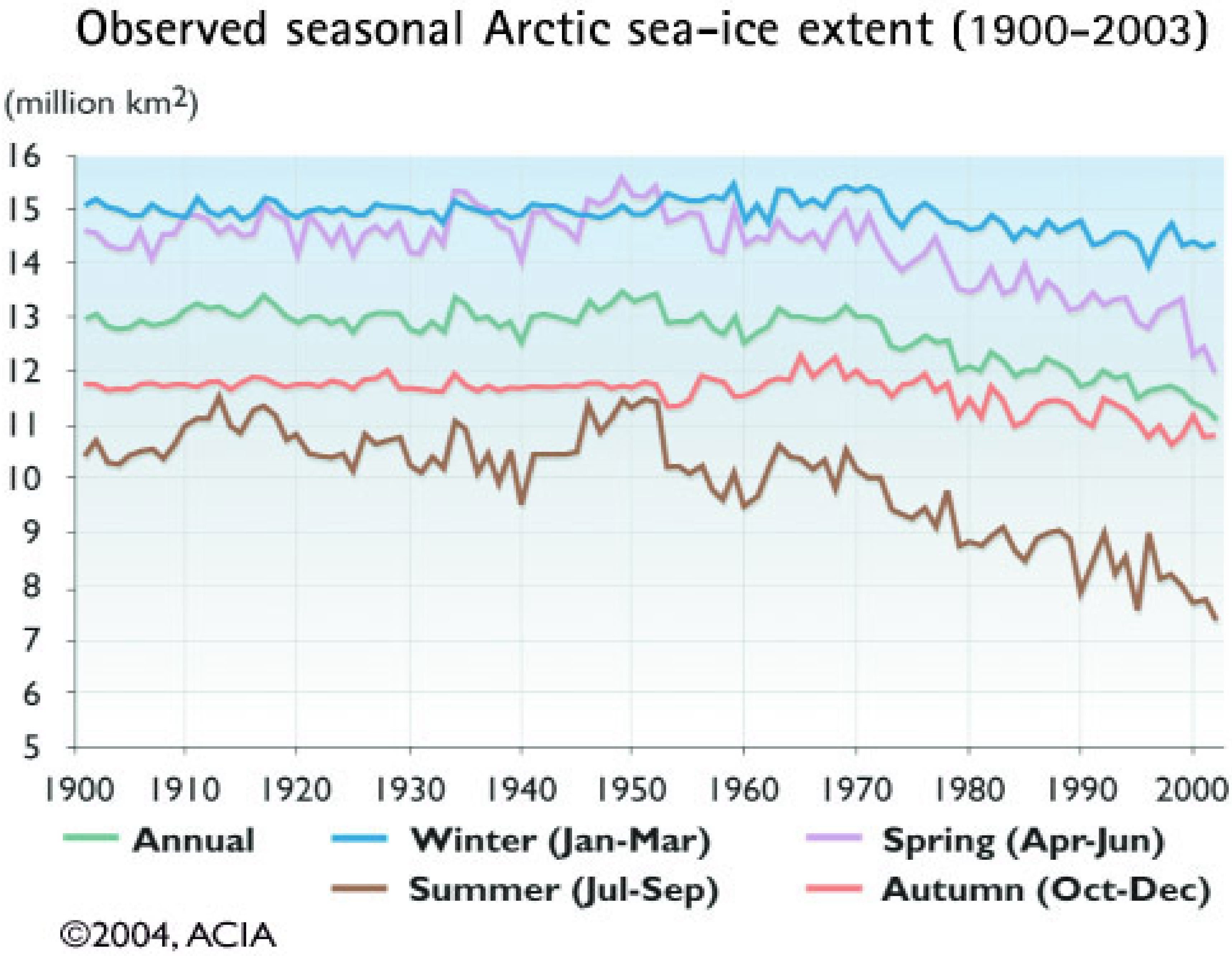
1. Is there any evidence for impacts of anthropogenic climate change that have already occurred?
   i. Do we see any change in natural systems (ecosystems, hydrology etc.)
   ii. If so, can we attribute that change to climate change?
   iii. If so, can we attribute part or all of the change to anthropogenic climate change?

Observed Sea Ice September 1979

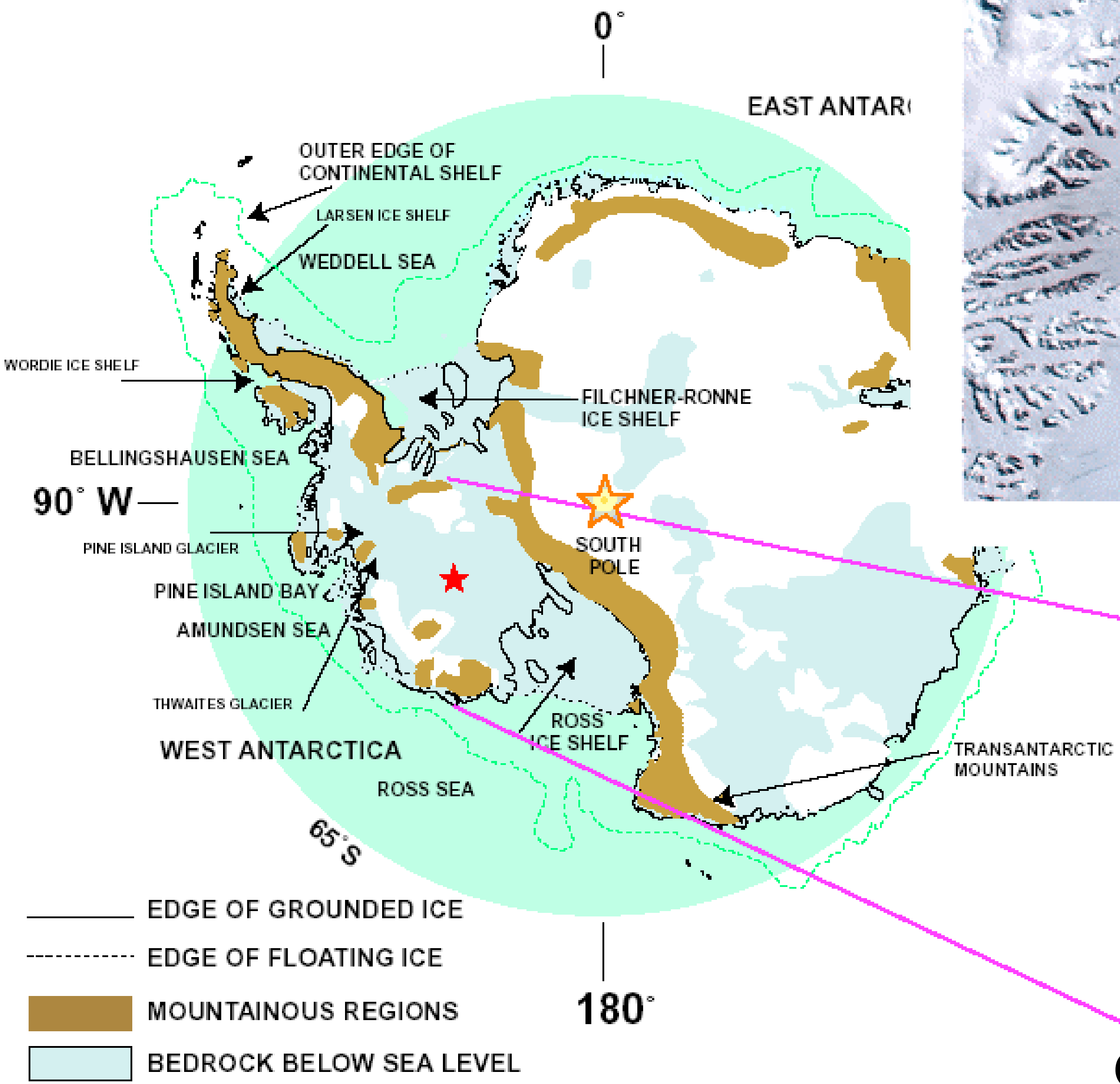
Observed Sea Ice September 2003

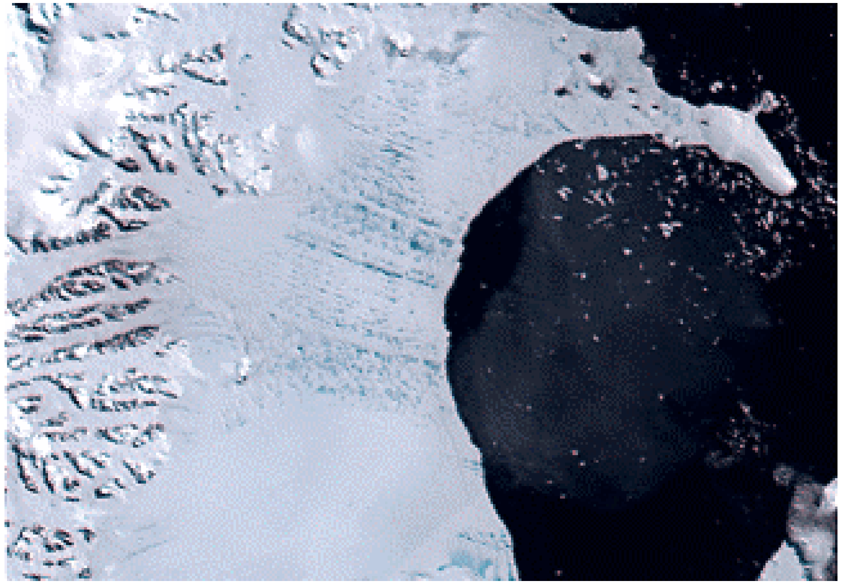


©NASA

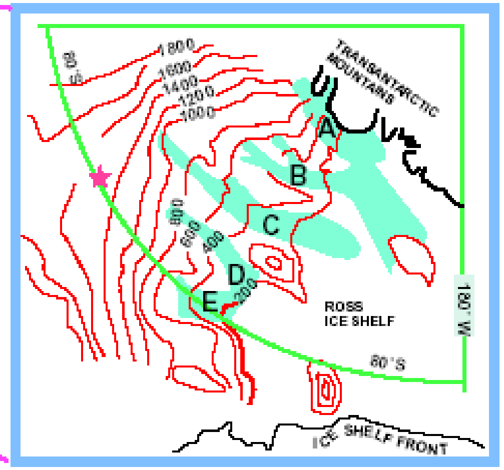

Observed seasonal Arctic sea-ice extent (1900-2003)
(million km2)
16
15
14
13
12
11
10
9
8
7
6
5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Annual
Winter (Jan-Mar)
Spring (Apr-Jun)
Summer (Jul-Sep)
Autumn (Oct-Dec)
©2004, ACIA

West-Antarktic Ice Shelf (WAIS)



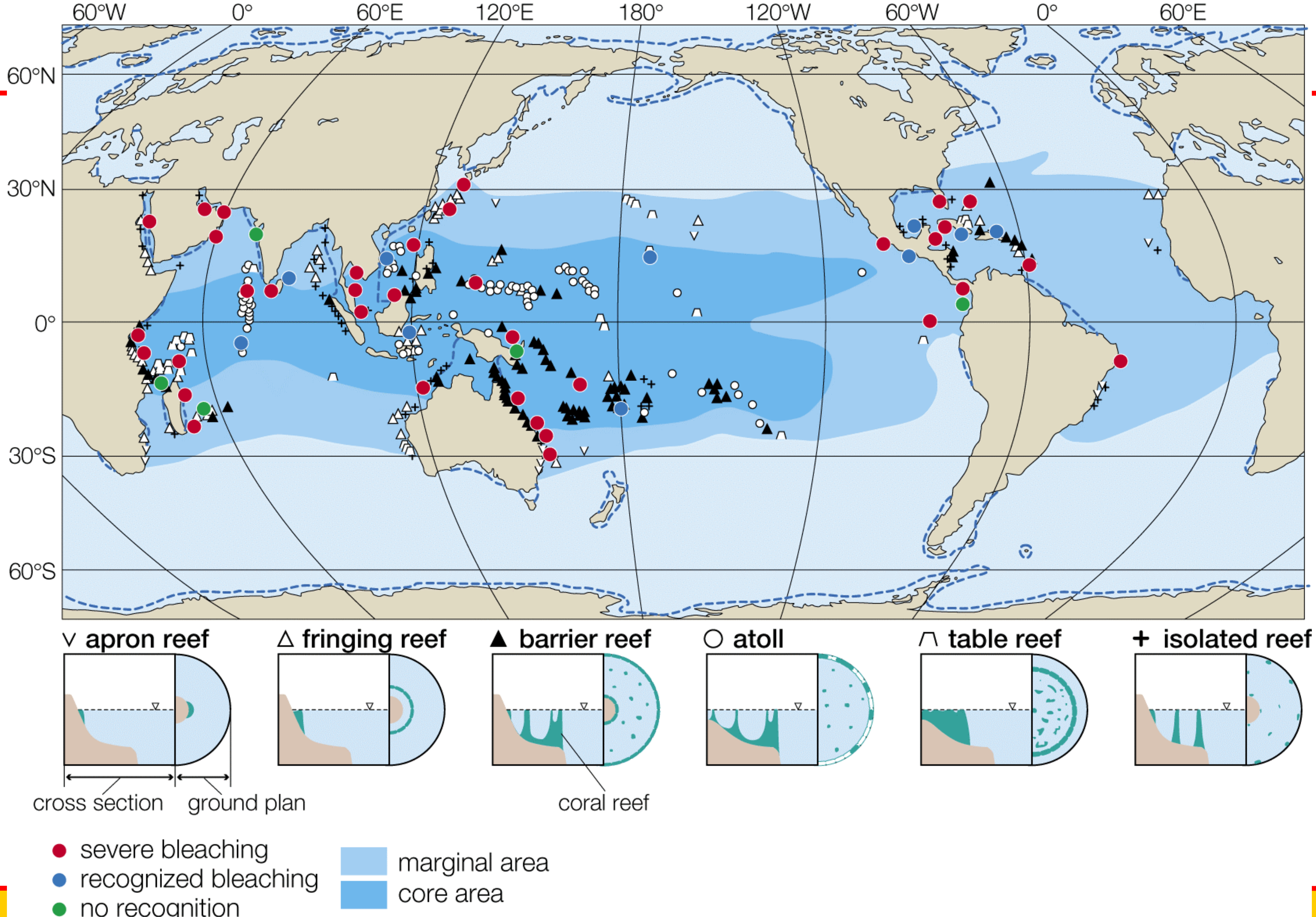


Februar 2002



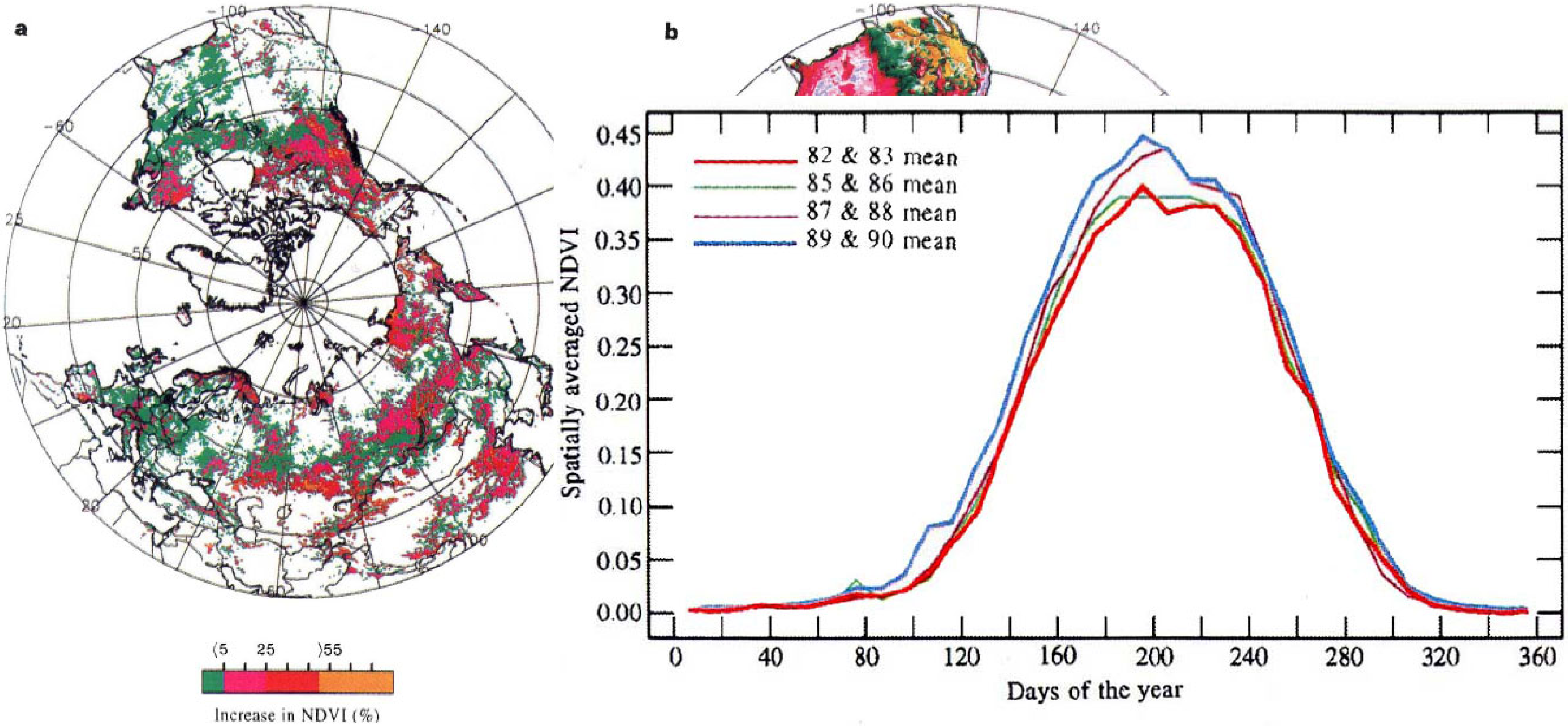
Oppenheimer, Nature 1998

Coral Reef Bleachings

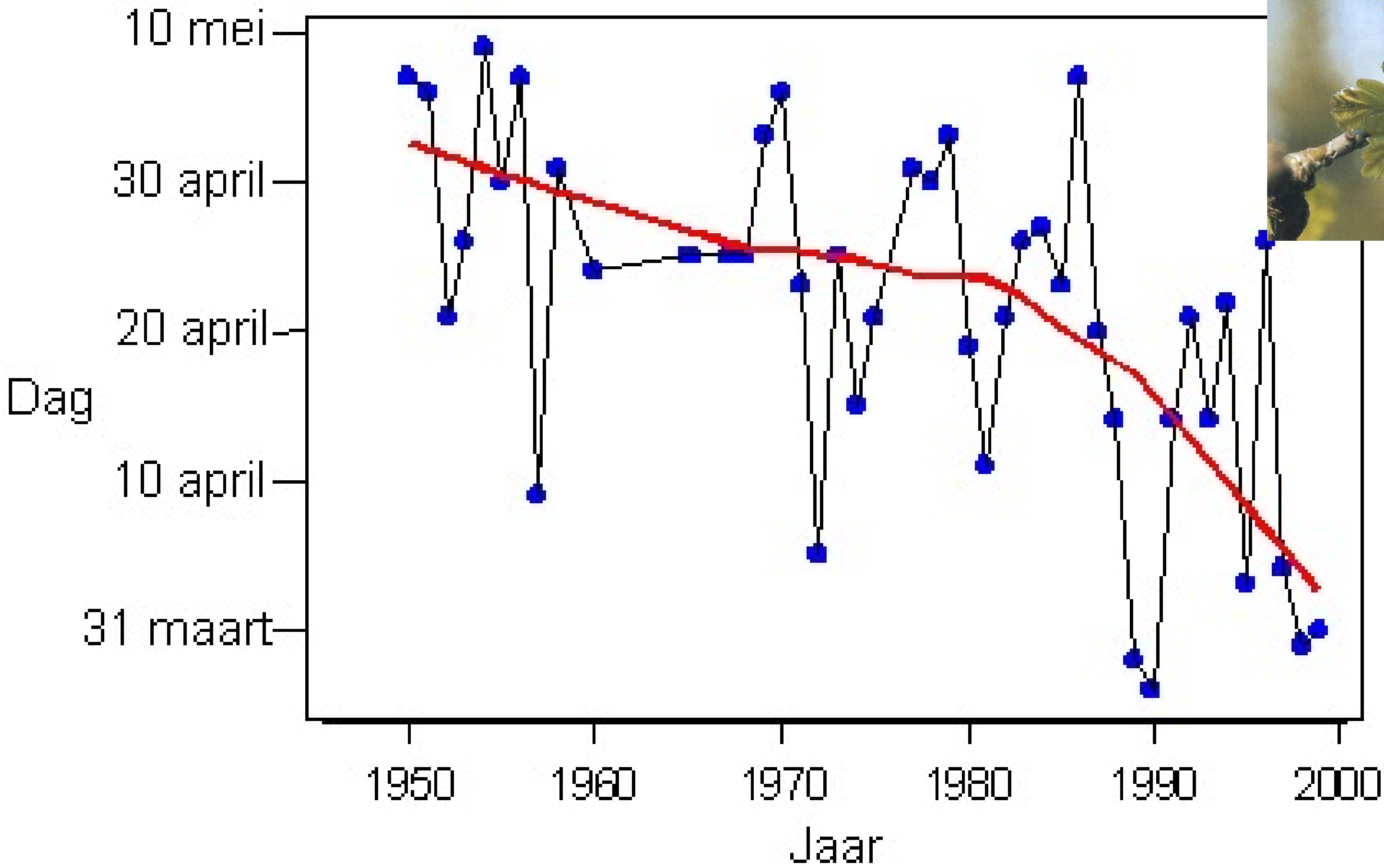


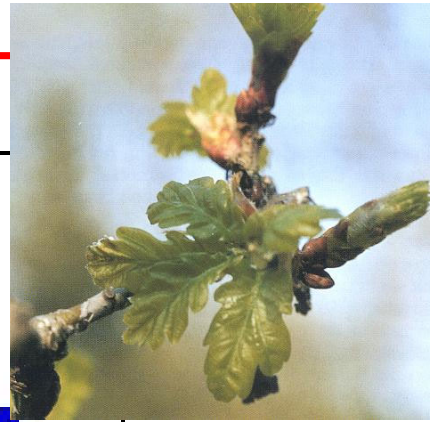
Changes in length of growing season from satellites

Myneni *et al.* 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. Nature **386**:698-702

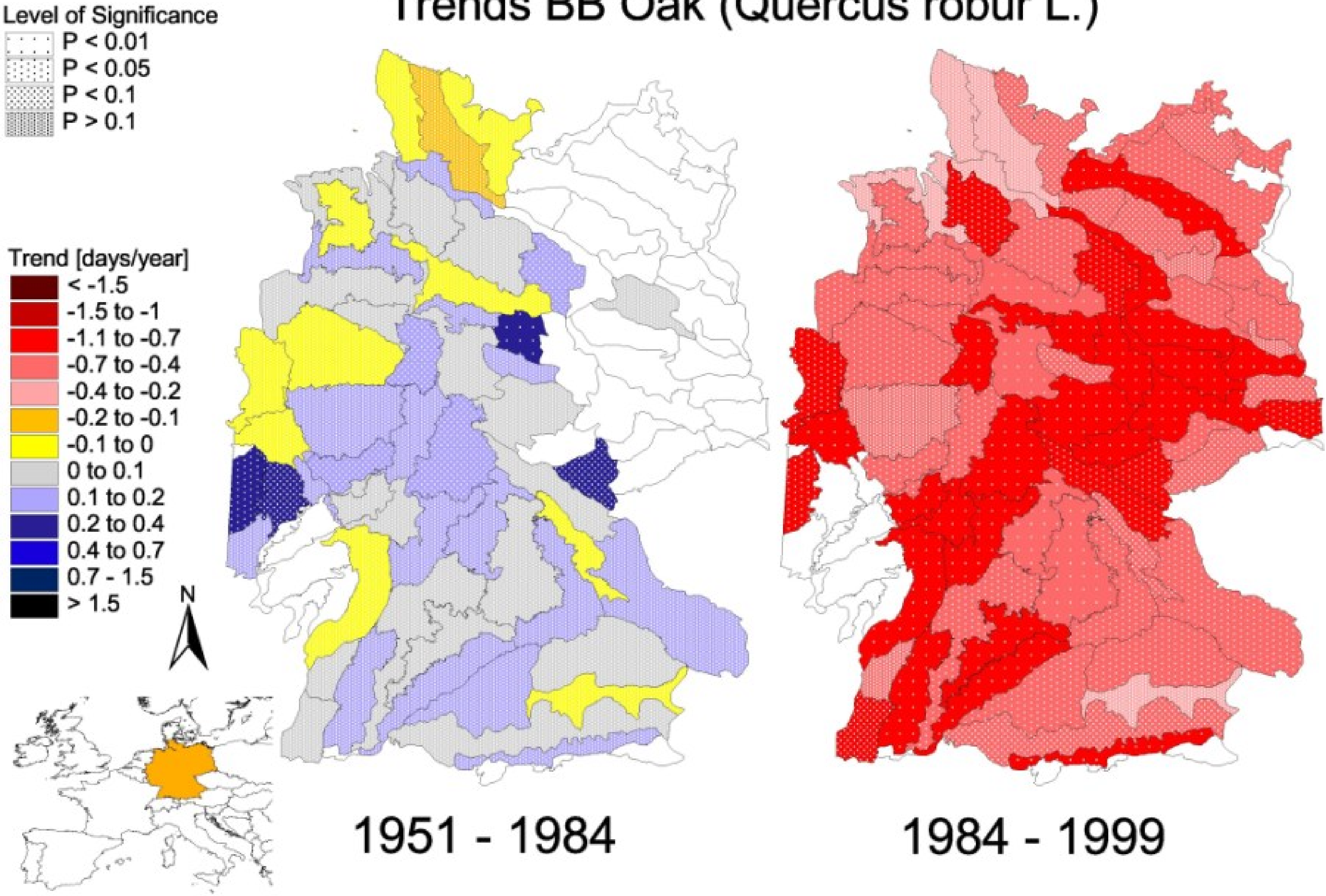


Oak budburst in the UK





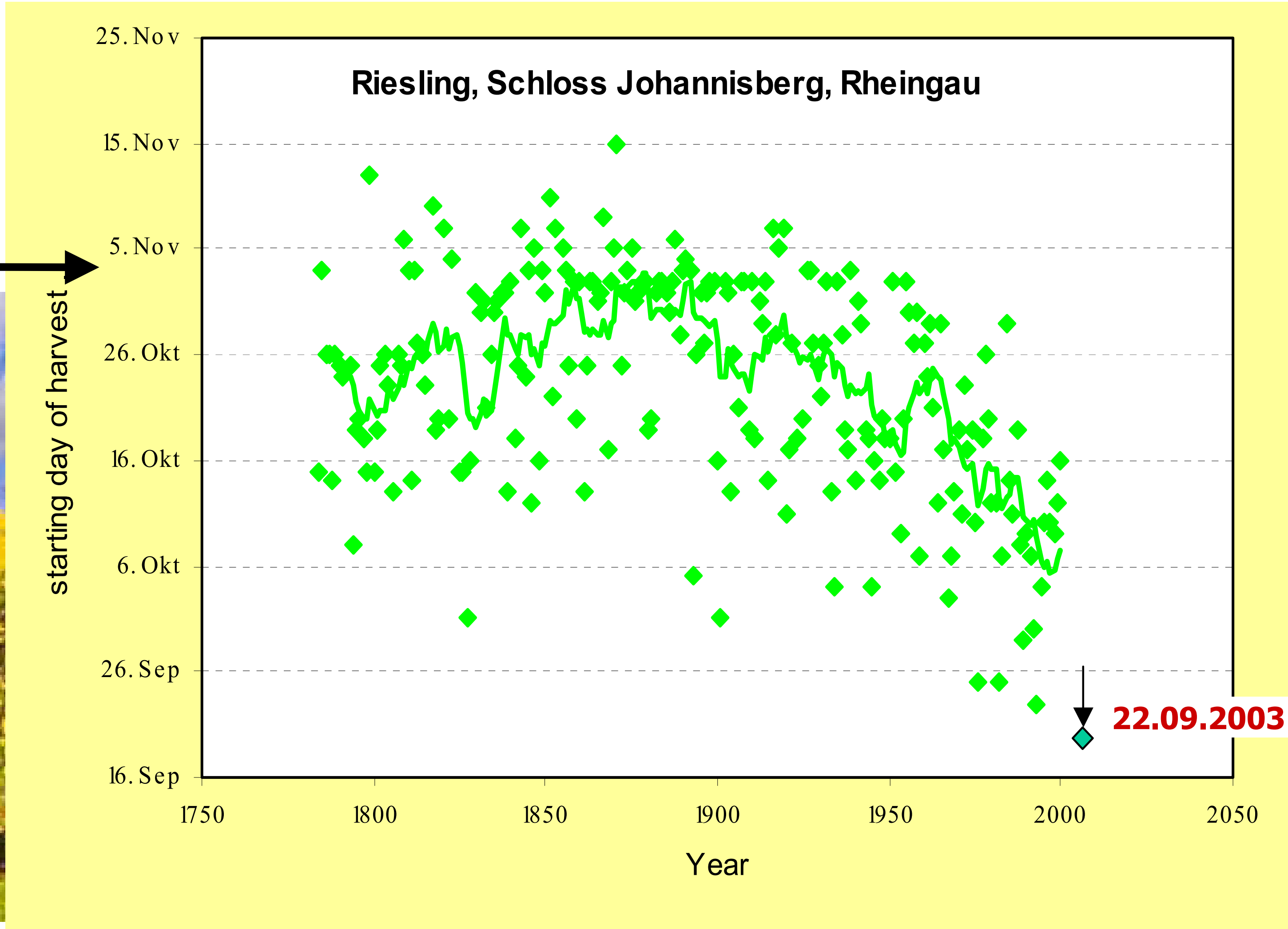
Trends BB Oak (Quercus robur L.)



 Dissertation Jörg Schaber, Potsdam

Accelerated development of grapevines

Advanced phenology:
1. bud burst
2. flowering
3. veraison
4. start of harvest



Growing season extended in Europe

Changes in phenology (seasonal plant and animal activity driven by environmental factors) from year to year may be a sensitive and easily observable indicator of changes in the biosphere. We have analysed data from more than 30 years of observation in Europe, and found that spring events, such as leaf unfolding, have advanced by 6 days, whereas autumn events, such as leaf colouring, have been delayed by 4.8 days. This means that the average annual growing season has lengthened by 10.8 days since the early 1960s. These shifts can be attributed to changes in air temperature.

Forests in cool and temperate zones are adapted to the seasonal cycle, having a dormancy period during winter that is triggered mainly by seasonal variation in temperature and light. Seasonal phases can also be influenced by soil, water supply and biotic factors, including genes[1,2]. Plants can therefore be used as biological indicators of changing environmental conditions, with springtime phases being particularly sensitive to temperature.

We have been analysing[3] observational data from the International Phenological

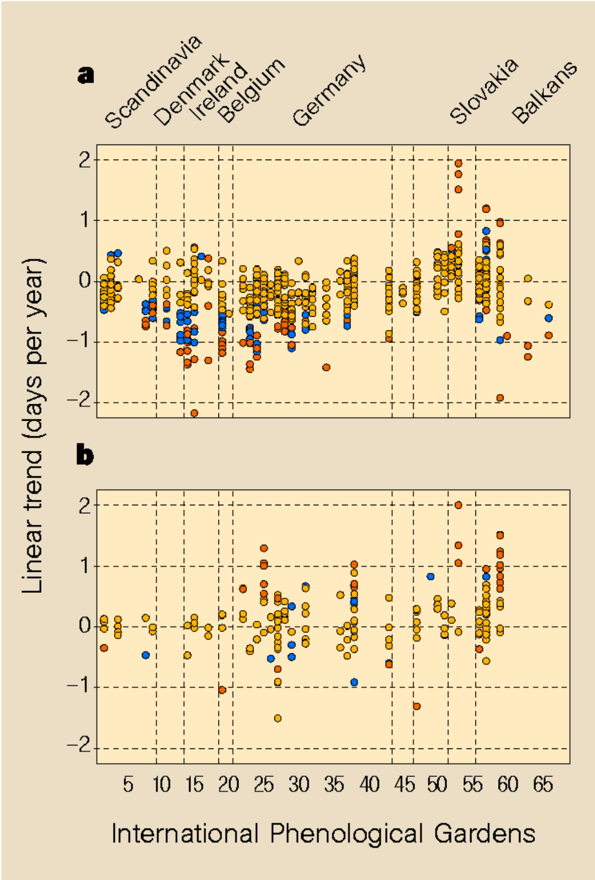


Figure 2 Linear trends of phenological phases. Data are for long observational series (20 years or more) during the 1959–93 period. Orange dots, significant at the 1% level; blue dots, significant at the 5% level; and yellow dots, not significant at the 5% level; *F*-

series reveals a mean positive trend of +0.16 days per year, which would mean a delay of 4.8 days over 30 years. The growing season over this period has therefore lengthened by 10.8 days on average.

Other factors that could result in similar trends can be excluded. Only a few of the IPGs are situated in city areas where the urban heat island could influence these trends. In addition, the trends of spring phases are not an artefact of plant ageing because the increasing age of trees would be expected to delay the start of spring.

Our Europe-wide results are supported by regional studies, including a shift towards earlier flowering of the locust tree *Robinia pseudoacacia* in Hungary[6] and the advance of spring and delay of autumn revealed by analysis of thermal seasons in Germany[7].

The apparent increase of 10.8 days in the mean annual growing season in Europe is in accord with an analysis of satellite data from 1981 to 1991, which estimates a global advance of 8±3 days for the beginning of the growing season and a prolongation by 4±2 days of the declining phase[8]. Our data also confirm a reported[9] advance in the seasonal cycle of about 7 days that was inferred

These are anecdotes but… how do we connect them to climate?

- Many systems differ between climate regions (e.g., forests / deserts)

  …therefore a change in climate likely causes an impact ("space for time")

- Many physically "obvious" connections exist between climate and system functioning (no palms in the tundra)

  …therefore impacts are the conservative assumption

Where, then, is the problem?

- Thresholds:

  …just how much change in climate causes important change in the system?

- Confounding factors:

  …land use, pollution etc. also trigger many system changes

- Variability:

  …what is just a fluctuation and what is lasting change?

Gradual and abrupt change

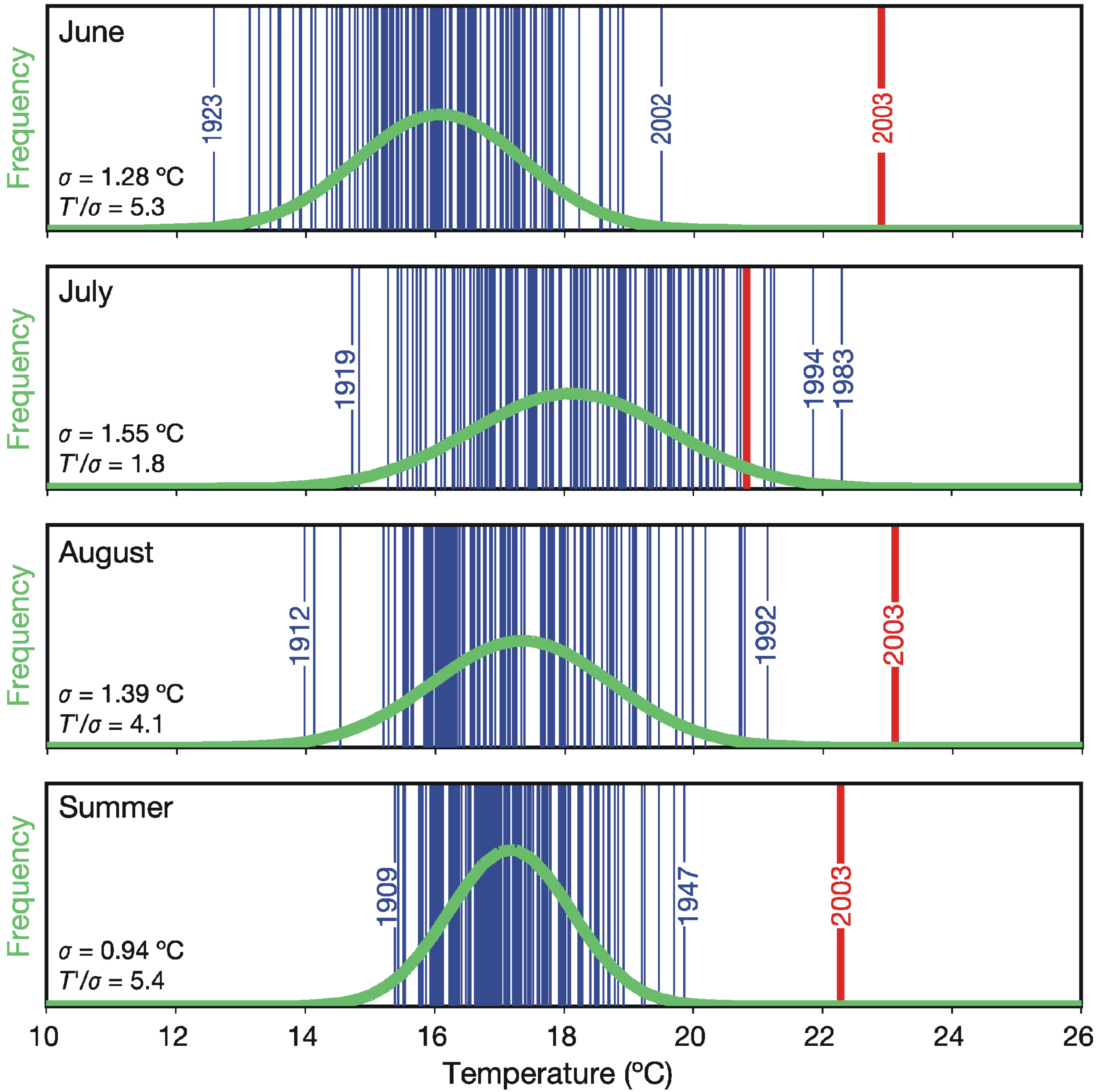
- In ecosystems, one can have steady changes in phenology, growth, biomass, respiration…
- …or there can be catastrophic change (e.g., destruction by extreme events, invasion by alien species)
- …or regular disturbances can change their frequency (natural wildfires)

- Rigorous attribution would have to distinguish between all these

The Elbe between Bitterfeld and Eilenburg, Germany 2002


Lothringen, Frankreich, August 2003

Distribution of Swiss Monthly and Seasonal Temperatures 1864-2003



Source: Schär et al. 2004

Preliminary conclusion

- Numerous anecdotes indicate that recent changes in many systems are due to climate change
- The bigger part of recent climate change is anthropogenic – therefore many impacts likely have anthropogenic origin

Before continuing, let us constrain the problem a little more

- Be specific about the confounding factors
- Focus on “changes that matter”
- Ecosystem goods and services
- Adaptation

Confounding factors

- Carbon dioxide
- Net radiation
- Temperature
- Evapotranspiration
- Precipitation (rain/snow)
- Soil moisture
- Pollutants
- Land management
- Deforestation / urbanization

“Changes that matter”

- Thresholds
- Feedbacks

Ecosystem goods and services

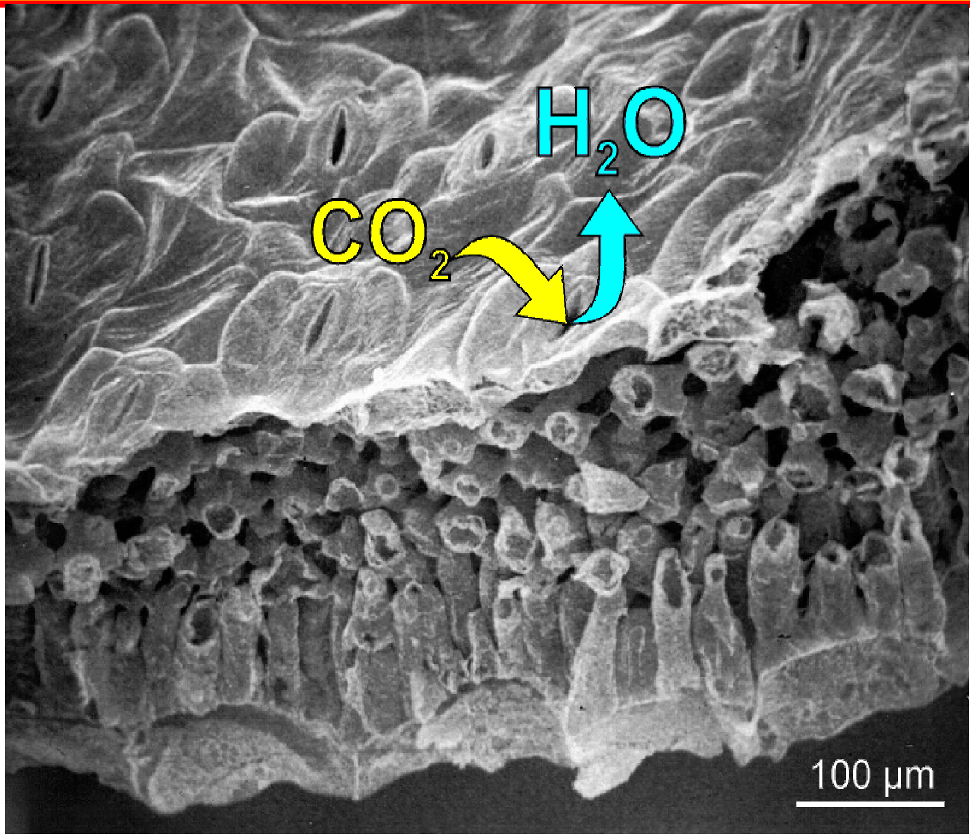
- Provisioning services
  - Food
  - Water
  - Fibres
- Regulating services
  - Climate
  - Floods
  - Disease
- Cultural services
  - Aesthetic, spiritual

Adaptation

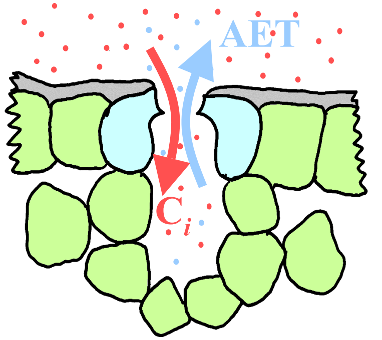
- Endogenous adaptation
- Managed adaptation

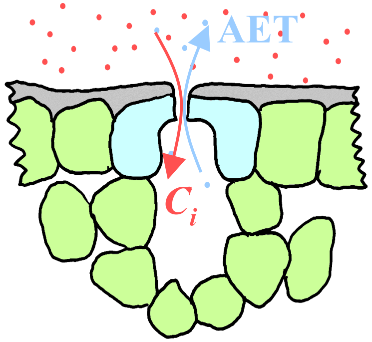
If we want to consider all this, what do we need to know about the system?

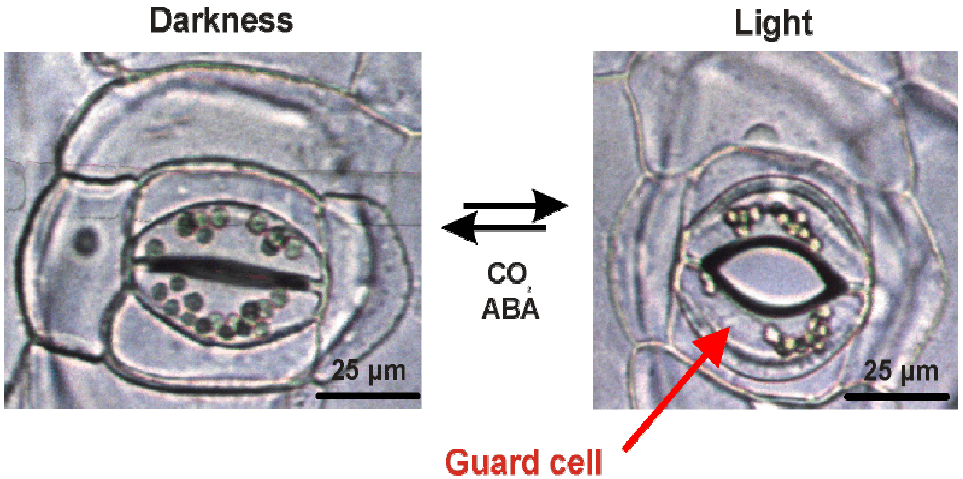
Interactions between forcings, e.g., water and CO_2



Stomatal Control of CO_2 uptake and H_2O- loss







"Canopy Conductance"
(mm/s)

CO_2 uptake

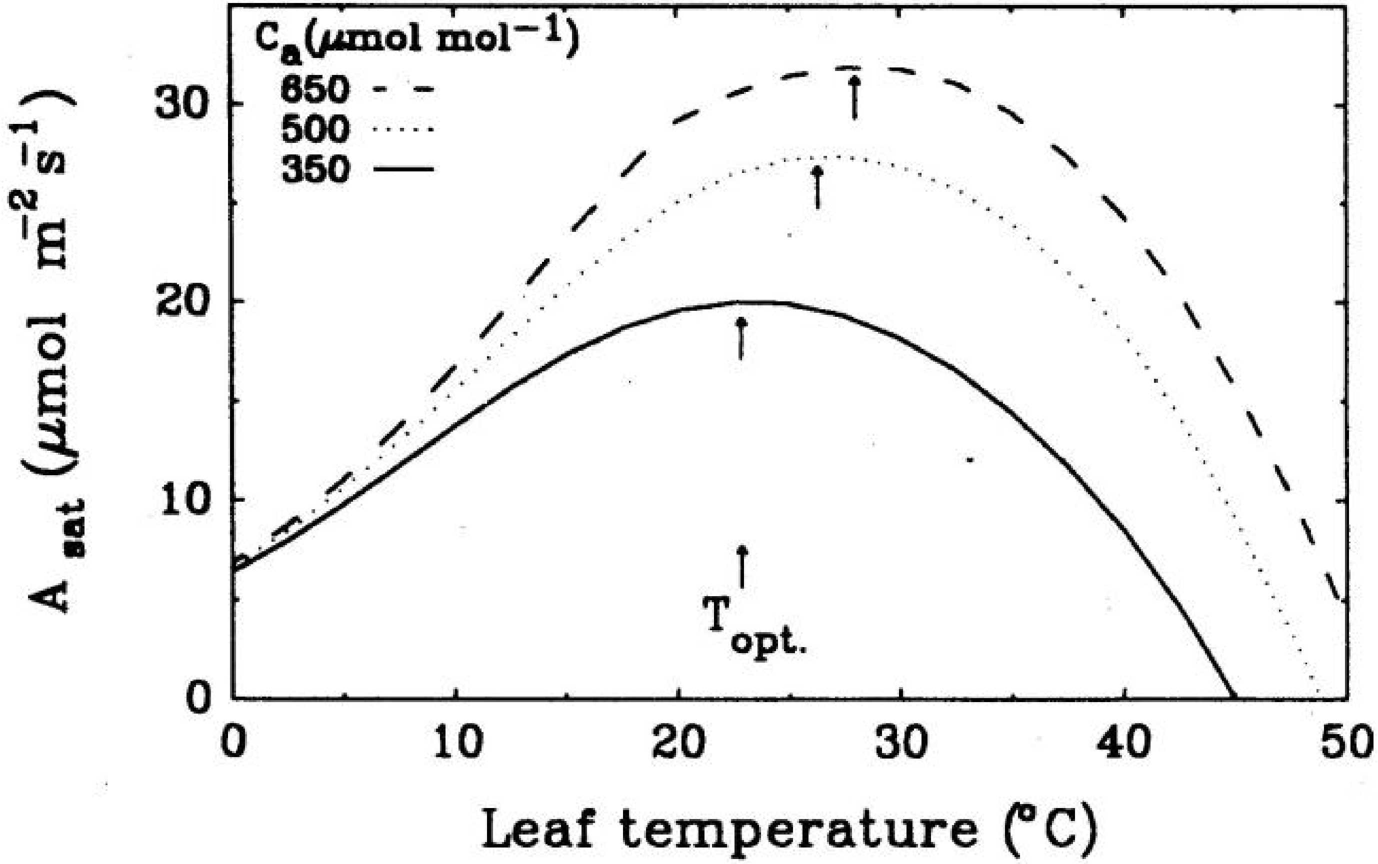
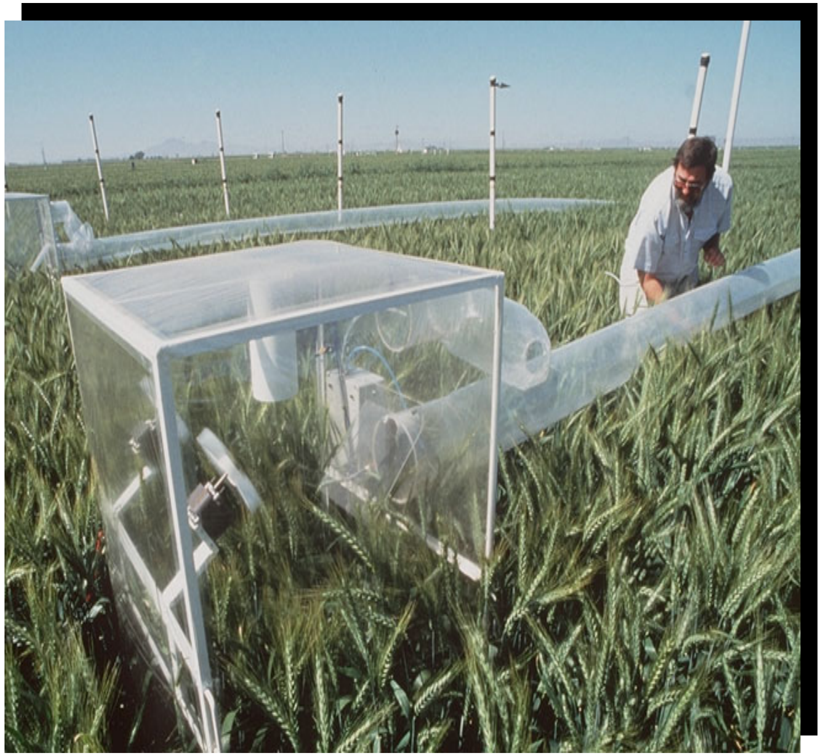
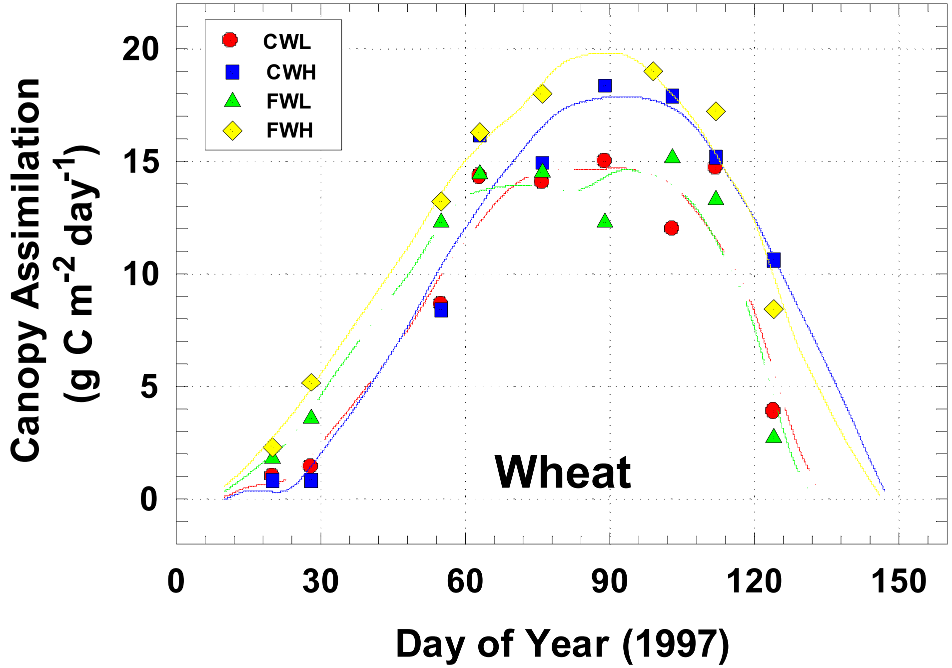


Figure 2. Predicted light-saturated rates of leaf CO_2 uptake (A_{sat}) with leaf temperature for three atmospheric CO_2 concentrations (C_a; µmol mol^{-1} of CO_2 in air). Arrows indicate T_{opt}, i.e. the temperature at which A_{sat} is maximal for each value of C_a.

CO_2 uptake in the canopy



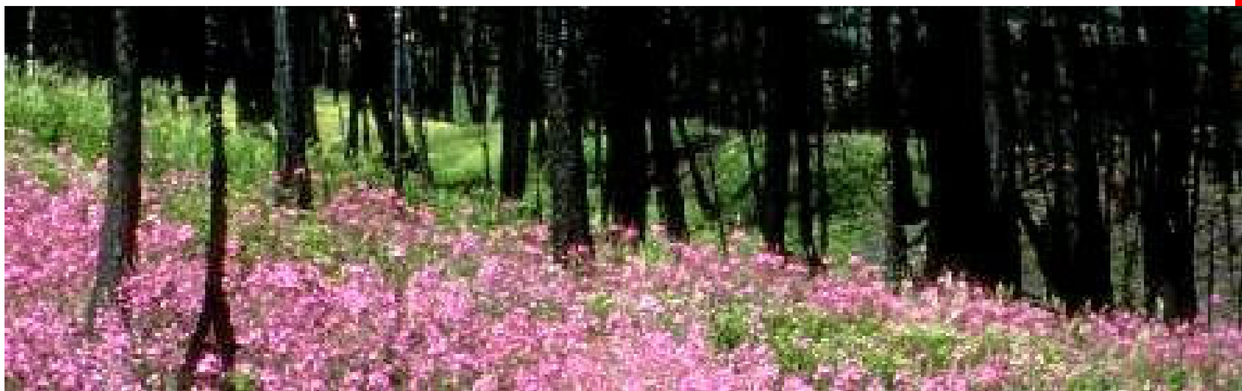


C uptake increased by 20-40% when ambient CO_2 is increased by 200 ppm

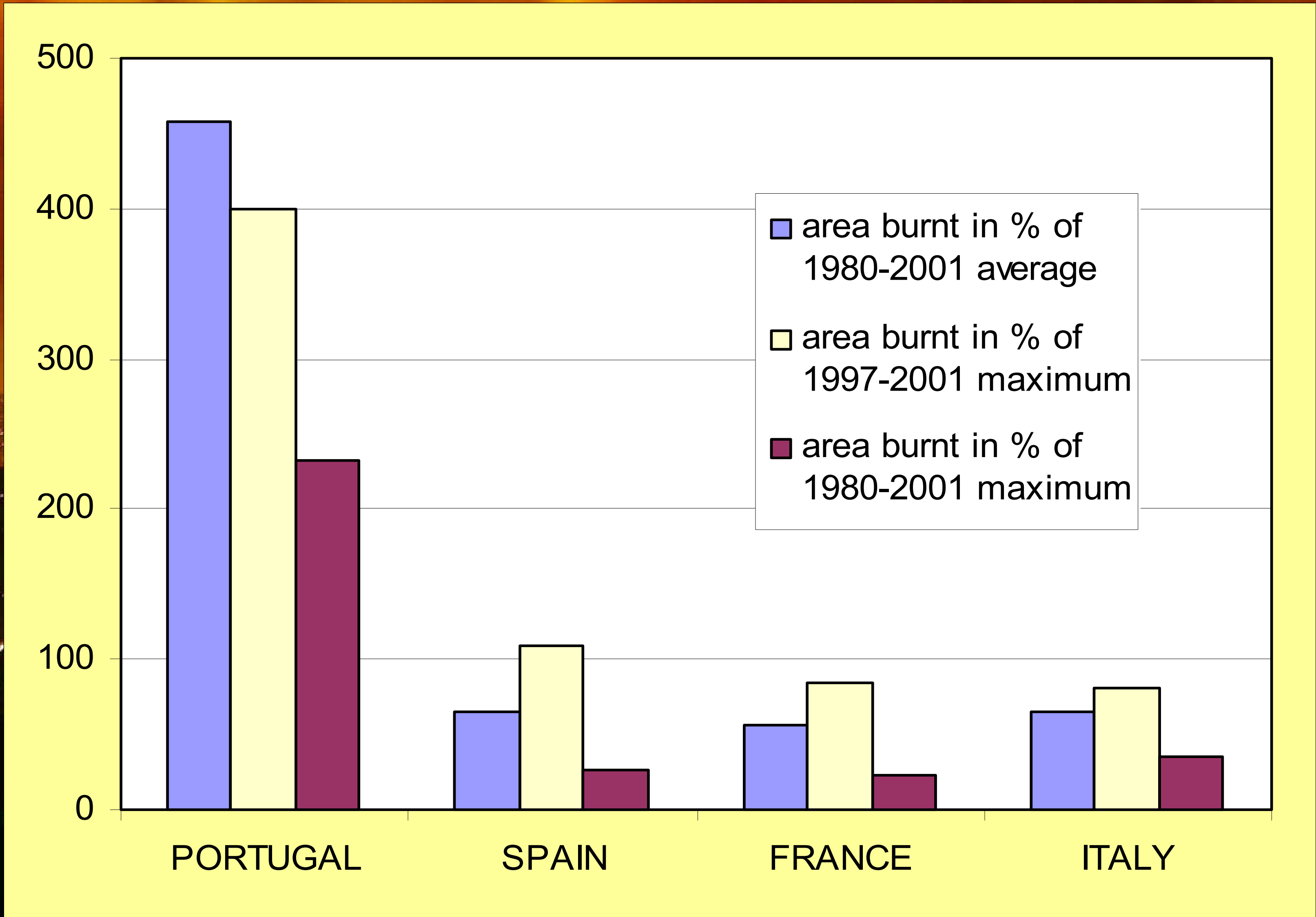

PHOTO BY WILL OWENS


20

Fire as disturbance factor



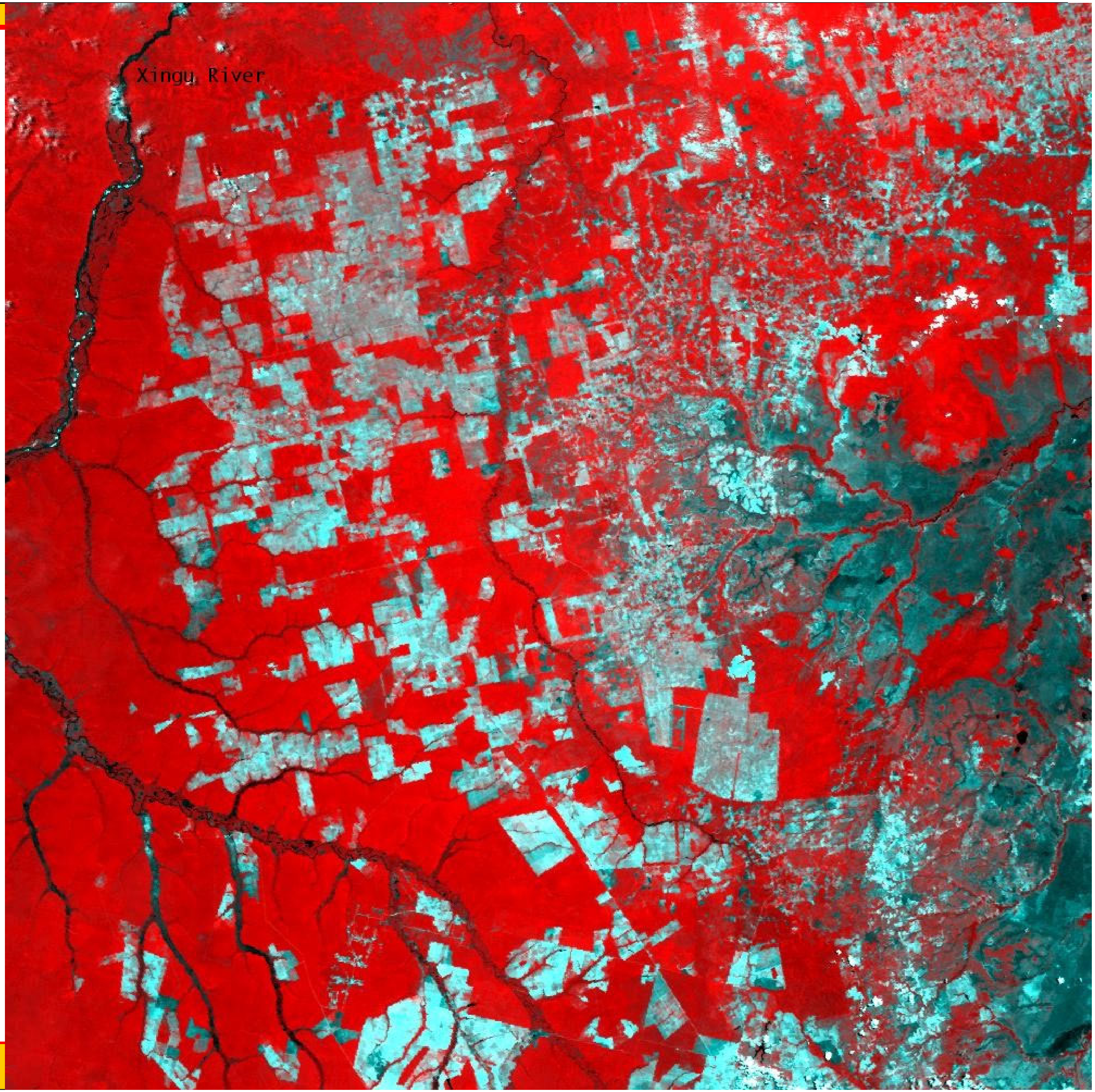
Forest Fires
Area burnt in 2003



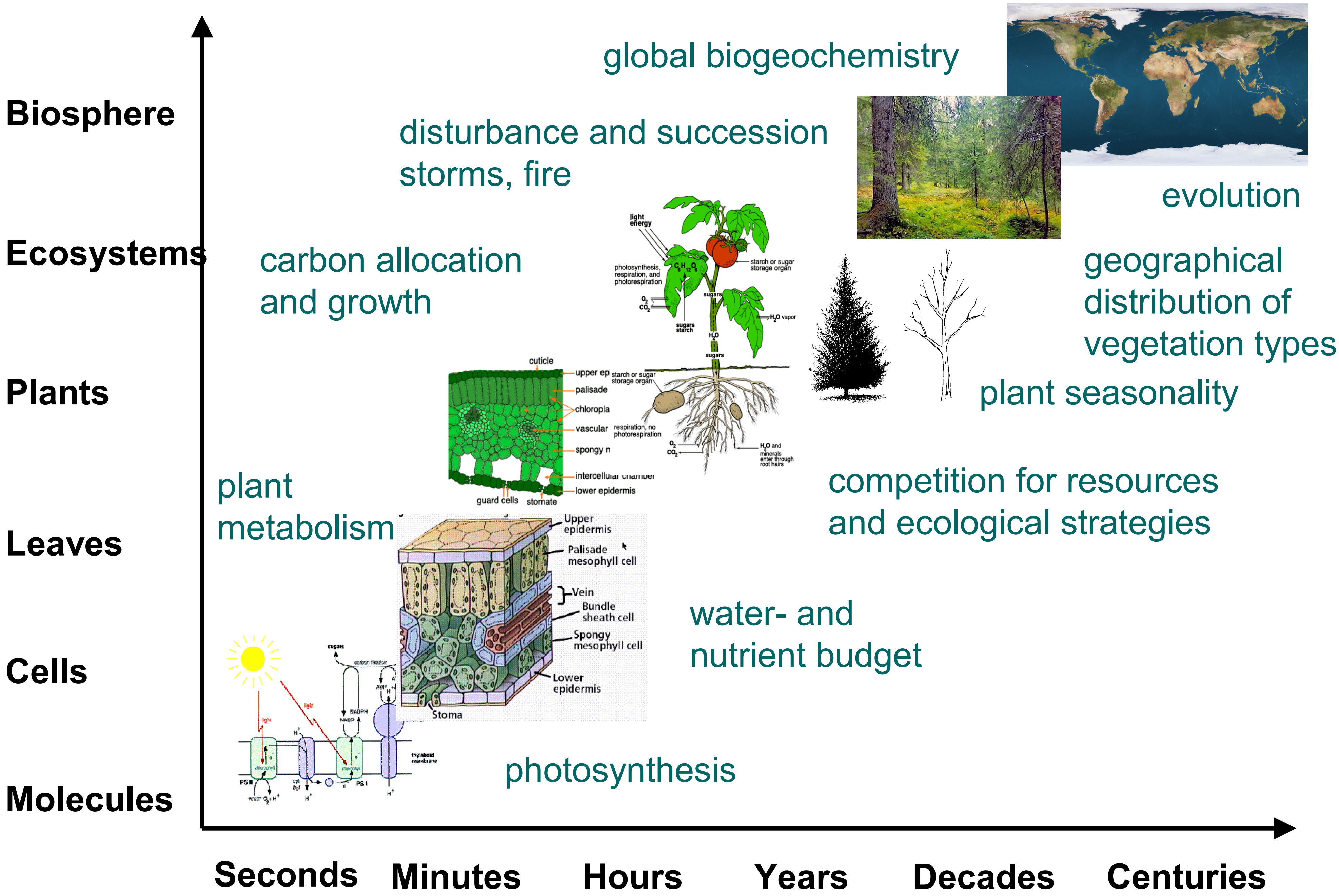
Data for 2003
Jan. through:
Portugal: 31. Oct
Spain: 14. Sep
France: 27. Aug
Italy: 7. Sep
Analysis: PIK

Deforestation Xingu River, Amazonia

(MODIS Image, 19.10.2000)

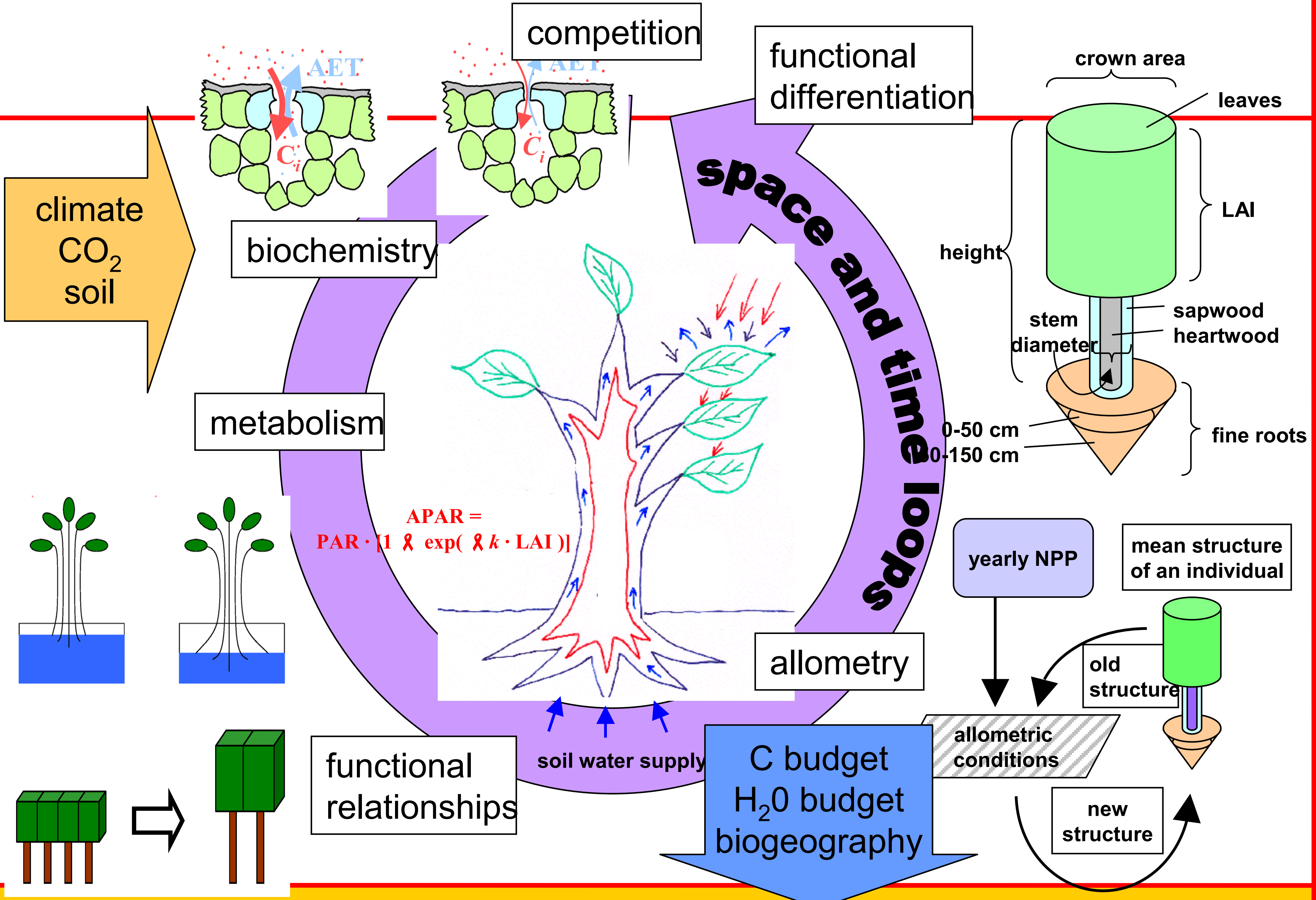


Interacting Scales in Biogeochemistry



From Wolfgang Lucht, PIK

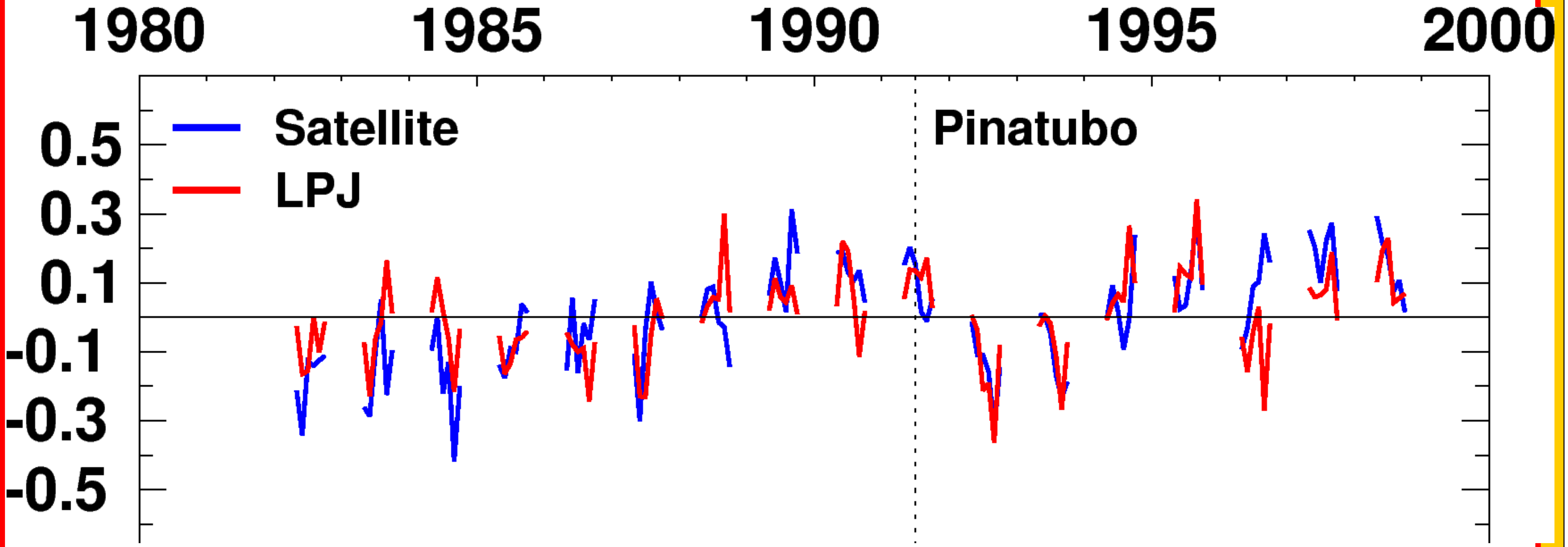
The LPJ DGVM


competition
functional differentiation
crown area
leaves
AET
AET
C_i
C_i
climate
CO_2
soil
biochemistry
LAI
space and time loops
height
stem diameter
sapwood
heartwood
metabolism
0-50 cm
50-150 cm
fine roots
APAR =
PAR · [1 − exp(− k · LAI)]
yearly NPP
mean structure of an individual
allometry
old structure
allometric conditions
soil water supply
C budget
H_2O budget
biogeography
functional relationships
new structure

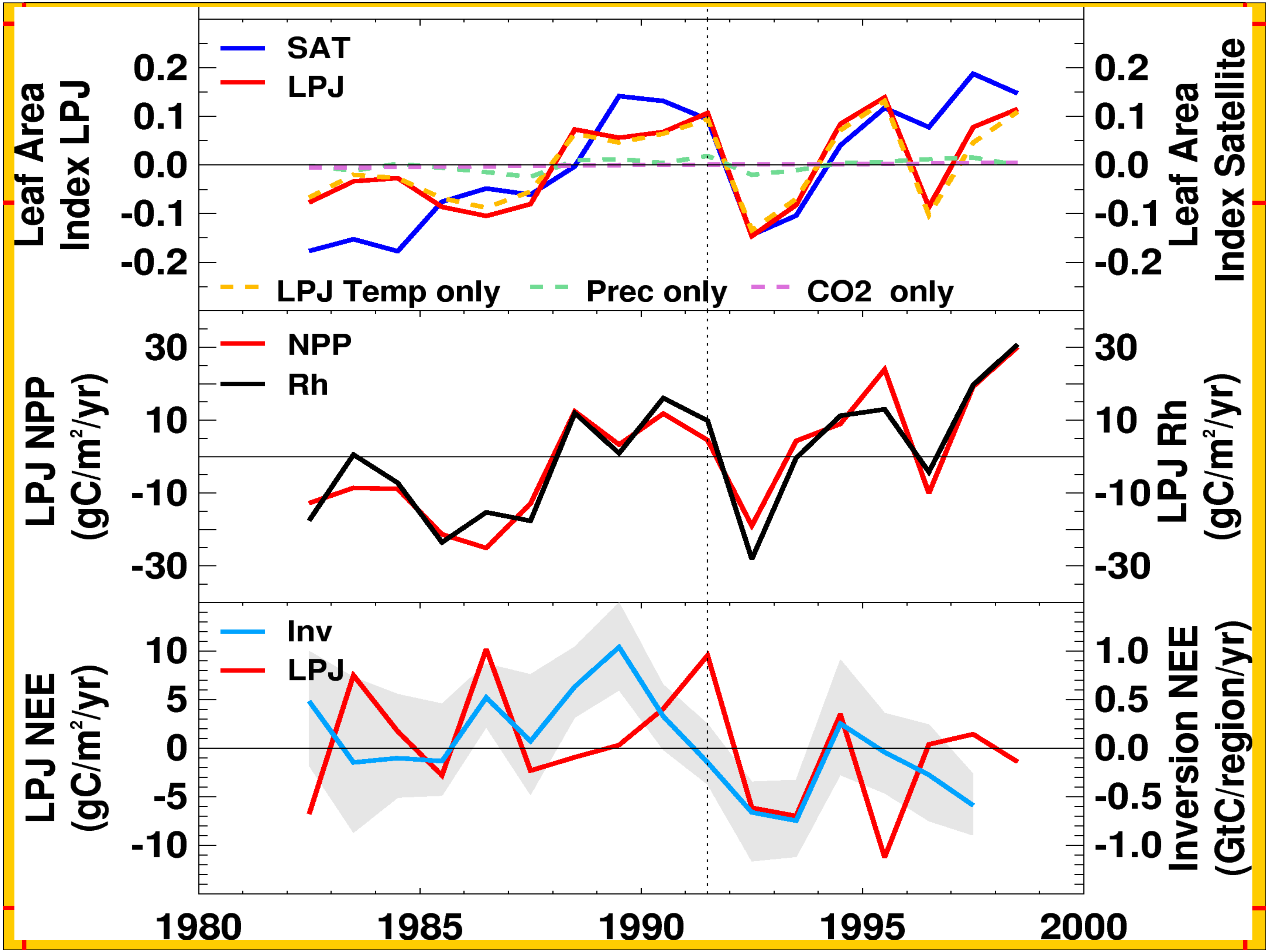
Climatic Control of the High-Latitude Vegetation Greening Trend and Pinatubo Effect

Wolfgang Lucht,[1*] I. Colin Prentice,[2] Ranga B. Myneni,[3] Stephen Sitch,[1] Pierre Friedlingstein,[4] Wolfgang Cramer,[1] Philippe Bousquet,[4] Wolfgang Buermann,[3] Benjamin Smith[5]

A biogeochemical model of vegetation using observed climate data predicts the high northern latitude greening trend over the past two decades observed by satellites and a marked setback in this trend after the Mount Pinatubo volcano eruption in 1991. The observed trend toward earlier spring budburst and increased maximum leaf area is produced by the model as a consequence of biogeochemical vegetation responses mainly to changes in temperature. The post-Pinatubo decline in vegetation in 1992–1993 is apparent as the effect of temporary cooling caused by the eruption. High-latitude CO_2 uptake during these years is predicted as a consequence of the differential response of heterotrophic respiration and net primary production.



1980
1985
1990
1995
2000
0.5
0.3
0.1
-0.1
-0.3
-0.5
Satellite
LPJ
Pinatubo



SAT
LPJ
Leaf Area Index LPJ
Leaf Area Index Satellite
0.2
0.1
0.0
-0.1
-0.2
LPJ Temp only
Prec only
CO2 only
NPP
Rh
LPJ NPP (gC/m²/yr)
LPJ Rh (gC/m²/yr)
30
10
-10
-30
Inv
LPJ
LPJ NEE (gC/m²/yr)
Inversion NEE (GtC/region/yr)
10
5
0
-5
-10
1.0
0.5
0.0
-0.5
-1.0
1980
1985
1990
1995
2000

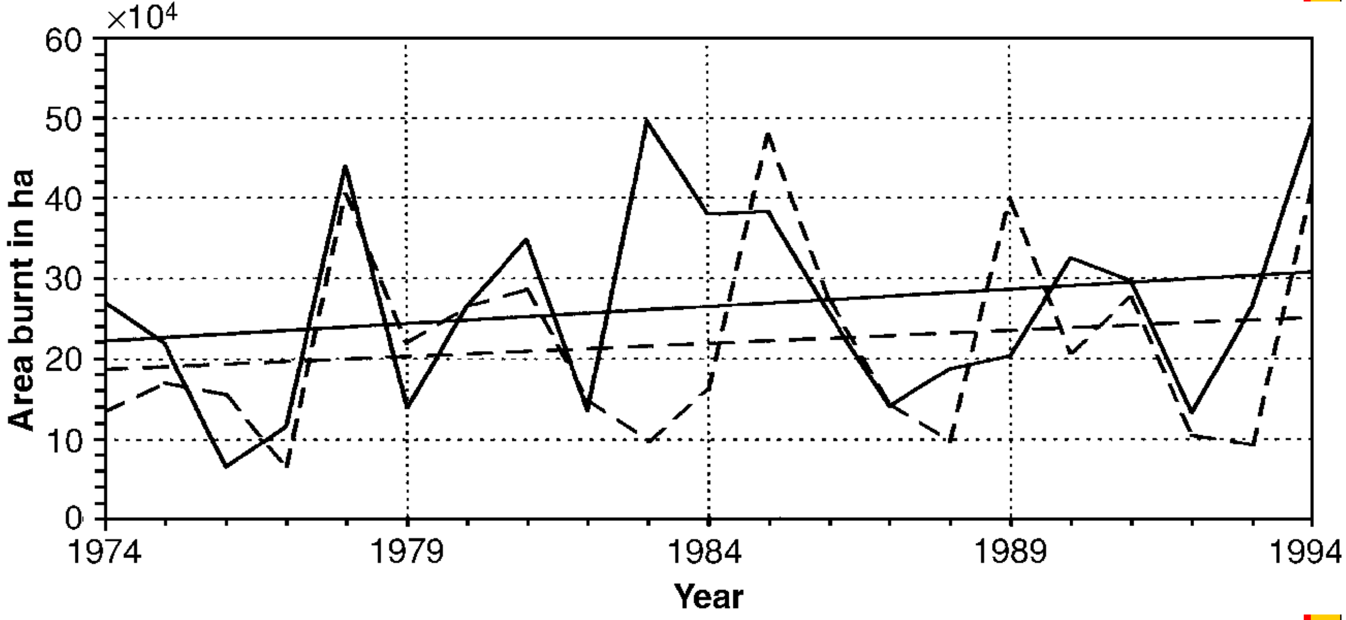
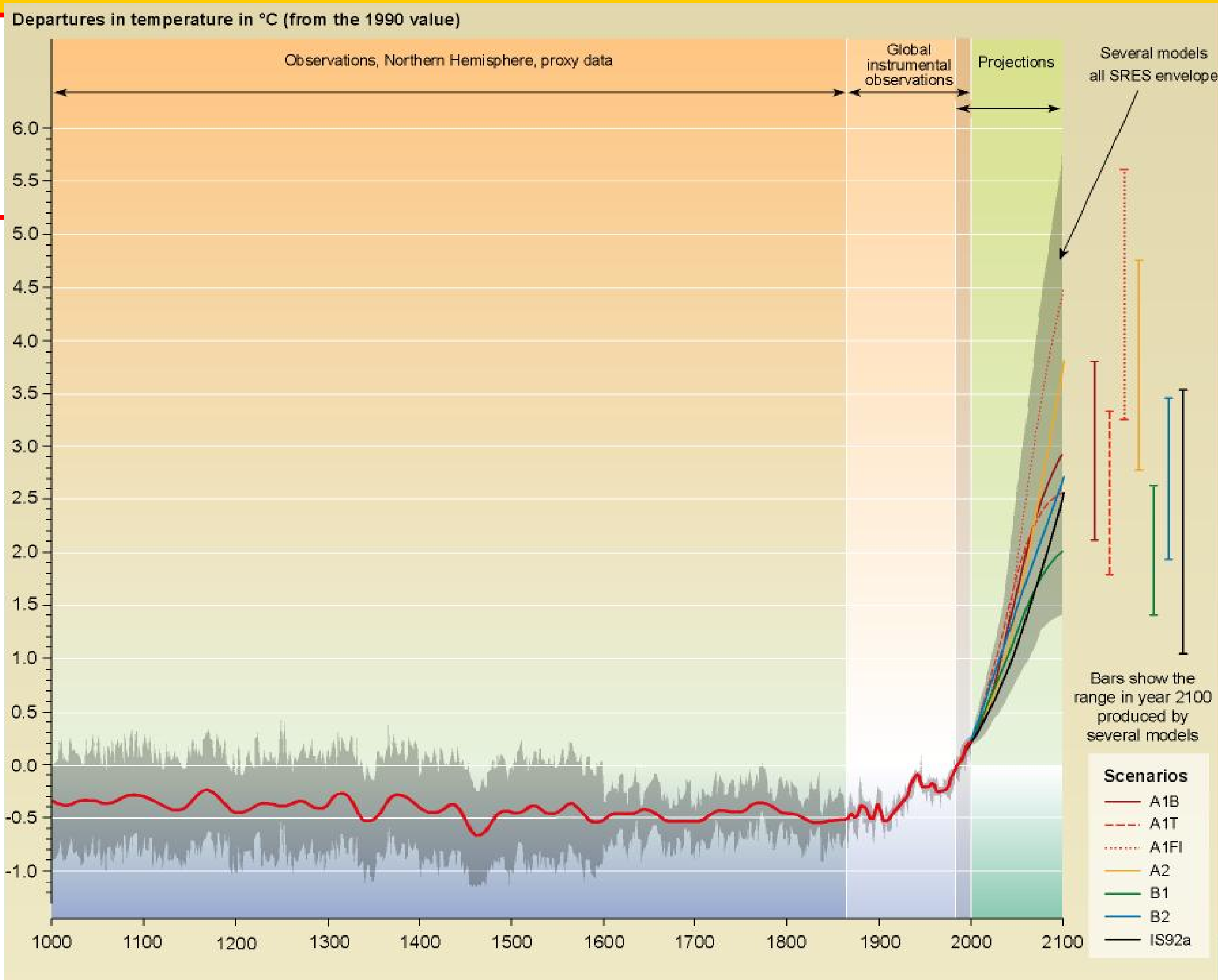


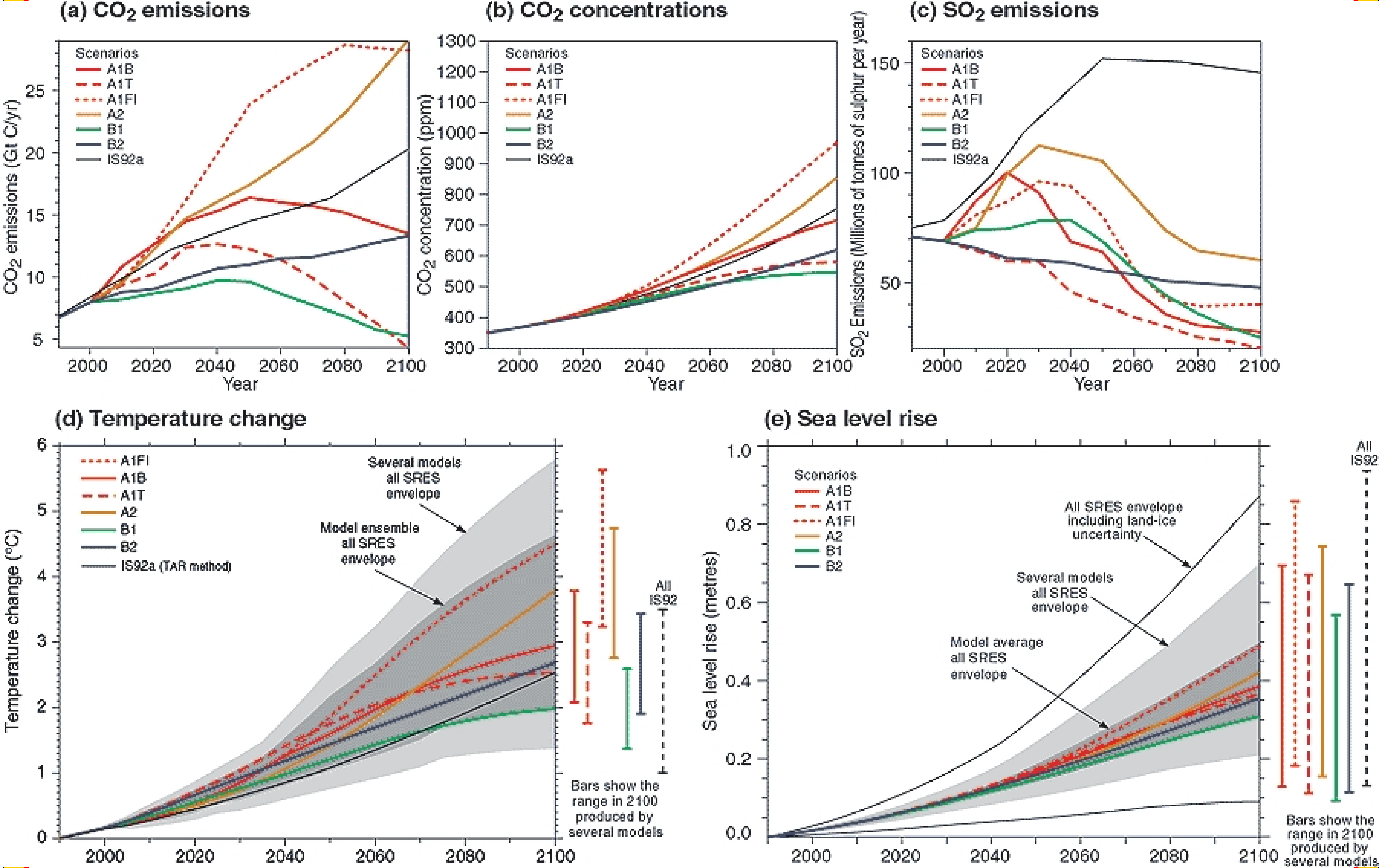
Fig. 5 Time series of the total area burnt (ha) in peninsular Spain during 1974–94. The dashed and solid lines represent the observed and simulated area burnt, respectively.


953. St-BAUZILE-du-PUTOIS (Hérault)
Rocher de Leuzière

Main questions

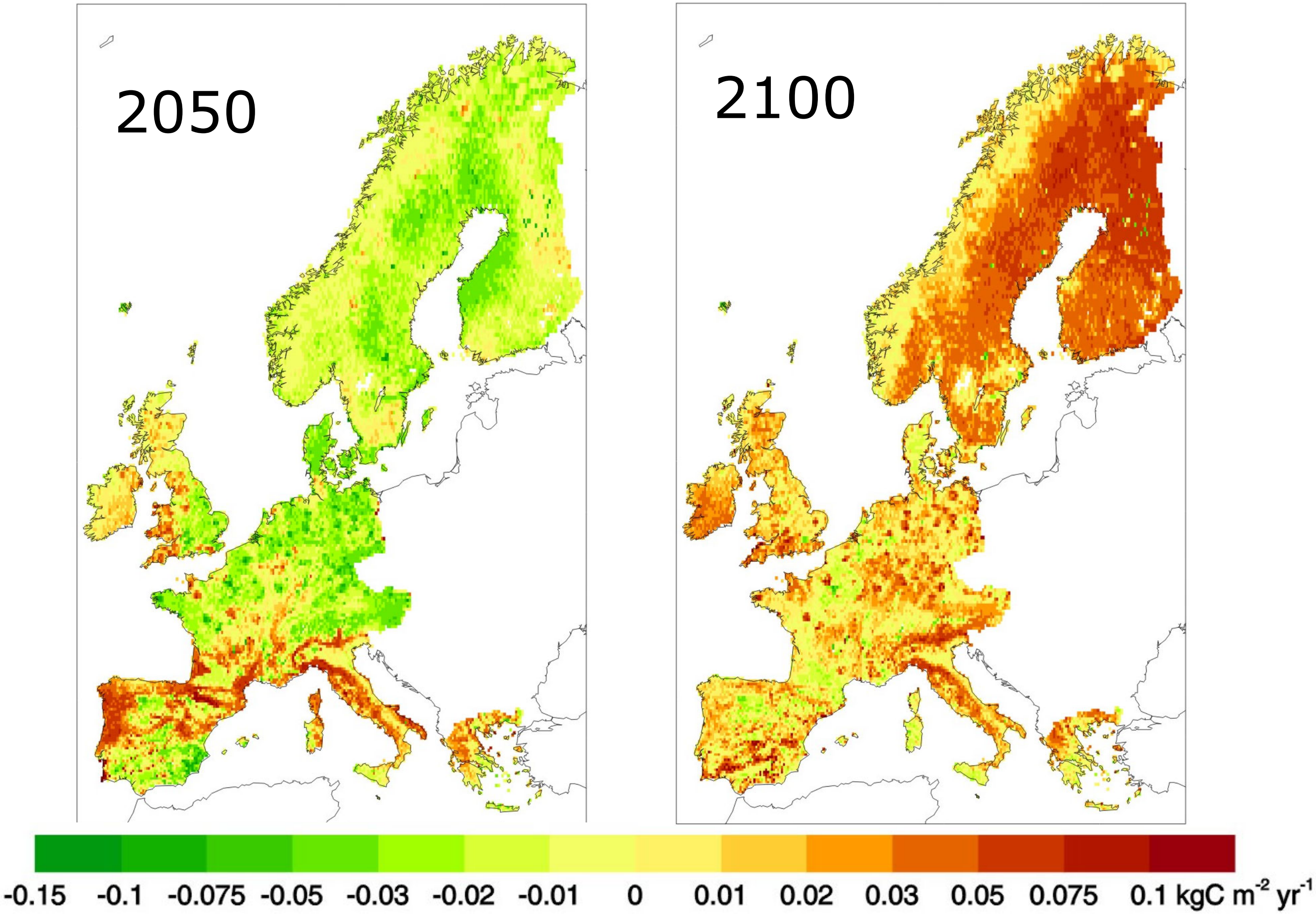
1. Is there any evidence for impacts of anthropogenic climate change that have already occurred?
2. Are future impacts of anthropogenic climate change to be expected?


Departures in temperature in °C (from the 1990 value)
Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
Several models all SRES envelope
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Bars show the range in year 2100 produced by several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a

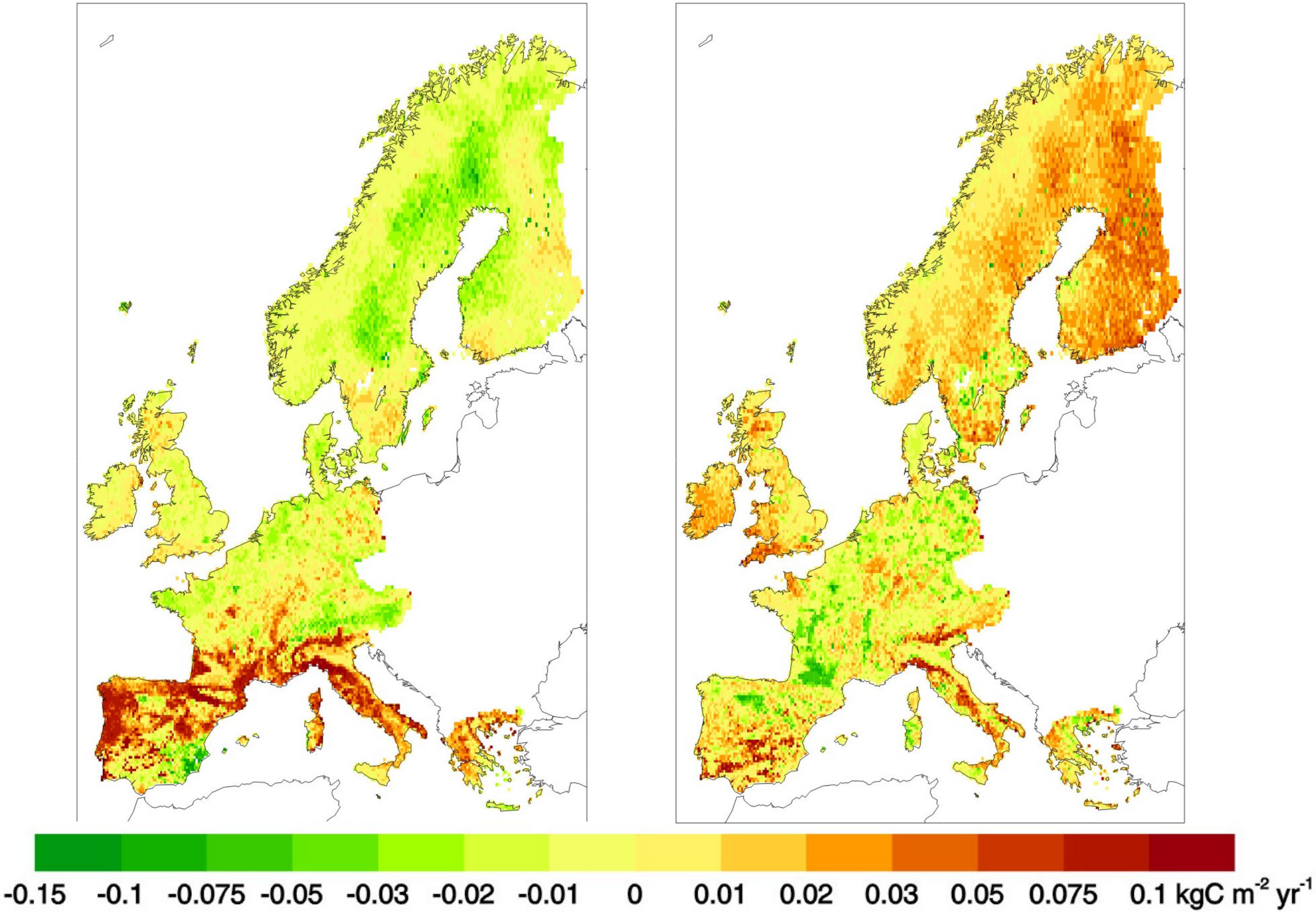


(a) CO2 emissions
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
CO2 emissions (Gt C/yr)
Year
(b) CO2 concentrations
CO2 concentration (ppm)
(c) SO2 emissions
SO2 Emissions (Millions of tonnes of sulphur per year)
(d) Temperature change
IS92a (TAR method)
Several models all SRES envelope
Model ensemble all SRES envelope
All IS92
Bars show the range in 2100 produced by several models
Temperature change (°C)
(e) Sea level rise
All SRES envelope including land-ice uncertainty
Several models all SRES envelope
Model average all SRES envelope
Sea level rise (metres)

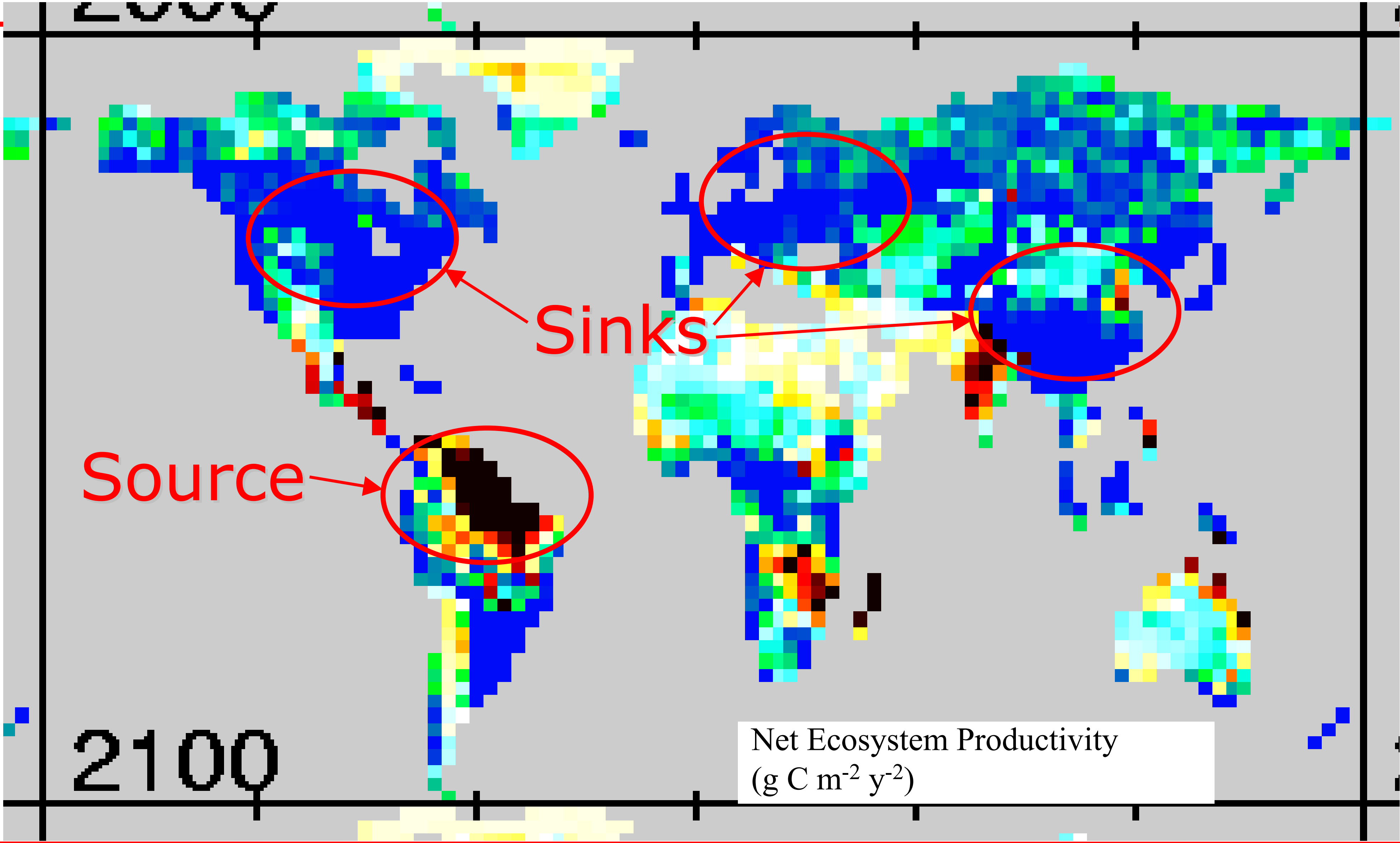
A2-LUCC scenario changing carbon storage



B1-LUCC scenario changing carbon storage



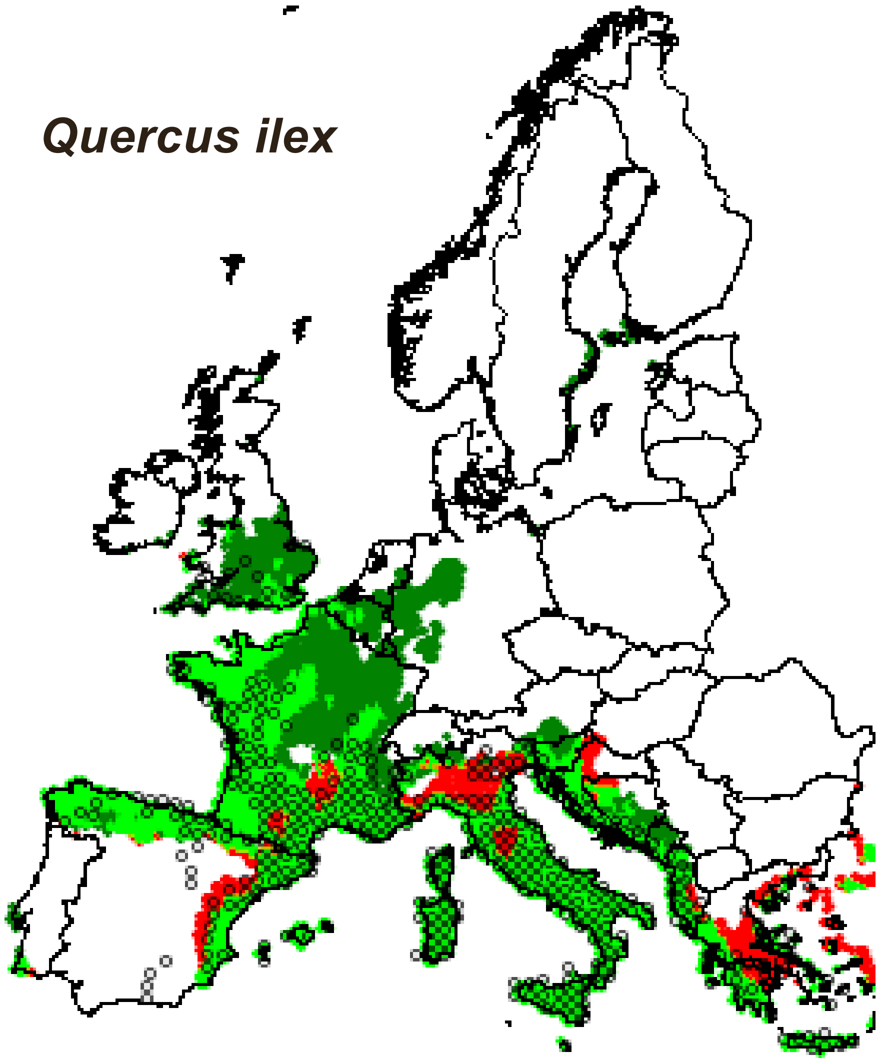
Land biosphere C balance for different DGVMs



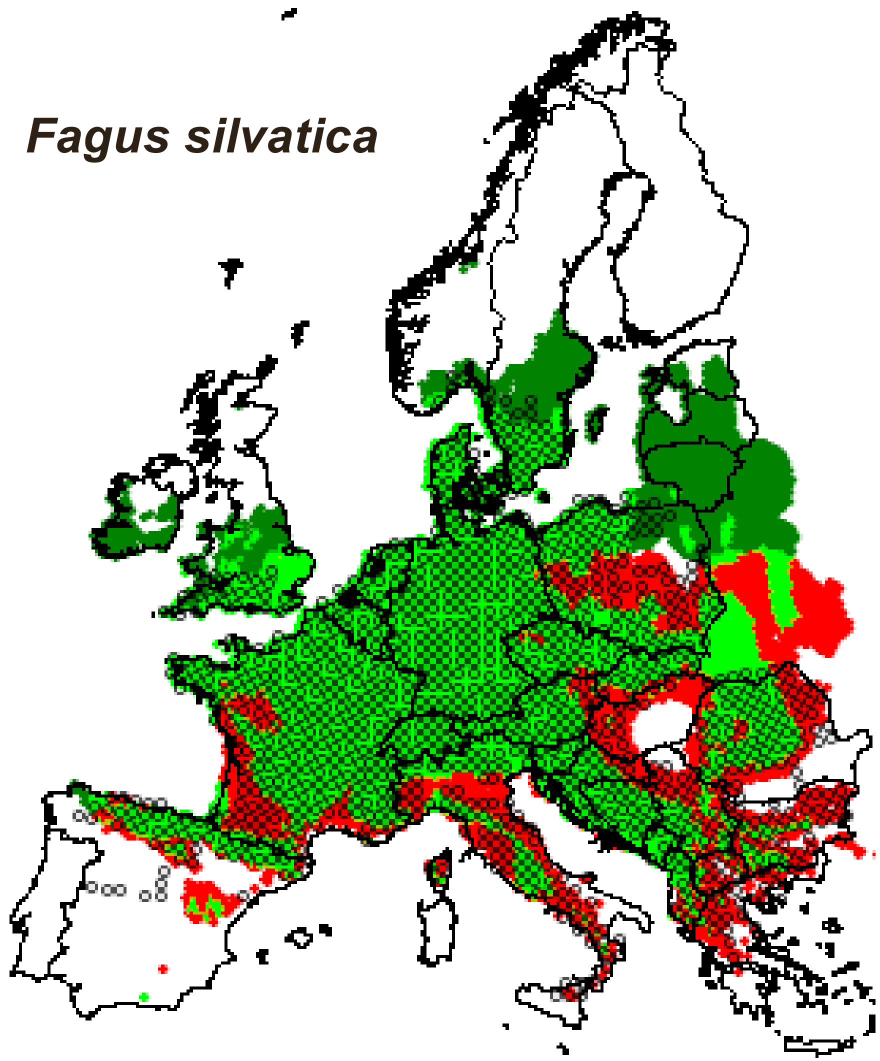
Examples for 2050 under A1 HadCM3

Red: habitat lost; clear green : habitat stable; dark green: new suitable habitat

Quercus ilex

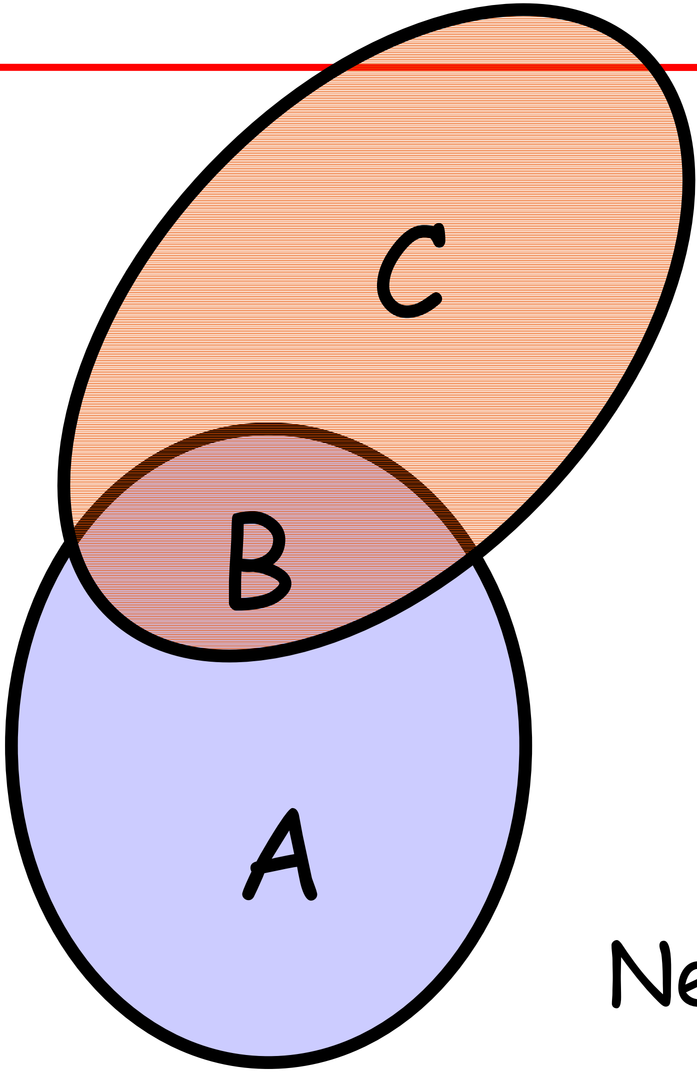


Fagus silvatica



Thuiller 2003 GCB

Defining shifts in biomes



1990 extent is A + B

Future extent is B + C

Decrease is A

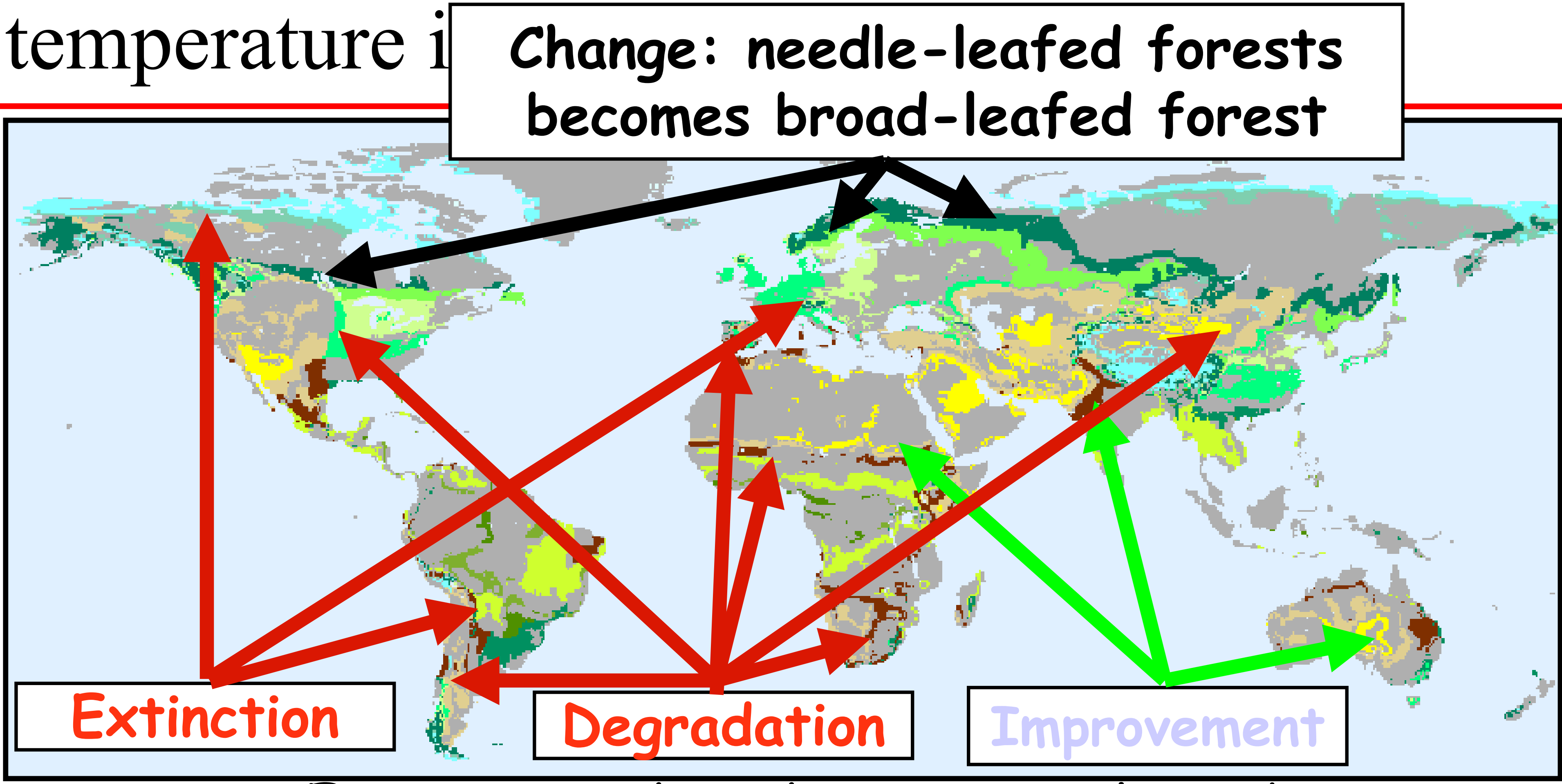
Stable area is B

Increase is C

Net change in extent is A - C

Net % change in extent is (B+C)/(A+B)

Changing ecosystems at a global mean temperature i

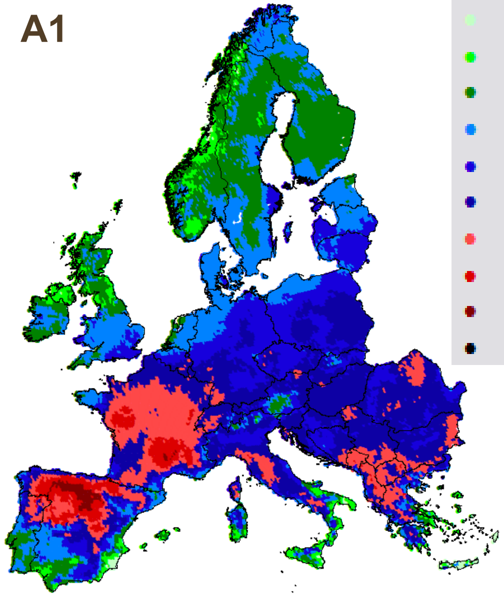


Ecosystems that change are coloured.

Improvement:	More trees and higher productivity
Change:	Different species composition and landscapes
Degradation:	Fewer trees and lower productivity
Extinction:	Large habitat decline and irreversible change

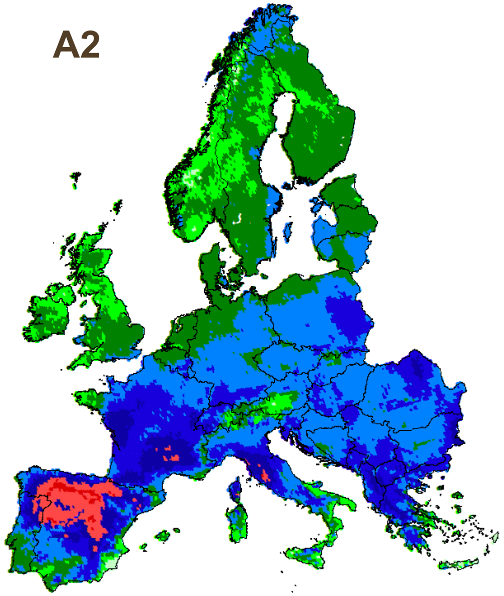
% of plant species loss by 2080 Hadcm3

A1



- 0 - 10%
- 10 - 20%
- 20 - 30%
- 30 - 40%
- 40 - 50%
- 50 - 60%
- 60 - 70%
- 70 - 80%
- 80 - 90%
- 90 - 100%

A2



ECONOMIC

T° ↗ 4,9

Economic growth

Homogeneous word

T° ↗ 4,1

Economic growth

Heterogeneous word

GLOBAL ⟵ ⟶ **REGIONAL**

T° ↗ 2,3

Economic and environmental viability

Homogeneous word

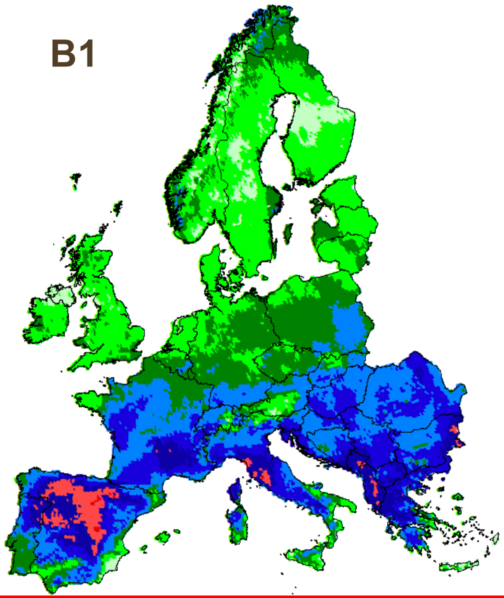
T° ↗ 3

Environmental policy

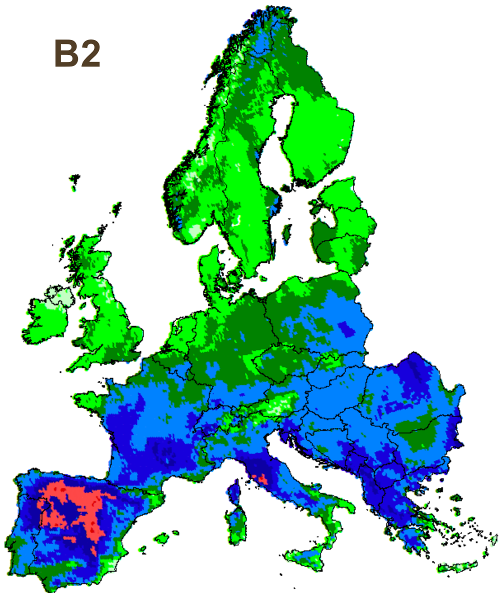
Heterogeneous word

SUBSTAINABLE DEVELOPMENT

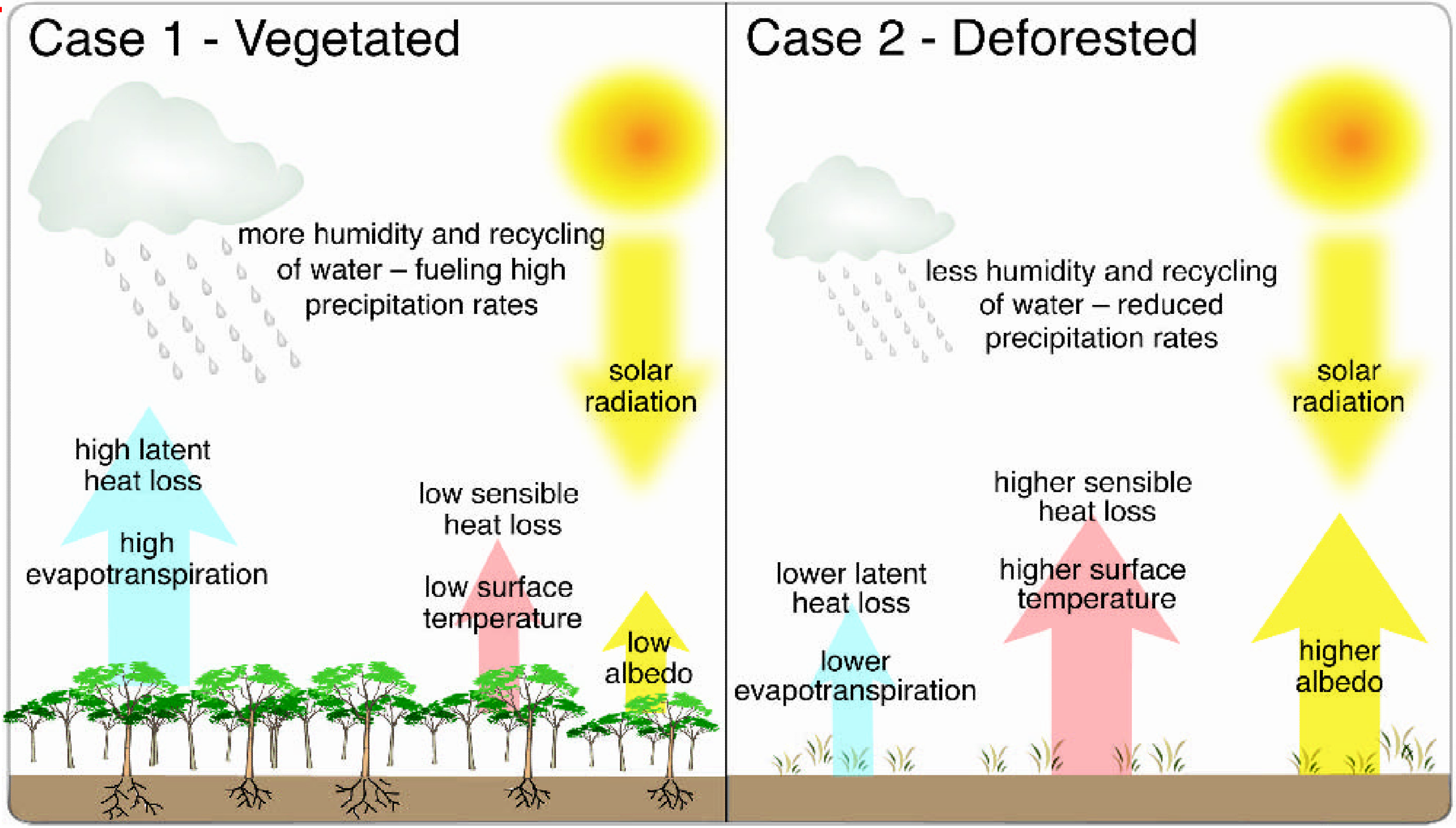
B1



B2

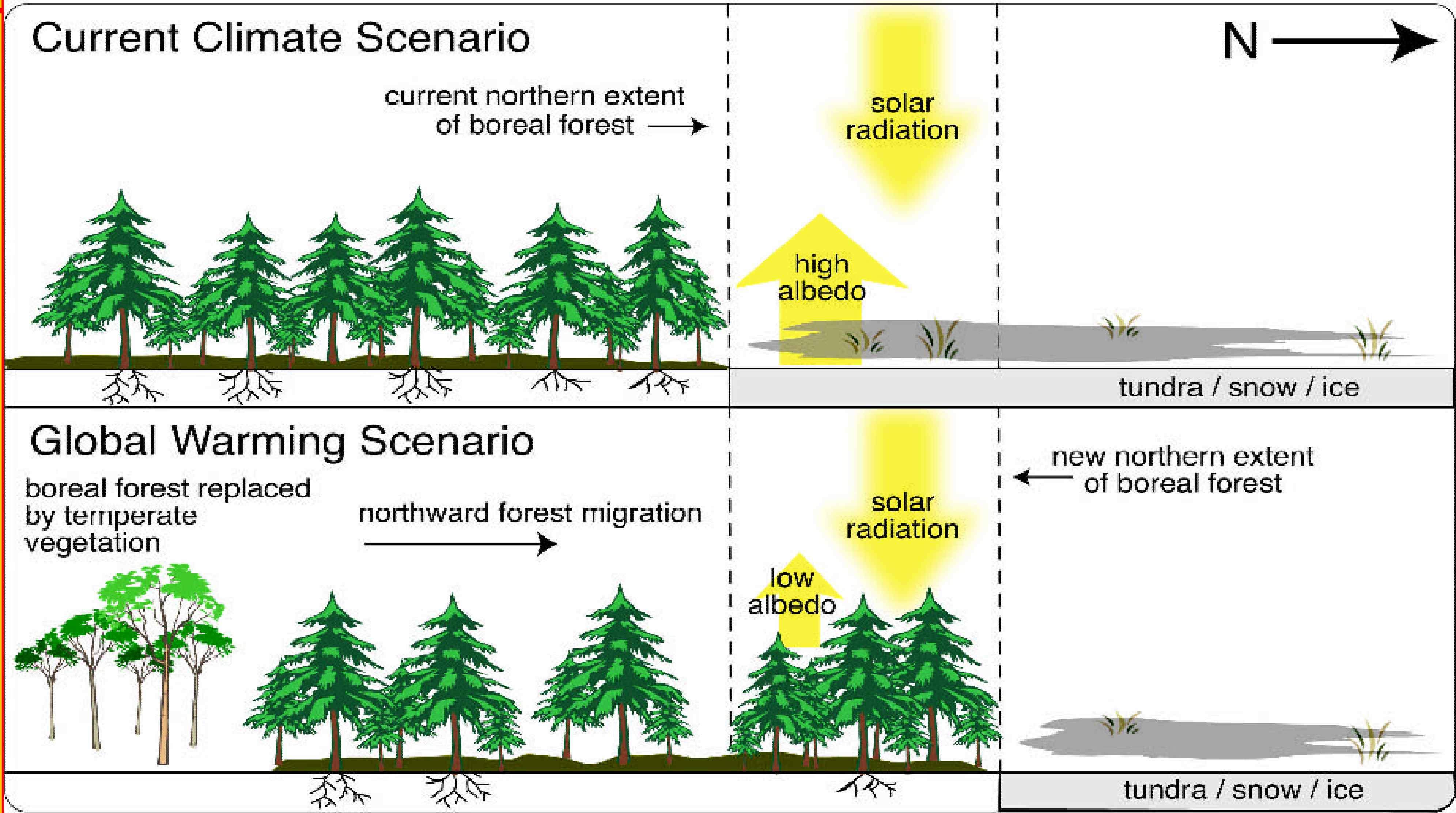


Feedbacks

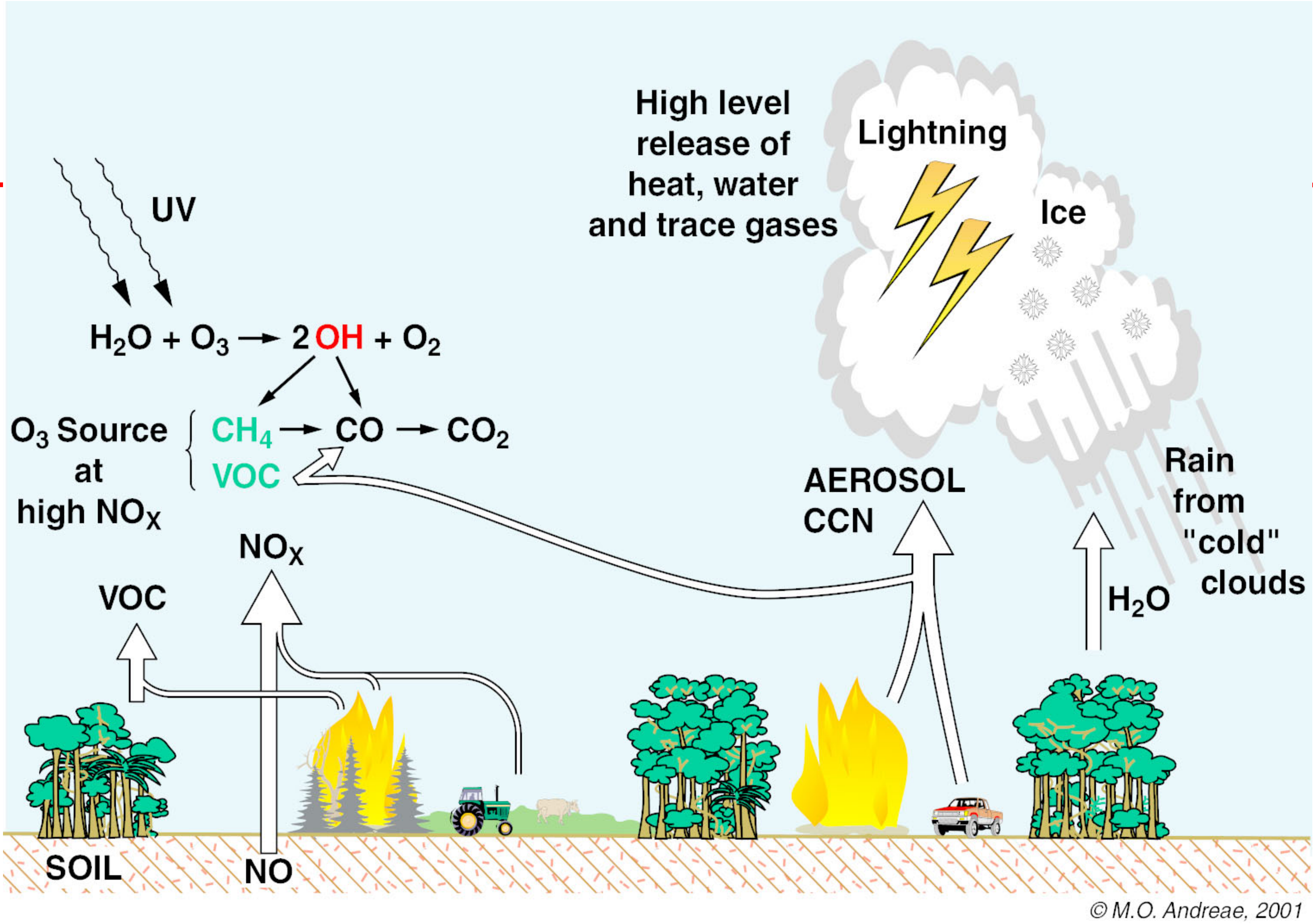


Case 1 - Vegetated
more humidity and recycling
of water – fueling high
precipitation rates
solar
radiation
high latent
heat loss
high
evapotranspiration
low sensible
heat loss
low surface
temperature
low
albedo
Case 2 - Deforested
less humidity and recycling
of water – reduced
precipitation rates
solar
radiation
higher sensible
heat loss
higher surface
temperature
lower latent
heat loss
lower
evapotranspiration
higher
albedo

Feedbacks



Current Climate Scenario
N
current northern extent
of boreal forest
solar
radiation
high
albedo
tundra / snow / ice
Global Warming Scenario
boreal forest replaced
by temperate
vegetation
northward forest migration
solar
radiation
low
albedo
new northern extent
of boreal forest
tundra / snow / ice


UV
$H_2O + O_3 \rightarrow 2\,OH + O_2$
O_3 Source at high NO_X
$CH_4 \rightarrow CO \rightarrow CO_2$
VOC
High level release of heat, water and trace gases
Lightning
Ice
AEROSOL CCN
Rain from "cold" clouds
H_2O
NO_X
VOC
SOIL
NO
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Final conclusion

- Despite the difficulties of attribution, there are observable impacts of anthropogenic climate change in many systems
- We have sophisticated methods (models) to analyze these changes and to distinguish between major driving factors
- Using scenarios and models, we can make quantitative assessments of future change in response to many drivers


Thank you for your interest!