Carbon Cycle and Global Vulnerability

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Avec Summer School, 22.09.2003

Peyresq, France

Suggested Reading:

Climate Change 2001:The Scientific Basis
Working Group I. Chapter 3

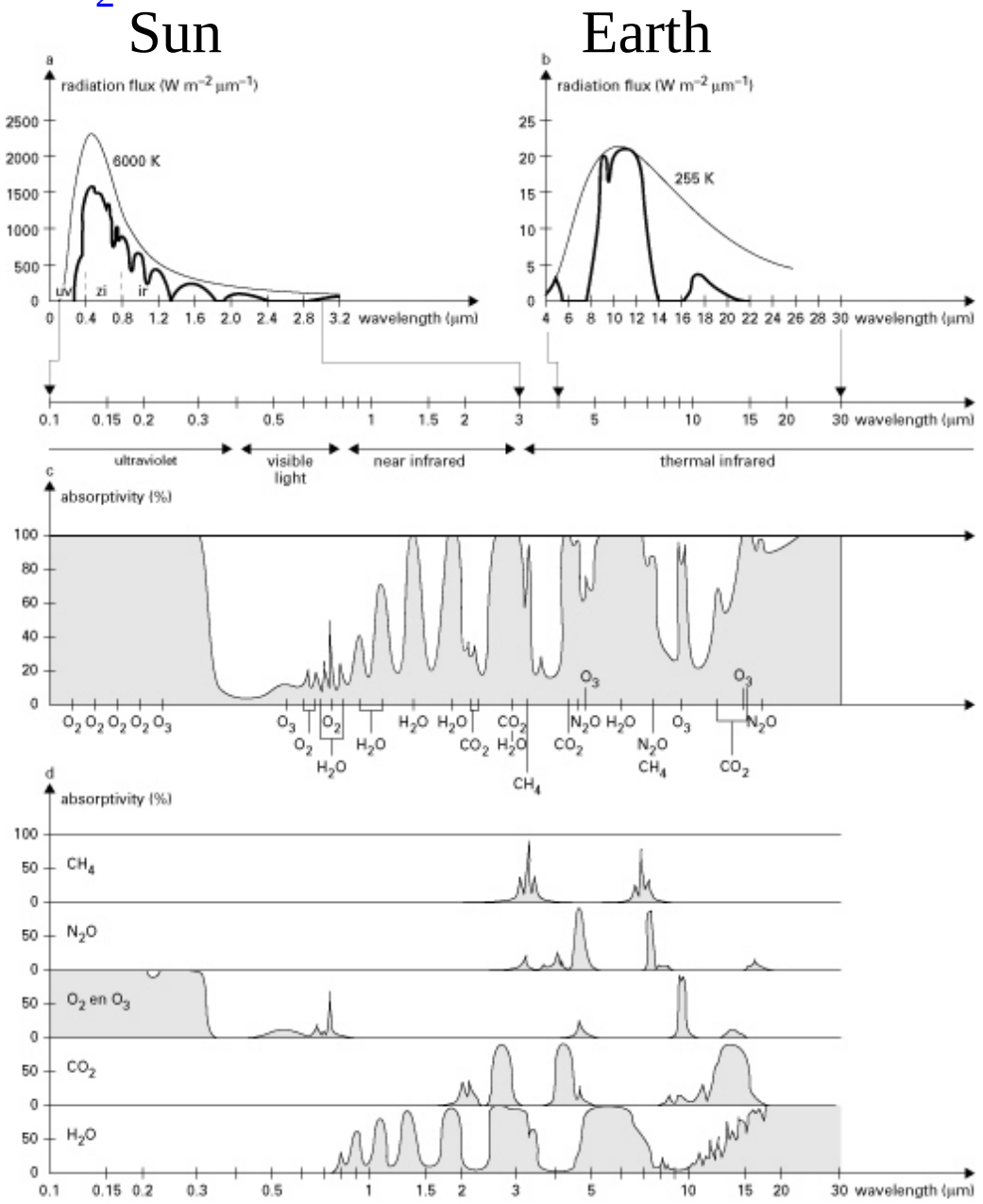
The Carbon Cycle and Atmospheric Carbon Dioxide.

Prentice et al.

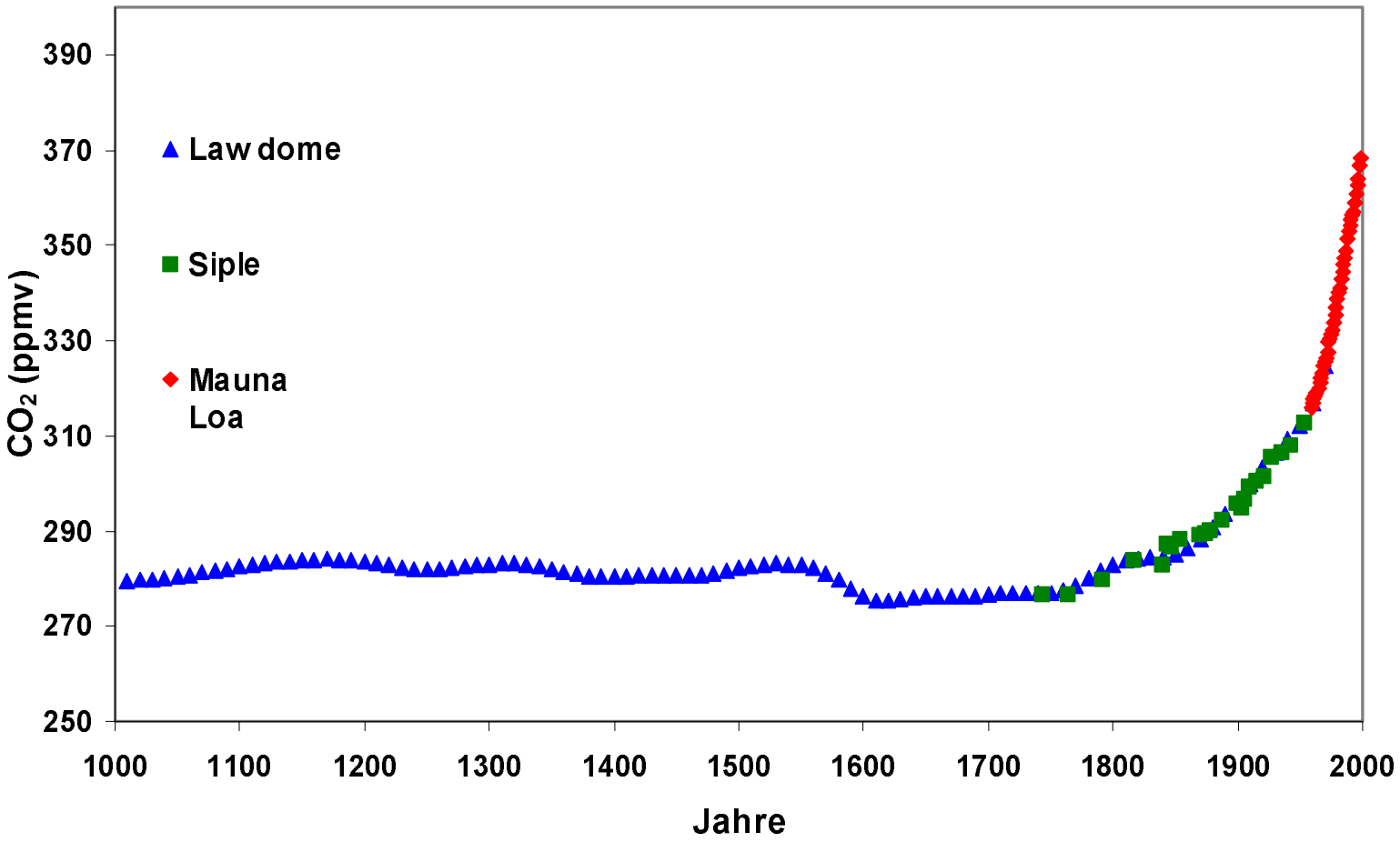
Outline

- **Introduction**
  - Greenhouse Gas CO_2
  - Atmospheric Observations
  - Vulnerability
- **The Carbon Cycle**
  - Carbon Budget of Earth System components
  - Contemporary Carbon Balance (1990´s)
  - Terrestrial Carbon Cycle: past, present, future
  - Climate-Carbon Cycle Feedbacks and mitigation
- **Conclusions**

Greenhouse Gas CO_2



Atmospheric CO_2 record



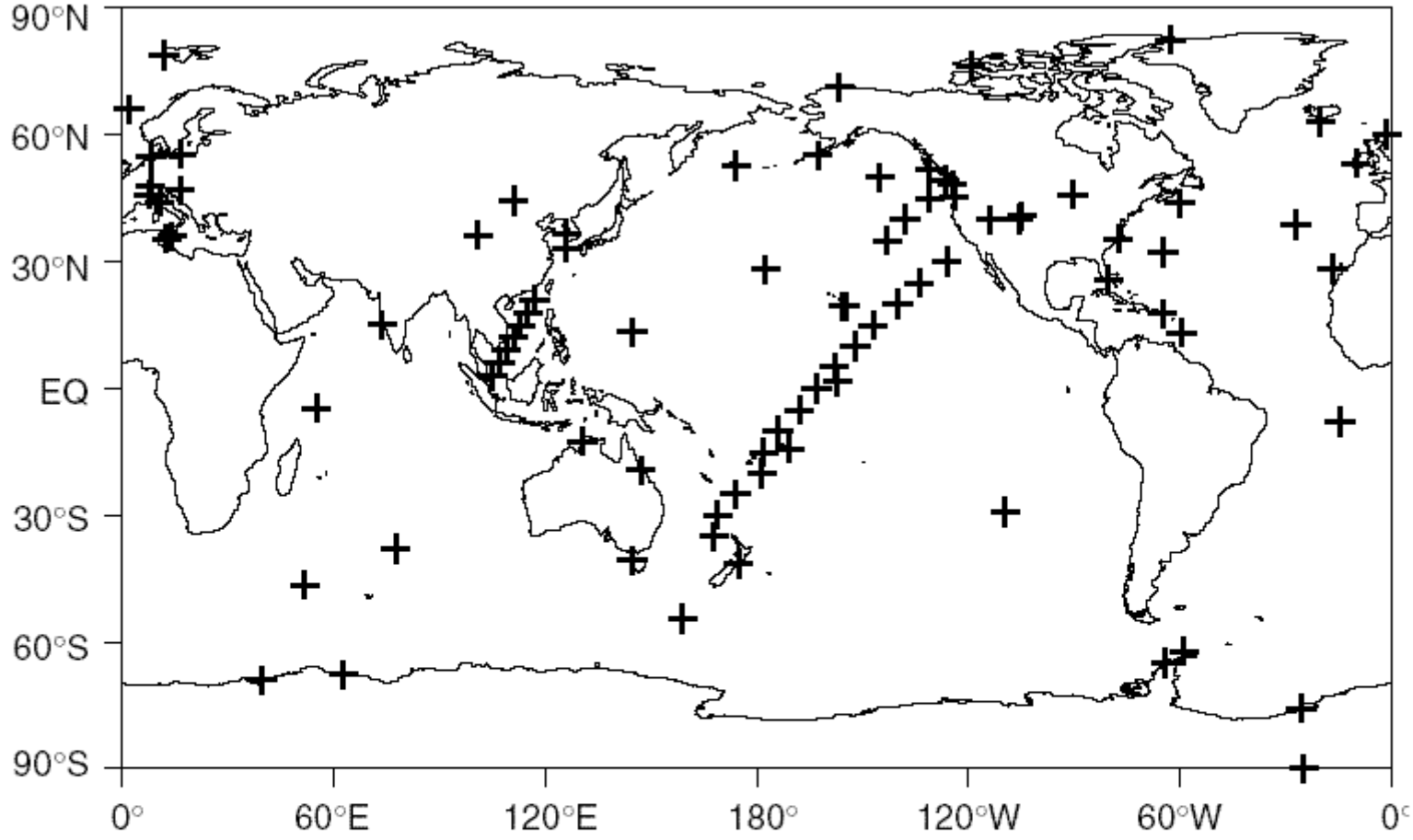
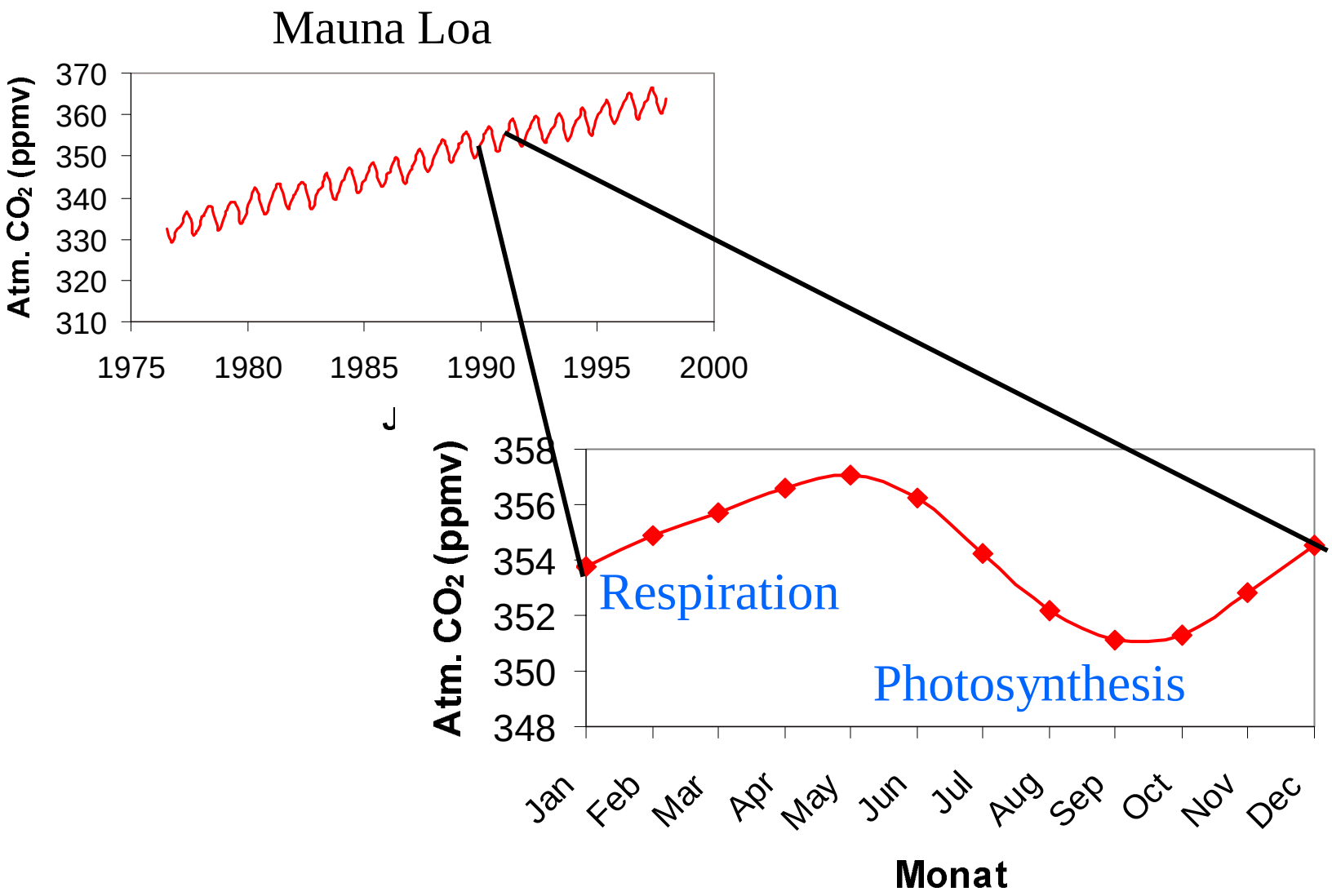
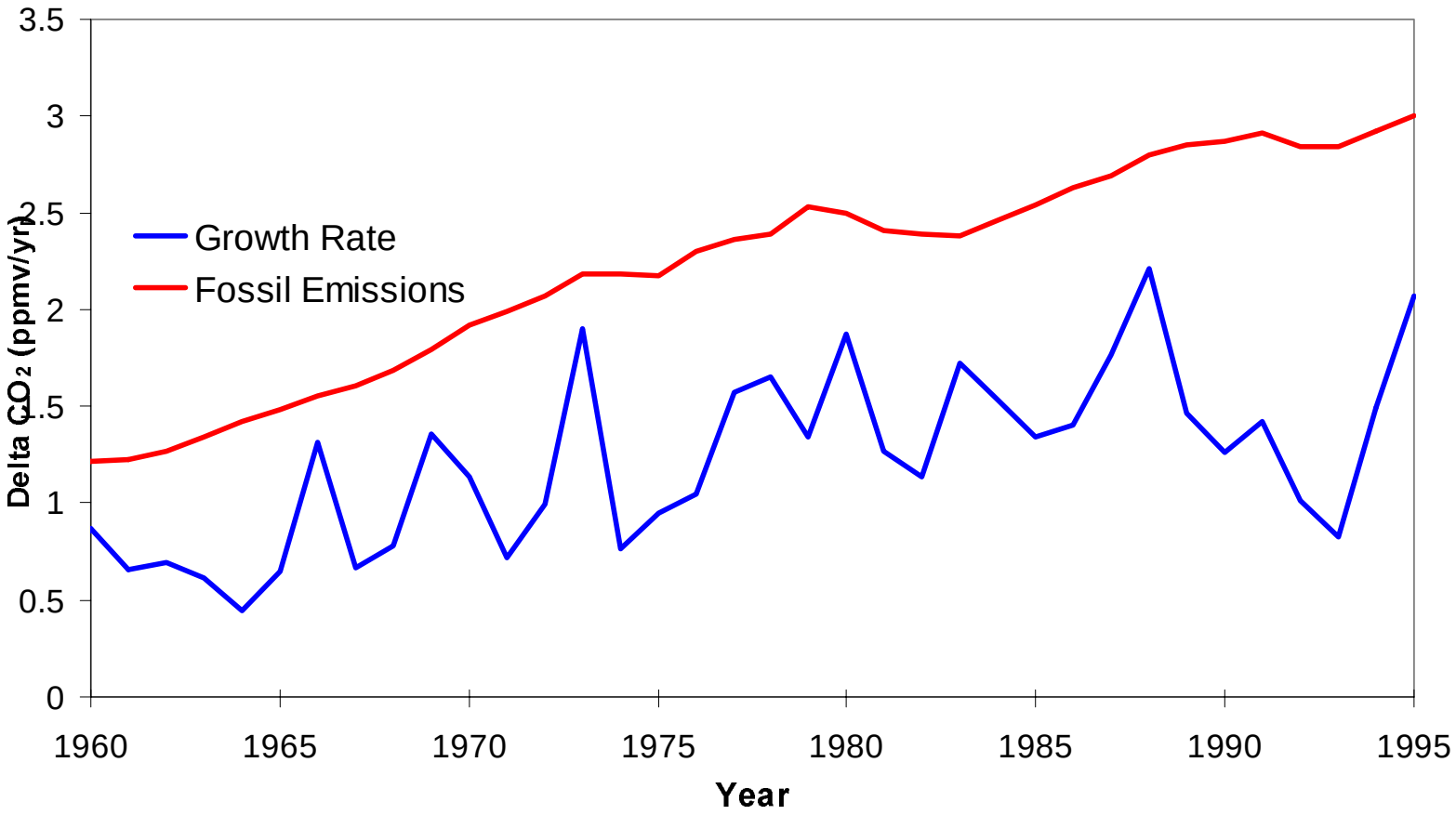


Figure 3.7: The atmospheric CO_2 measuring station network as represented by GLOBAL VIEW–CO_2 (Comparative Atmosphere Data Integration Project – Carbon Dioxide, NOAA/CMDL, http://www.cmdl.noaa.gov/ccg/co2).

„ Breathing Planet“



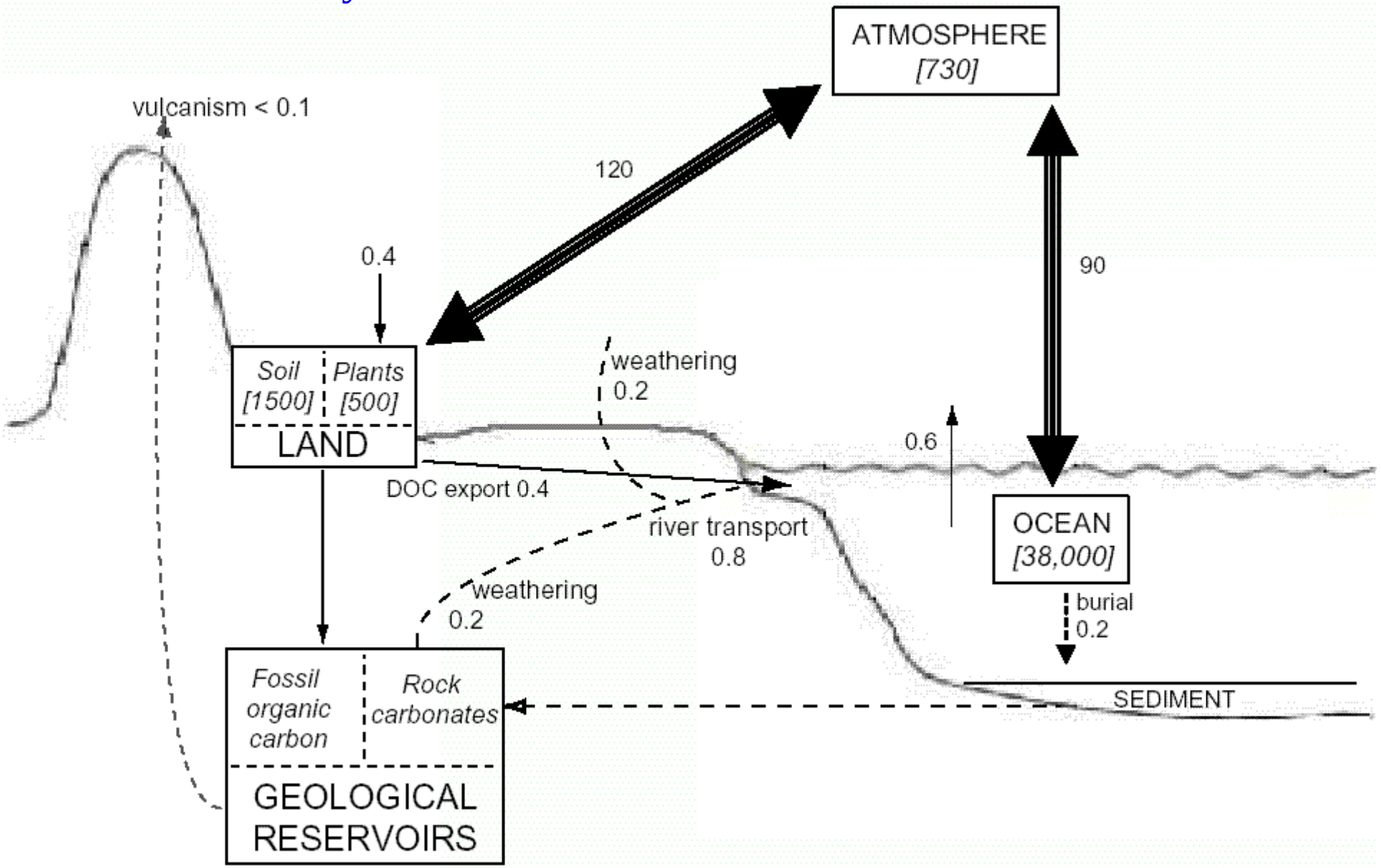
Atmospheric CO_2 growth rate

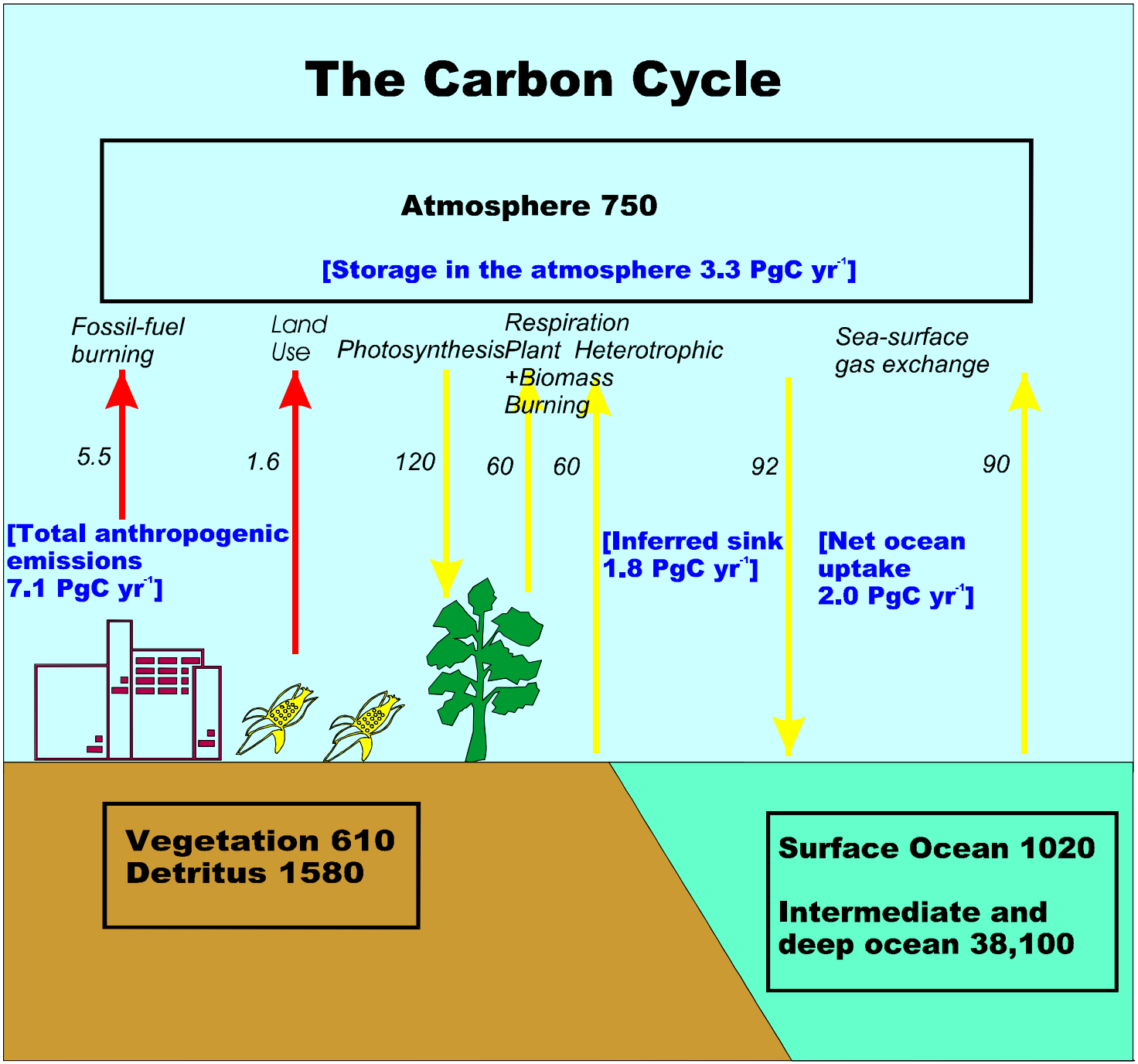


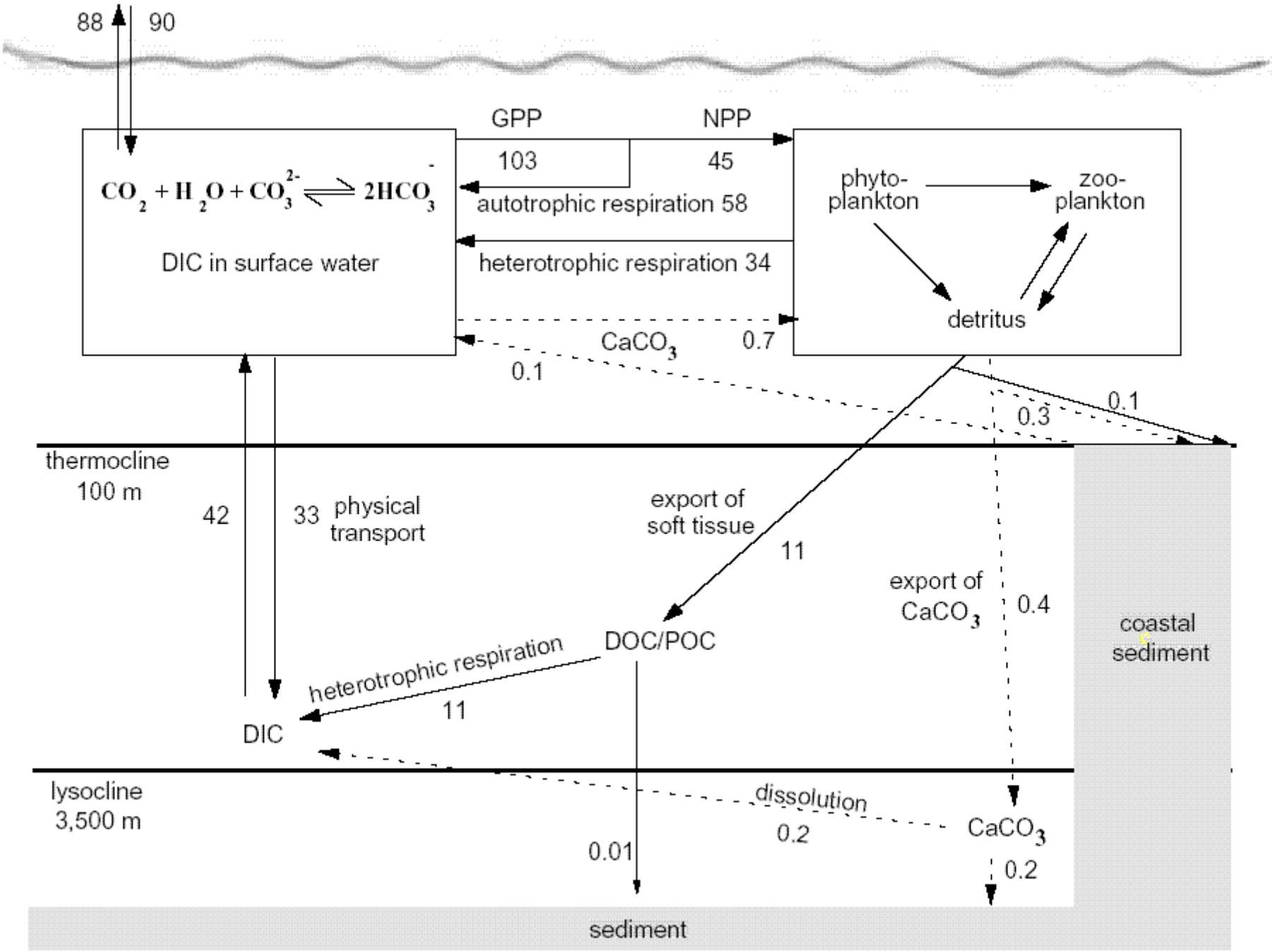
Vulnerability

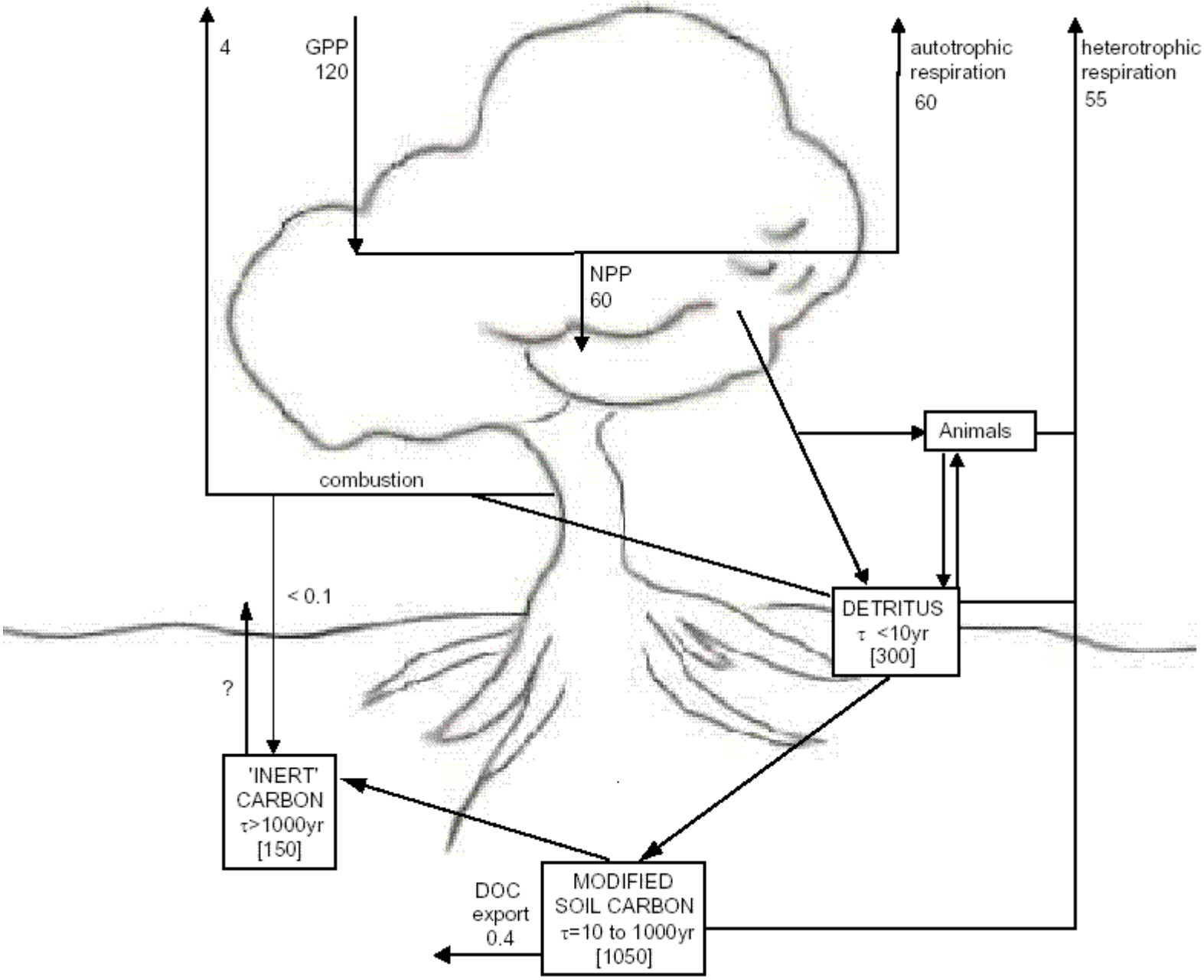
- Exposure
  - Indirect effect Carbon Cycle via Climate Change
- Sensitivity
  - E.g. Agricultural yields, forestry, carbon feedbacks
- Adaptive Capacity
  - Local/regional studies on impact of climate change

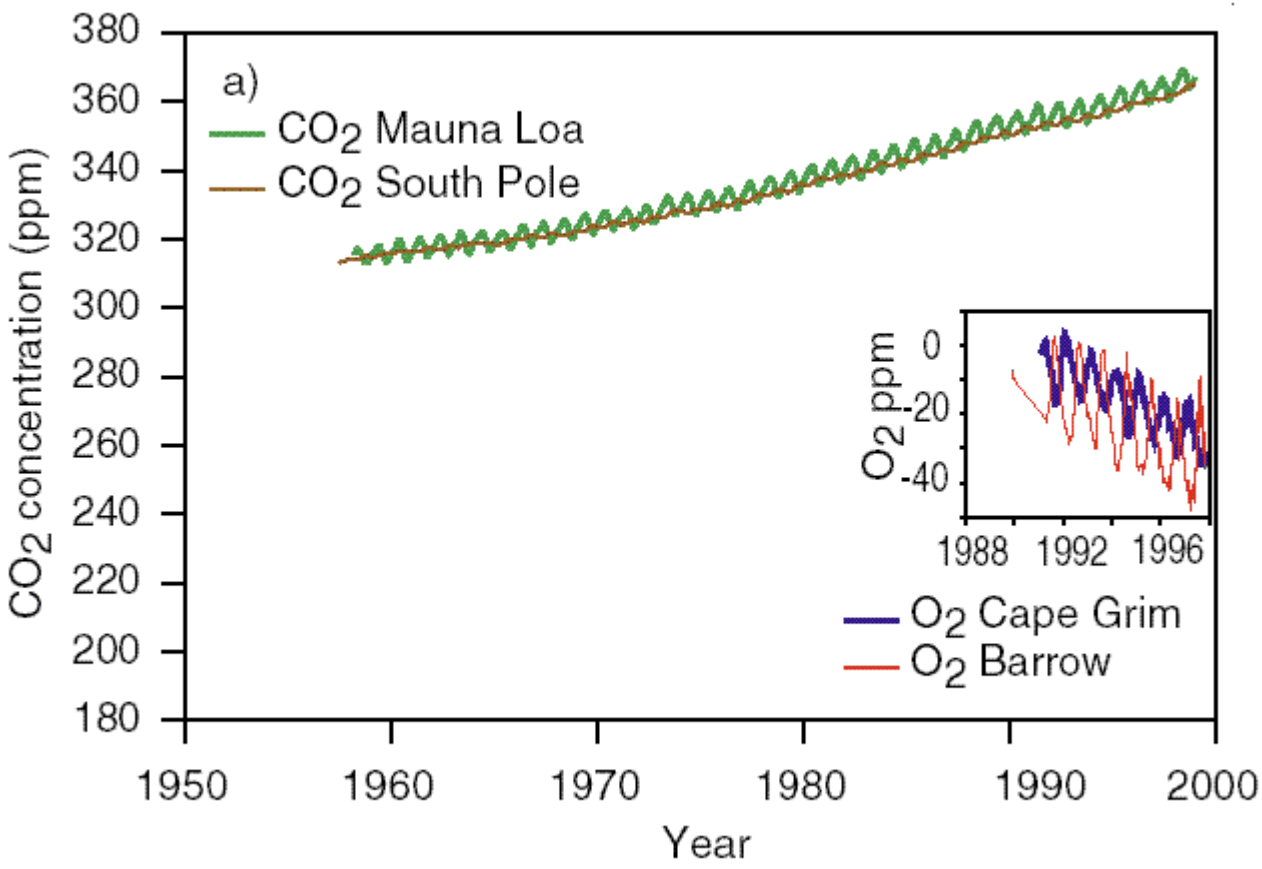
Natural Carbon Cycle

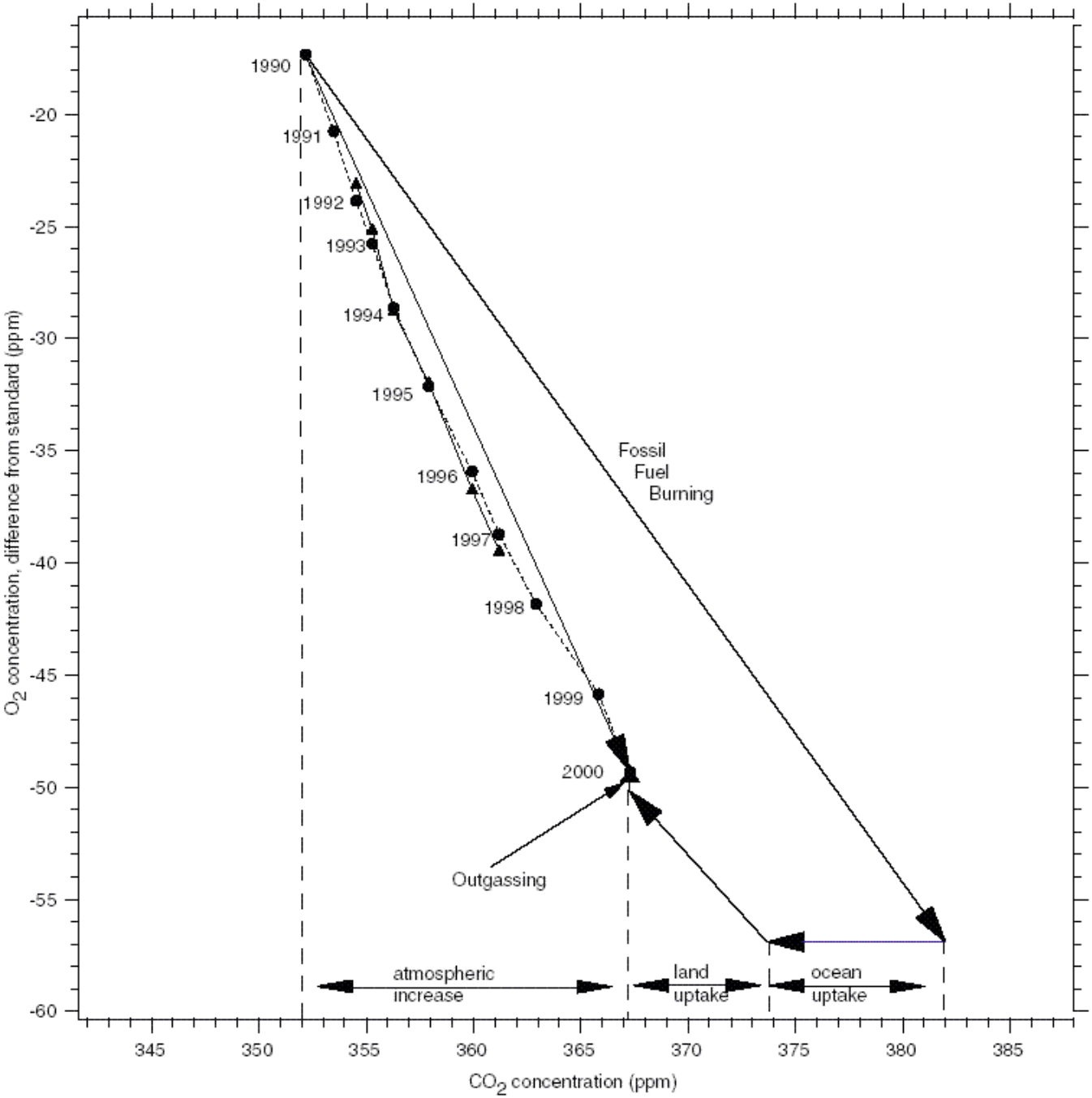


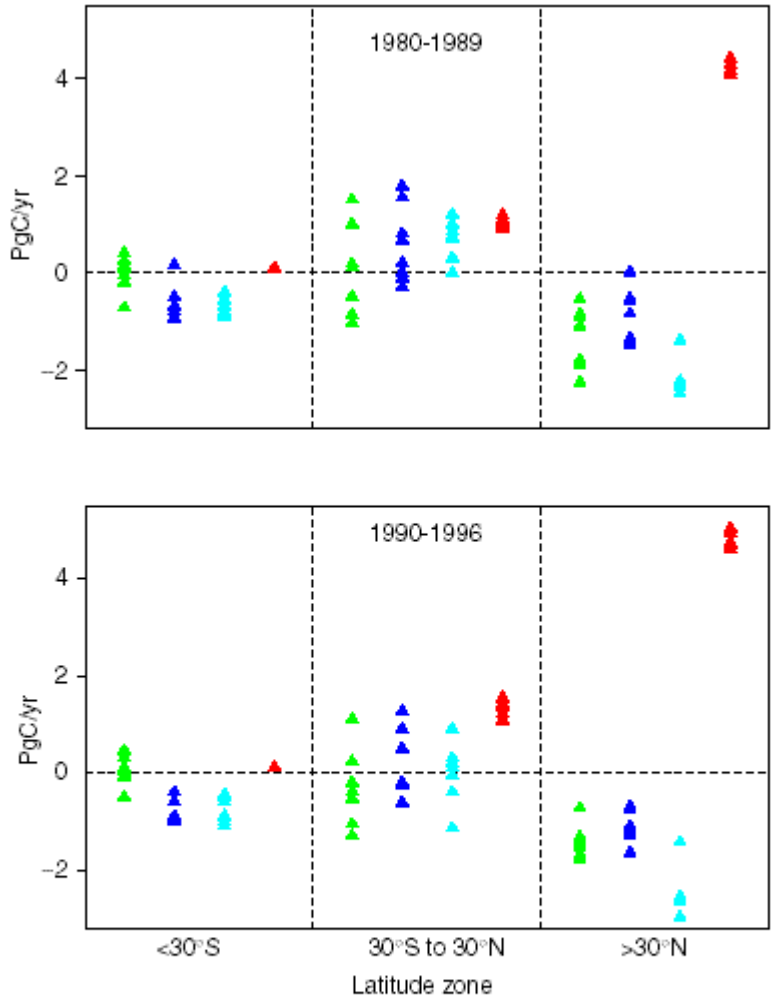

The Carbon Cycle
Atmosphere 750
[Storage in the atmosphere 3.3 PgC yr-1]
Fossil-fuel burning
Land Use
Photosynthesis
Respiration Plant +Biomass Burning
Heterotrophic
Sea-surface gas exchange
5.5
1.6
120
60
60
92
90
[Total anthropogenic emissions 7.1 PgC yr-1]
[Inferred sink 1.8 PgC yr-1]
[Net ocean uptake 2.0 PgC yr-1]
Vegetation 610
Detritus 1580
Surface Ocean 1020
Intermediate and deep ocean 38,100


88
90
GPP
NPP
103
45
$CO_2 + H_2O + CO_3^{2-} \rightleftharpoons 2HCO_3^-$
DIC in surface water
autotrophic respiration 58
heterotrophic respiration 34
phyto-plankton
zoo-plankton
detritus
$CaCO_3$
0.7
0.1
0.1
0.3
thermocline
100 m
42
33
physical transport
export of soft tissue
11
export of $CaCO_3$
0.4
coastal sediment
DOC/POC
heterotrophic respiration
11
DIC
lysocline
3,500 m
dissolution
0.2
$CaCO_3$
0.2
0.01
sediment


4
GPP
120
autotrophic
respiration
60
heterotrophic
respiration
55
NPP
60
Animals
combustion
< 0.1
?
DETRITUS
τ <10yr
[300]
'INERT'
CARBON
τ>1000yr
[150]
DOC
export
0.4
MODIFIED
SOIL CARBON
τ=10 to 1000yr
[1050]

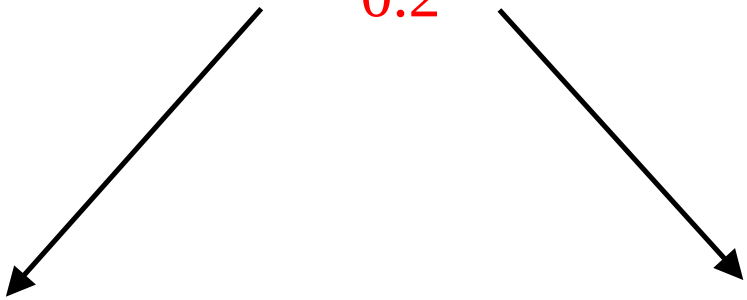

a)
CO2 Mauna Loa
CO2 South Pole
CO2 concentration (ppm)
380
360
340
320
300
280
260
240
220
200
180
1950
1960
1970
1980
1990
2000
Year
O2 ppm
0
-20
-40
1988
1992
1996
O2 Cape Grim
O2 Barrow


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Fossil
Fuel
Burning
Outgassing
atmospheric
increase
land
uptake
ocean
uptake
-20
-25
-30
-35
-40
-45
-50
-55
-60
345
350
355
360
365
370
375
380
385
O2 concentration, difference from standard (ppm)
CO2 concentration (ppm)


1980-1989
1990-1996
PgC/yr
4
2
0
−2
<30°S
30°S to 30°N
>30°N
Latitude zone
land-atmosphere flux
ocean-atmosphere flux
sum of ocean-atmosphere and land-atmosphere fluxes
fossil-fuel emissions

Carbon Balance **1990´s**

Atmospheric Growth	=	Fossil Fuel Emissions	-	Land-Uptake	-	Ocean-Uptake
3.2		5.4		0.2		2.0



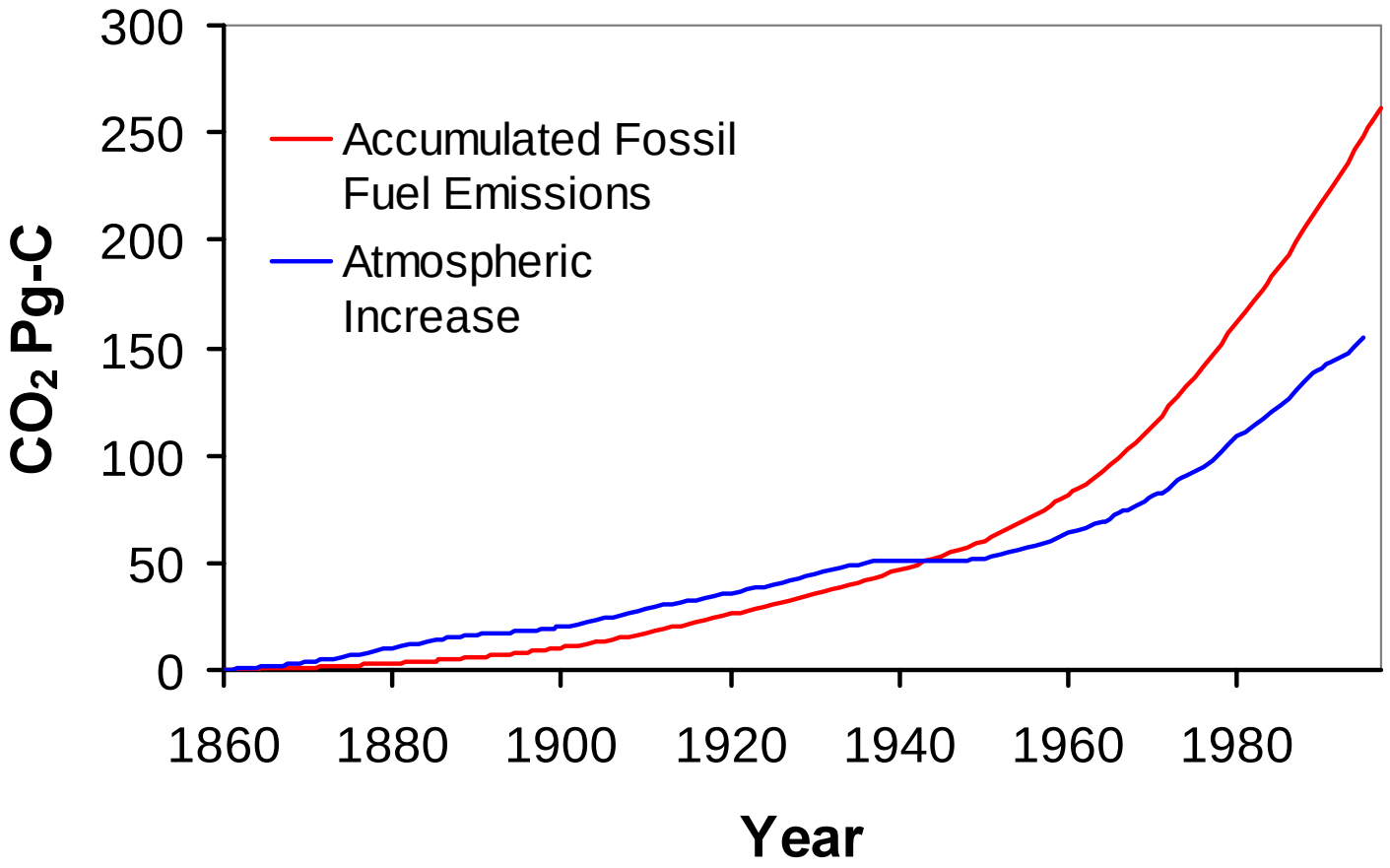
Deforestation

-1.7

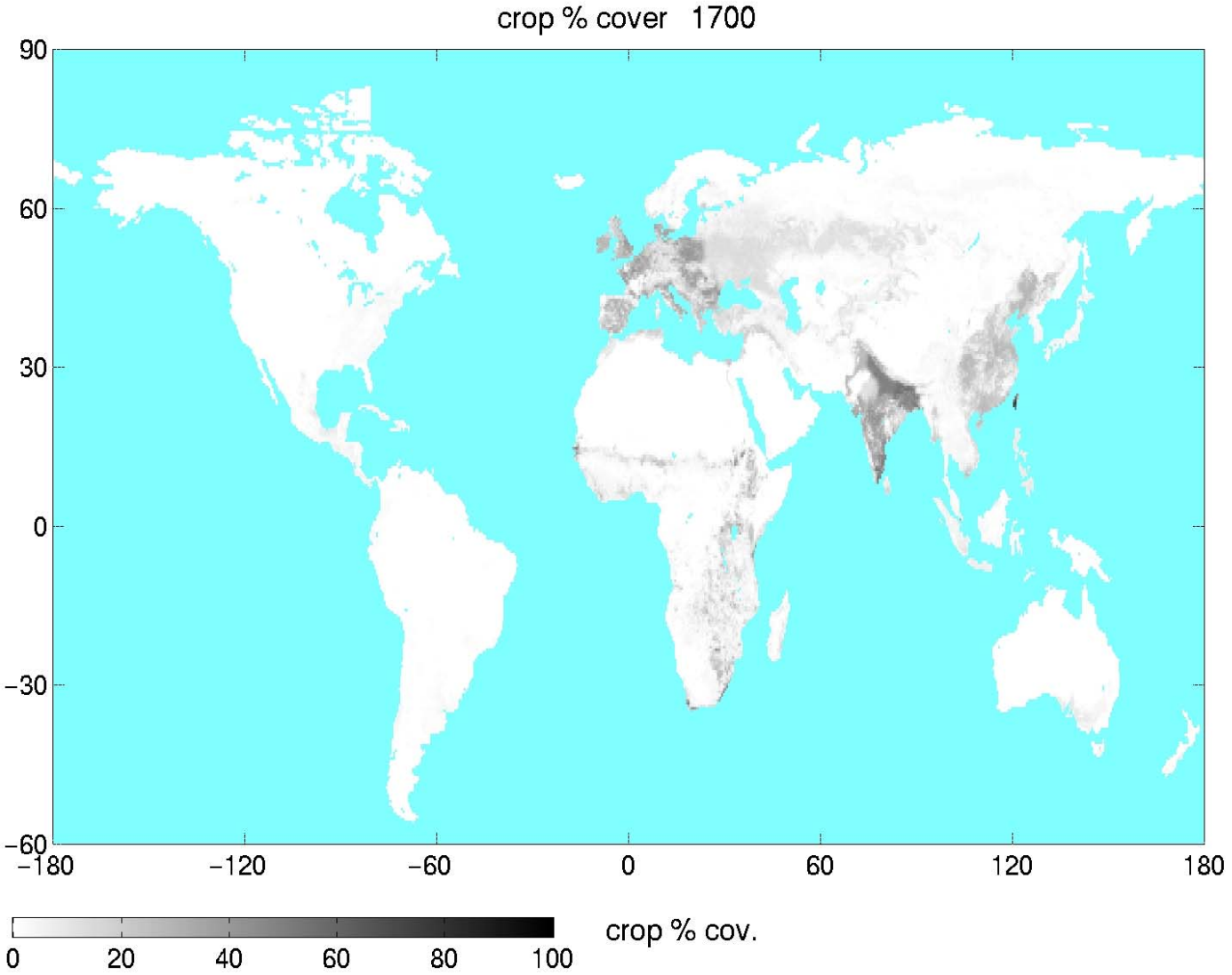
Increased Productivity

1.9

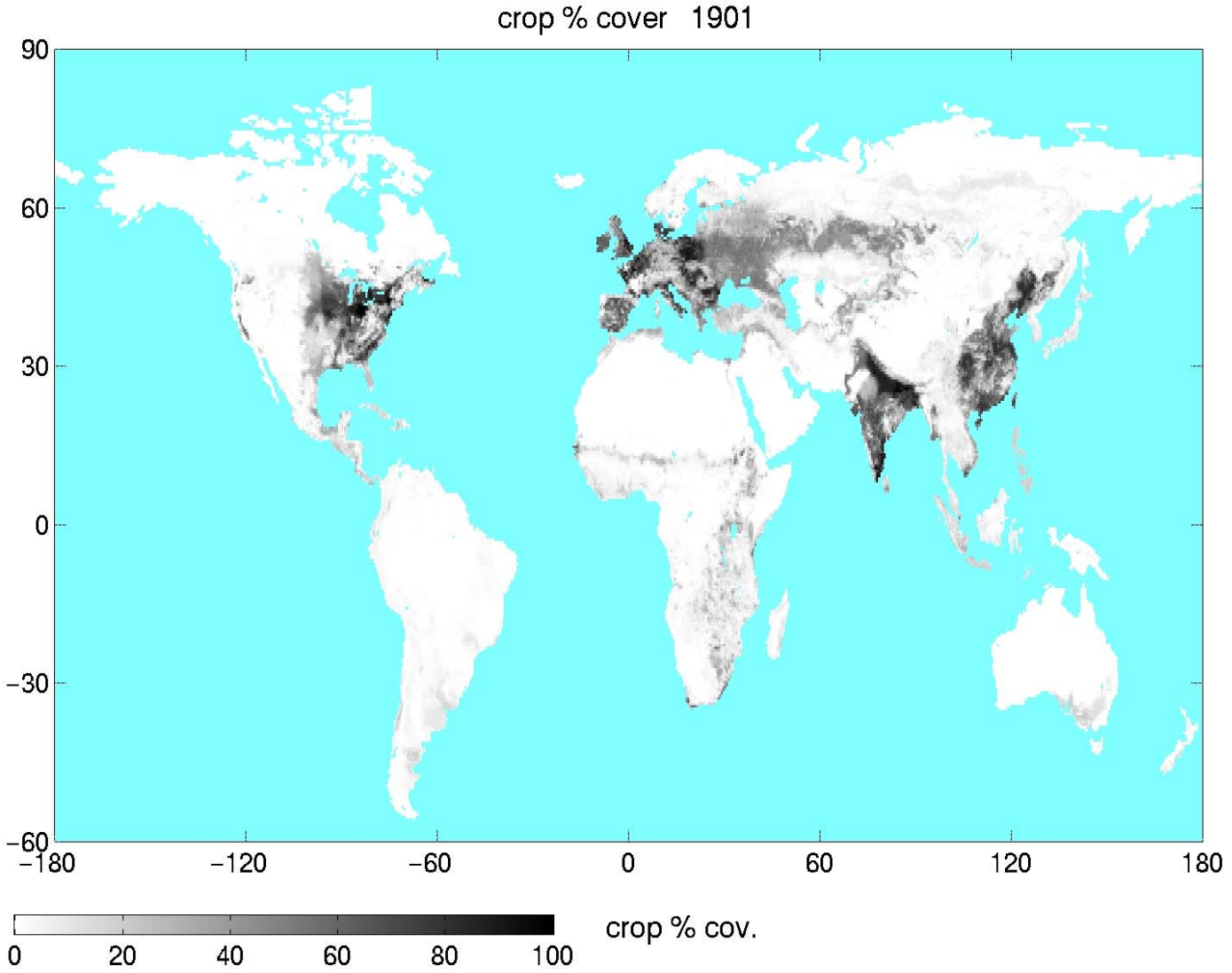
Fossil Fuel Emissions and role of the biosphere (Land und Ocean)



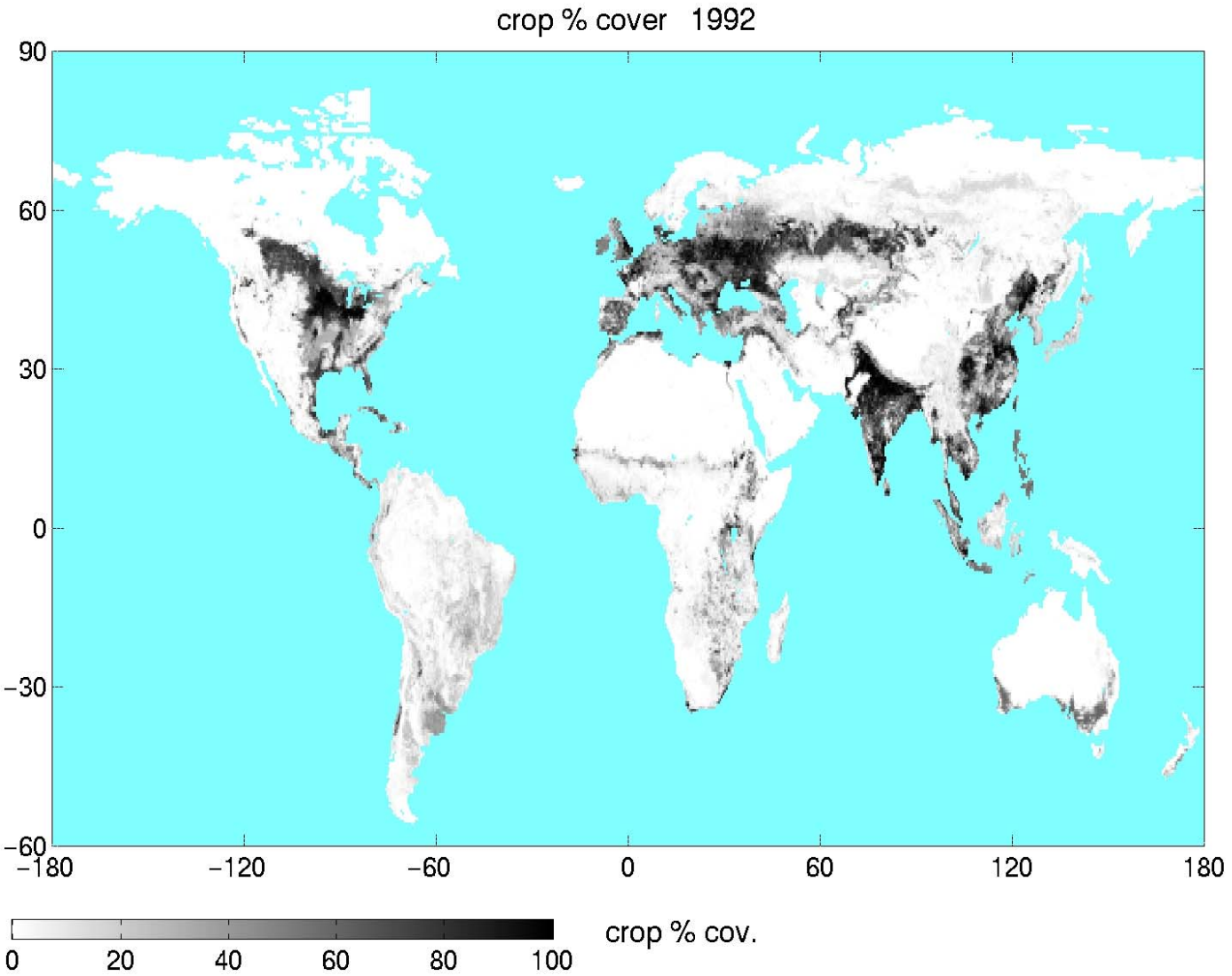
Cropland 1700 – 1992 [Ramankutty & Foley 1999, GBC 13(4), 997-1027]

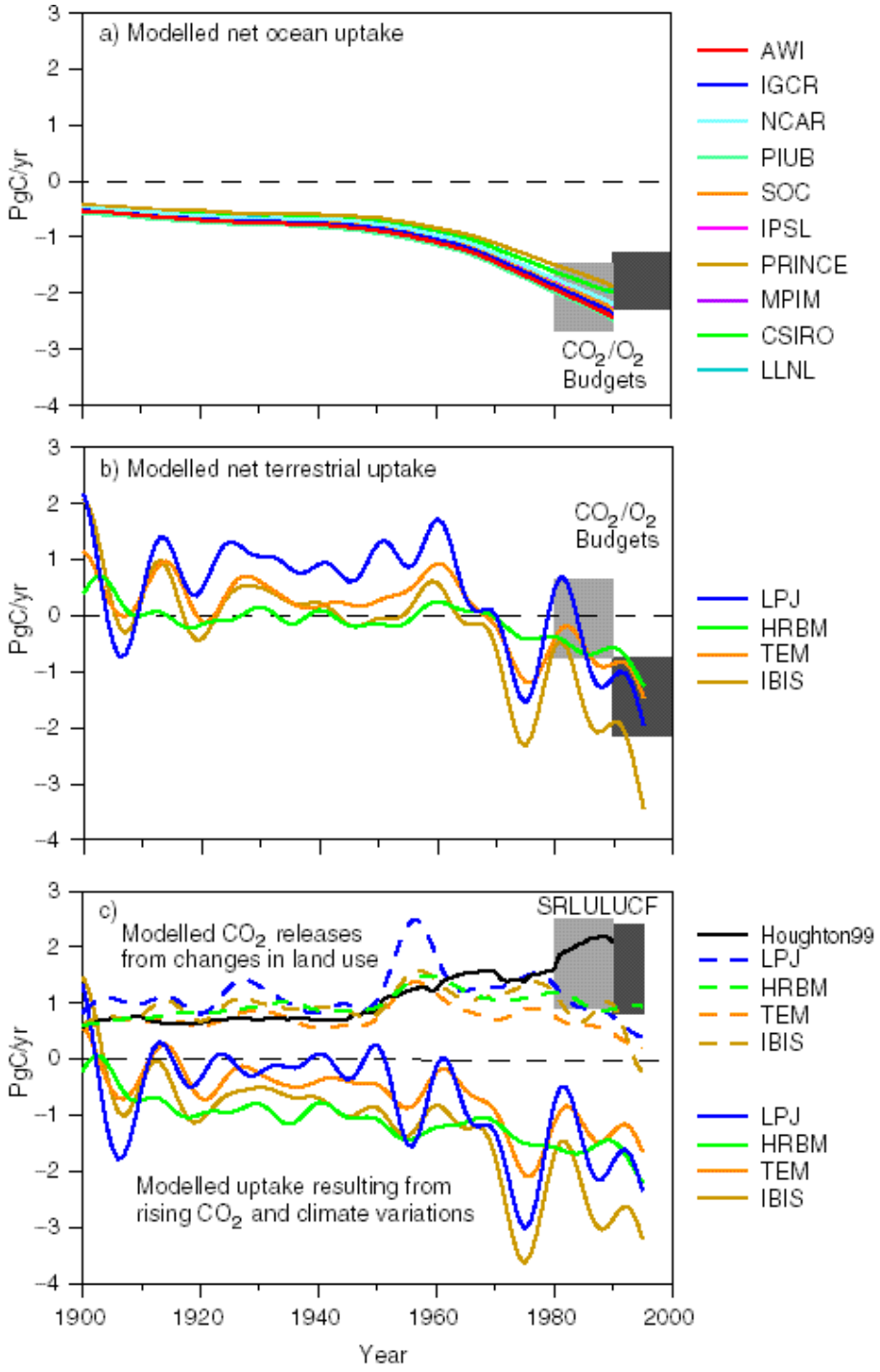


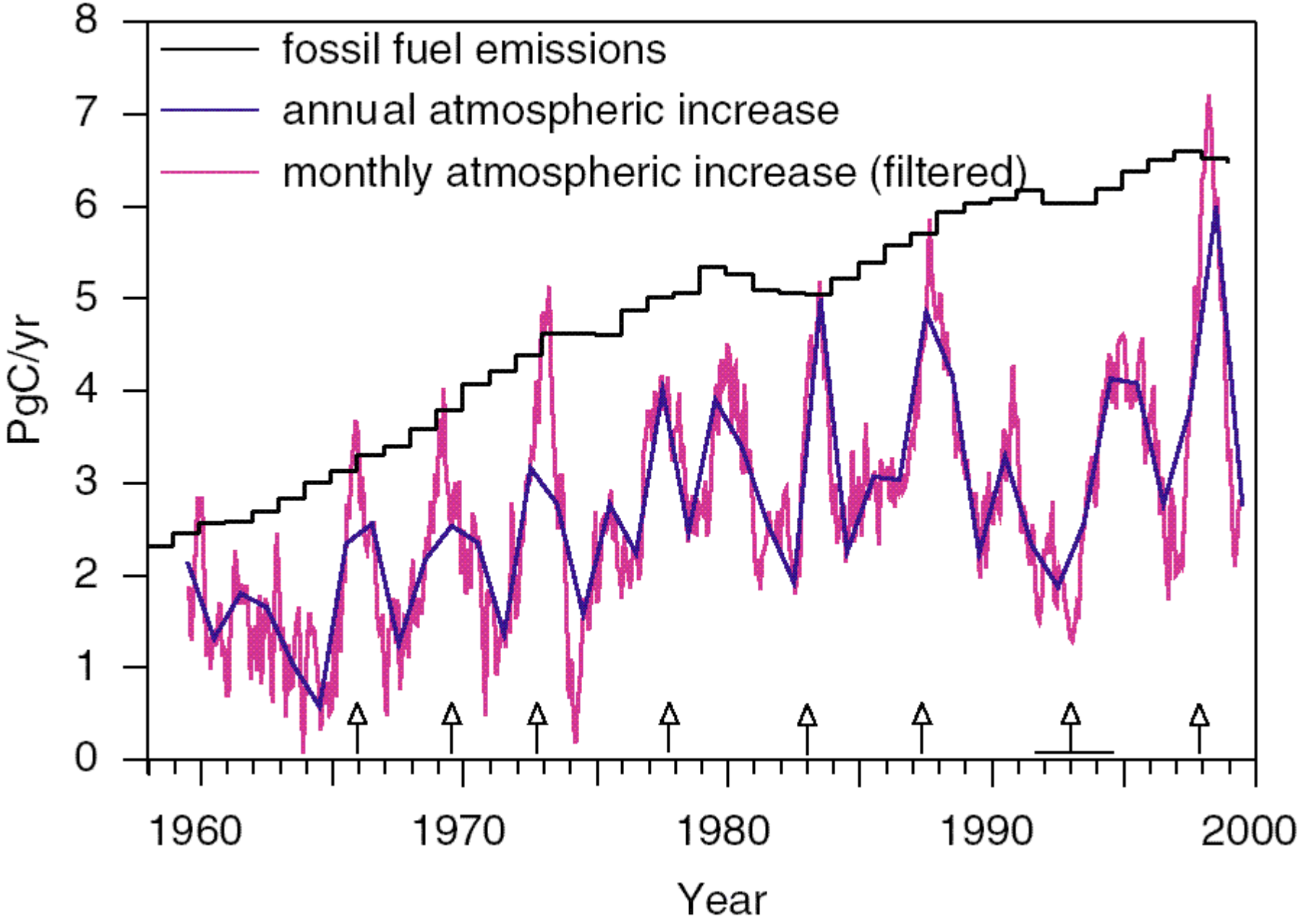
Cropland 1700 – 1992 [Ramankutty & Foley 1999, GBC 13(4), 997-1027]

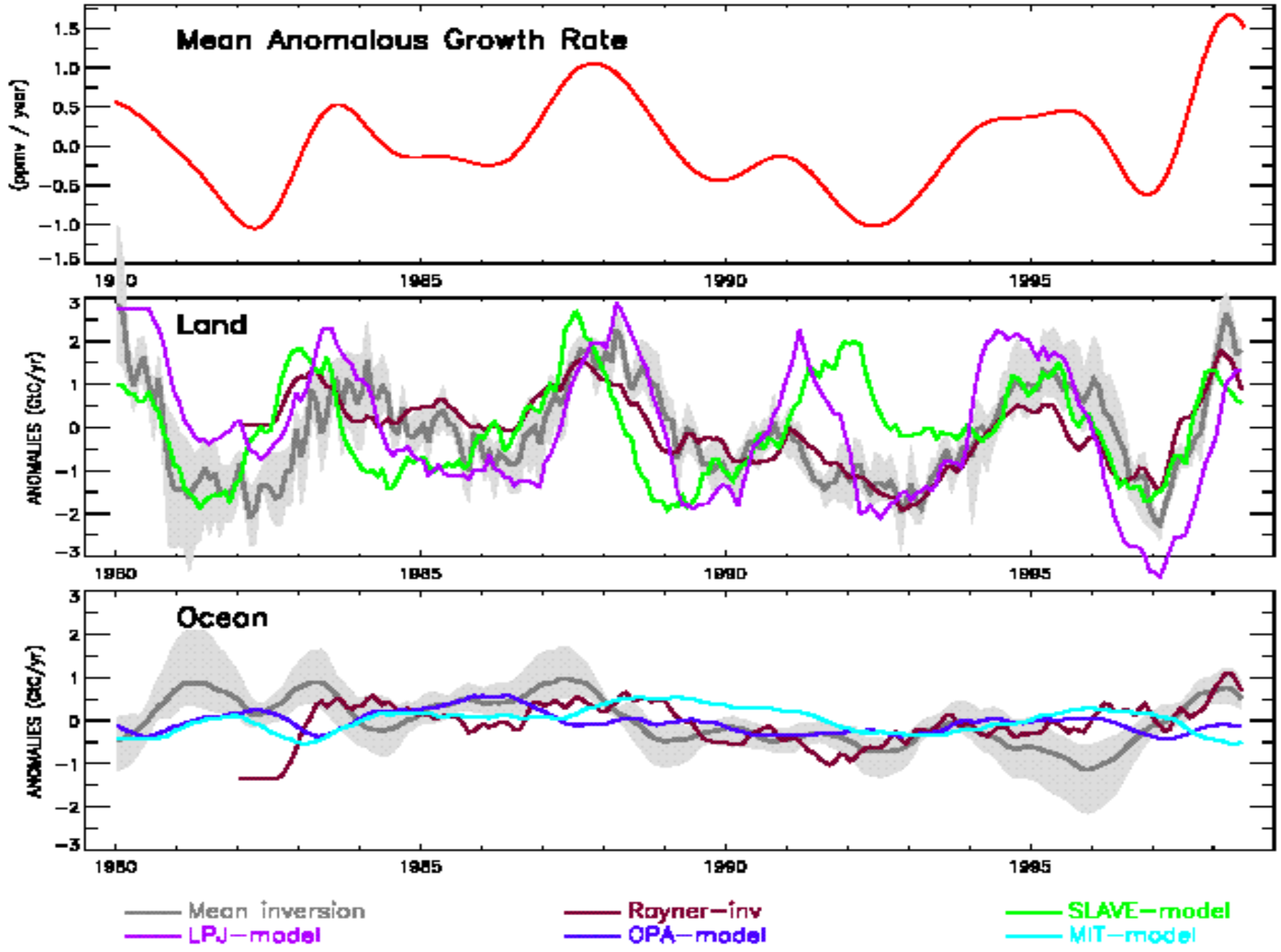


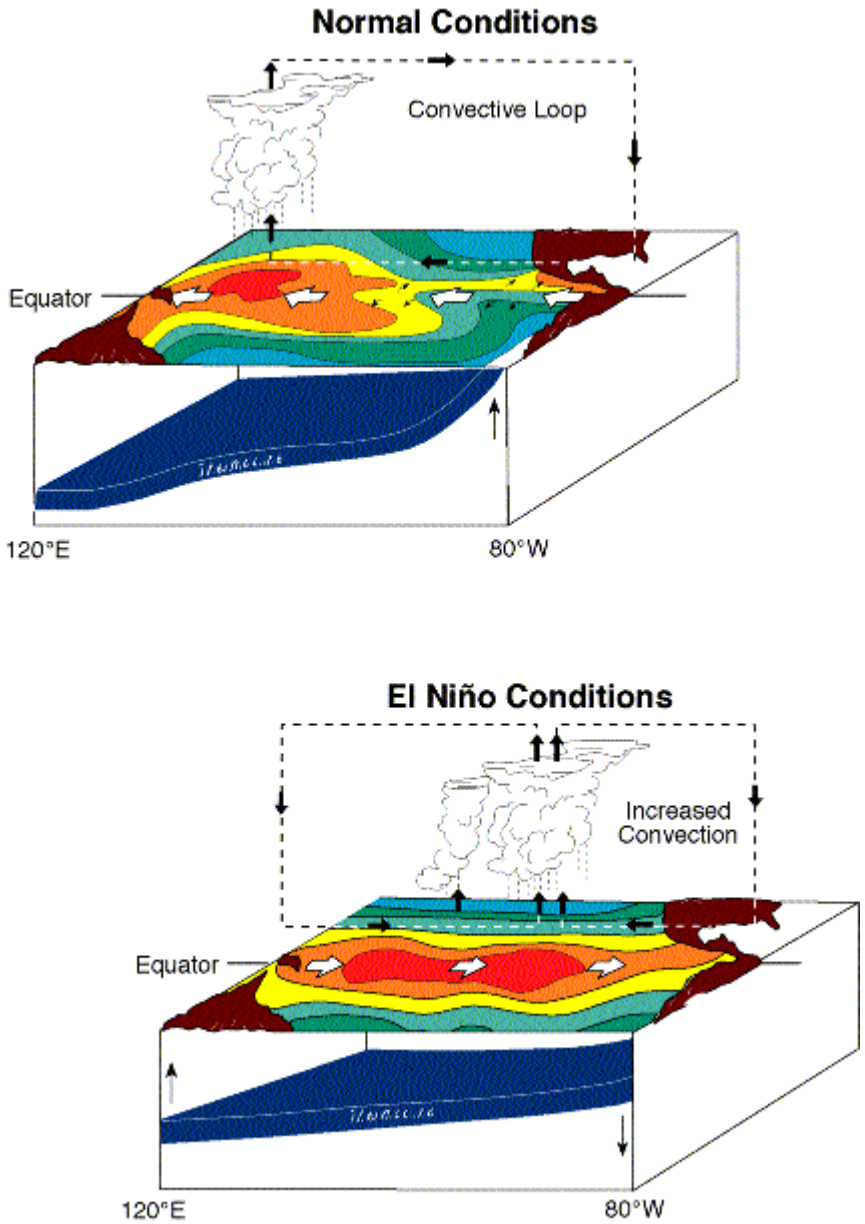
Cropland 1700 – 1992 [Ramankutty & Foley 1999, GBC 13(4), 997-1027]



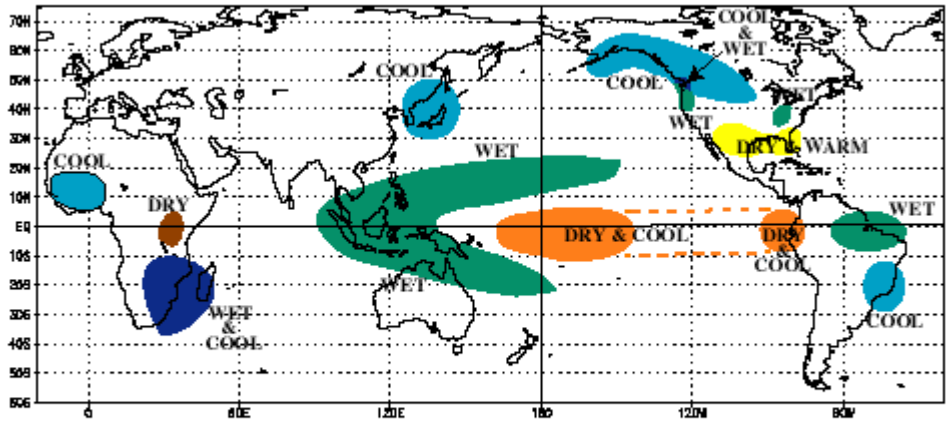

a) Modelled net ocean uptake
PgC/yr
3
2
1
0
−1
−2
−3
−4
CO_2/O_2 Budgets
AWI
IGCR
NCAR
PIUB
SOC
IPSL
PRINCE
MPIM
CSIRO
LLNL
b) Modelled net terrestrial uptake
CO_2/O_2 Budgets
LPJ
HRBM
TEM
IBIS
c)
Modelled CO_2 releases from changes in land use
SRLULUCF
Houghton99
LPJ
HRBM
TEM
IBIS
Modelled uptake resulting from rising CO_2 and climate variations
LPJ
HRBM
TEM
IBIS
1900
1920
1940
1960
1980
2000
Year


fossil fuel emissions
annual atmospheric increase
monthly atmospheric increase (filtered)
PgC/yr
0
1
2
3
4
5
6
7
8
1960
1970
1980
1990
2000
Year

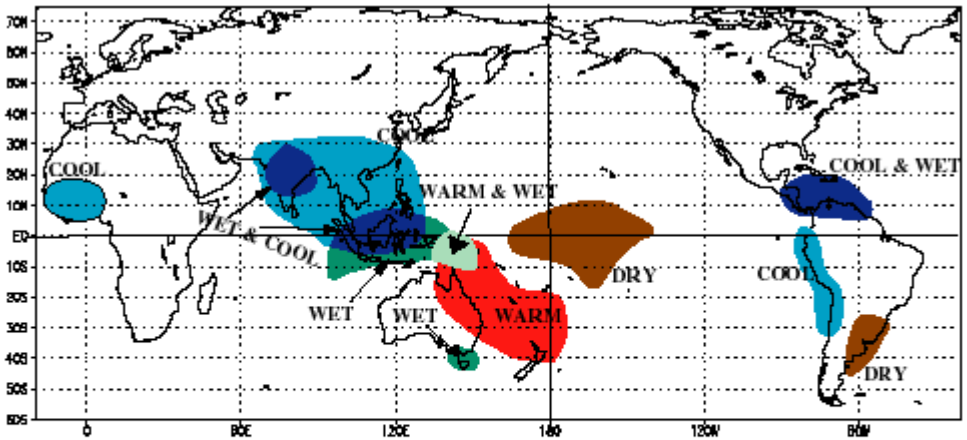

Mean Anomalous Growth Rate
(ppmv / year)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1985
1990
1995
Land
ANOMALIES (GtC/yr)
3
2
1
0
−1
−2
−3
1985
1990
1995
Ocean
ANOMALIES (GtC/yr)
3
2
1
0
−1
−2
−3
1985
1990
1995
Mean inversion
LPJ−model
Rayner−inv
OPA−model
SLAVE−model
MIT−model


Normal Conditions
Convective Loop
Equator
120°E
80°W
El Niño Conditions
Increased
Convection
Equator
120°E
80°W
NOAA/PMEL/TAO

COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY

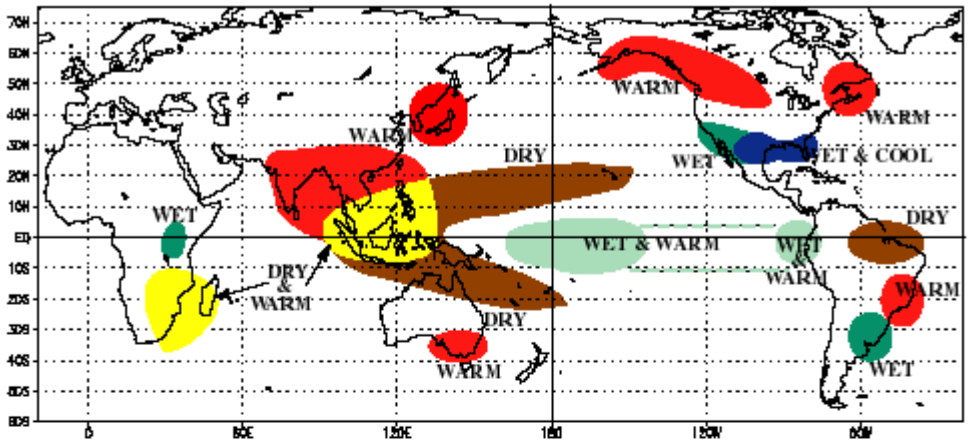


COLD EPISODE RELATIONSHIPS JUNE - AUGUST

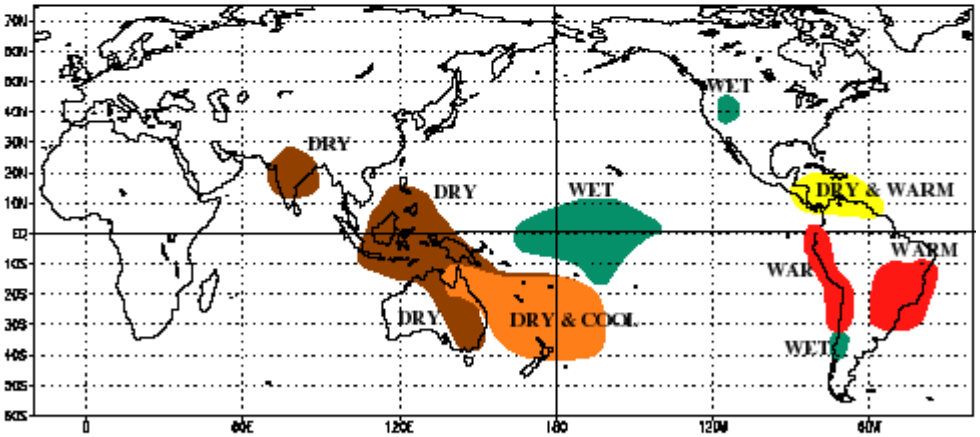


Climate Prediction Center
NCEP

WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY

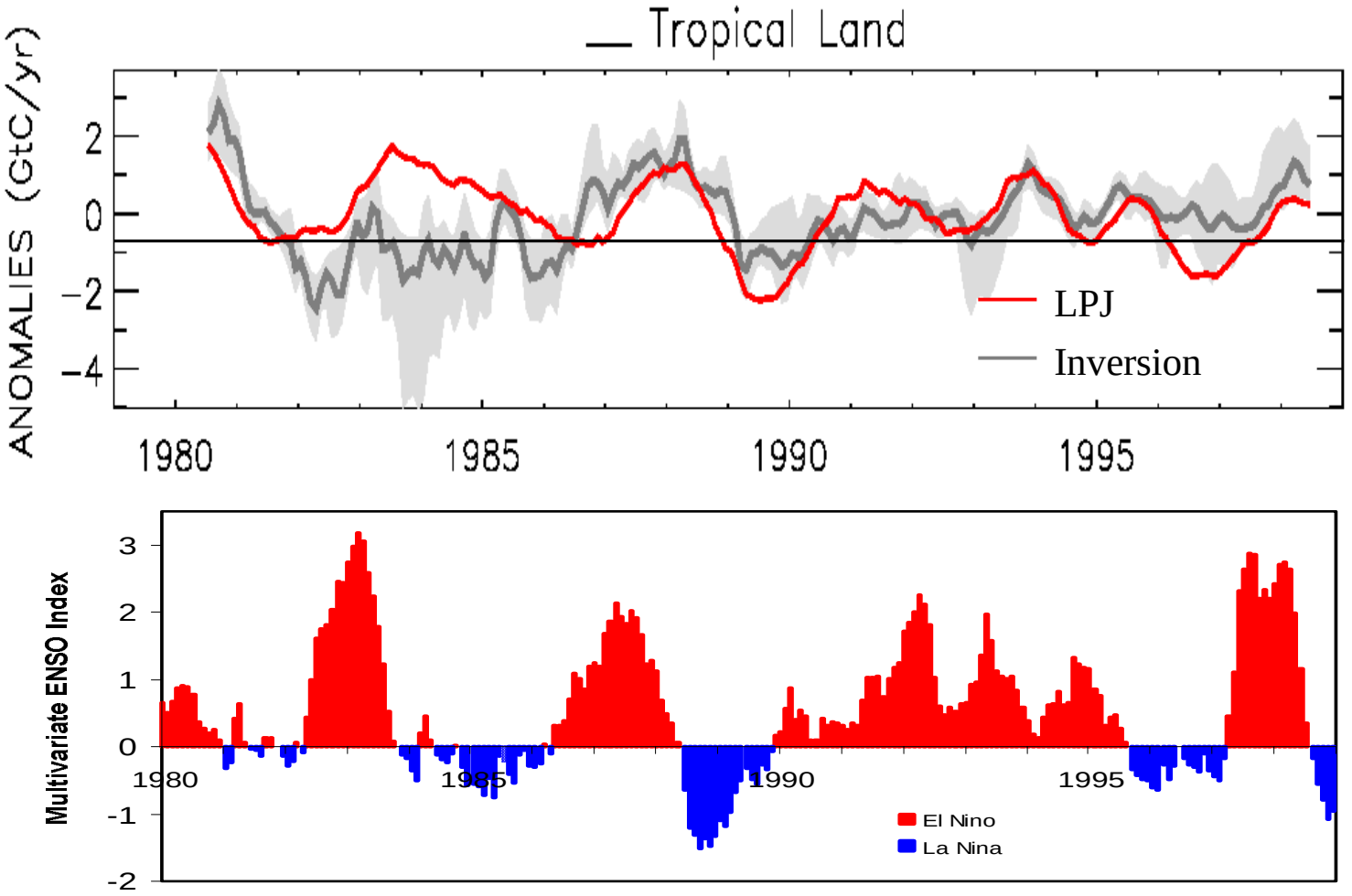


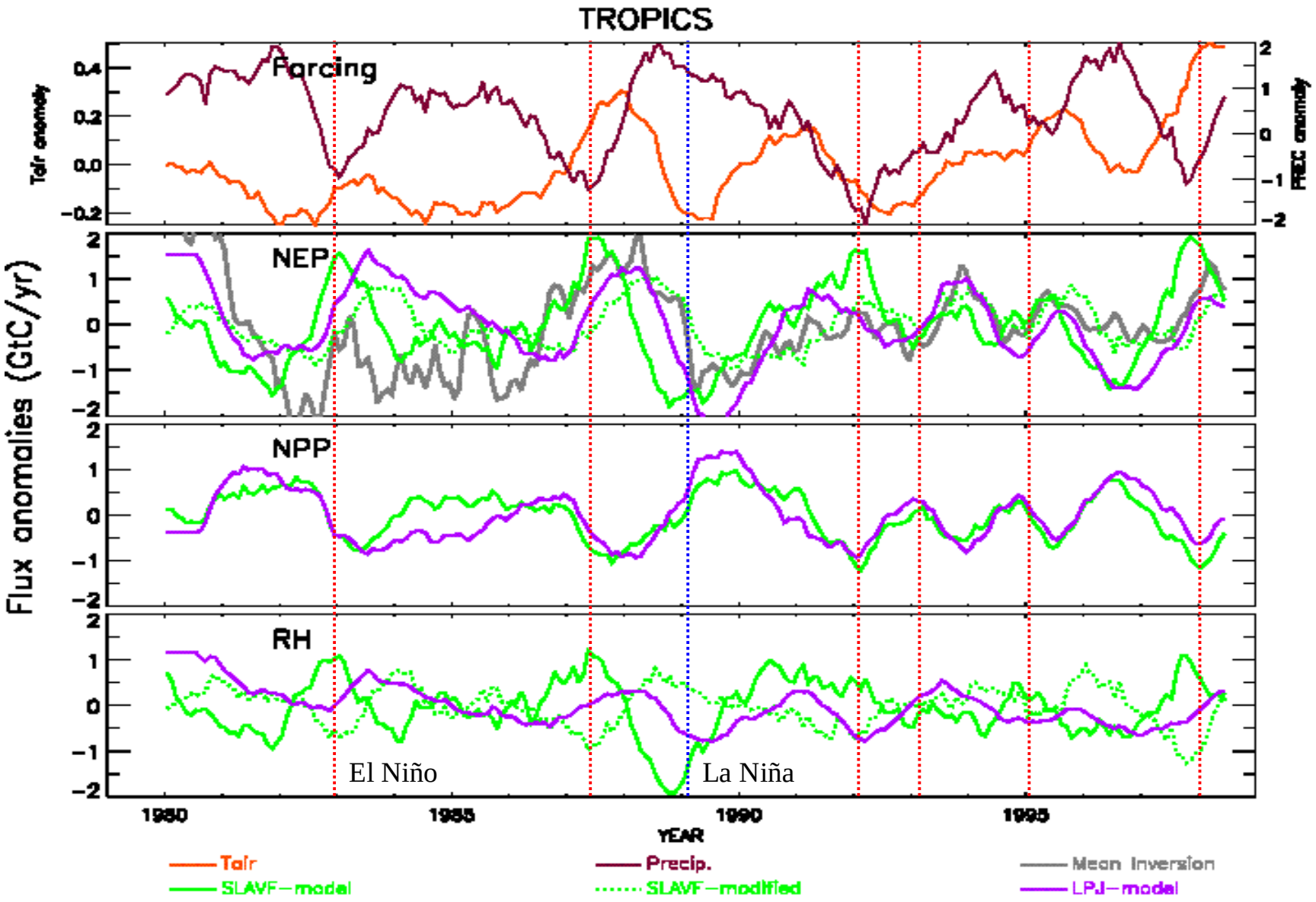
WARM EPISODE RELATIONSHIPS JUNE - AUGUST



Climate Prediction Center
NCEP


7 November 2002
International weekly journal of science
nature
www.nature.com/nature
Neutron stars
The facts of the matter
Extinguishing fear
New memories for old
Distributed computing
Protein folding comes home
Scorched earth
Environmental legacy of tropical peat fires
naturejobs

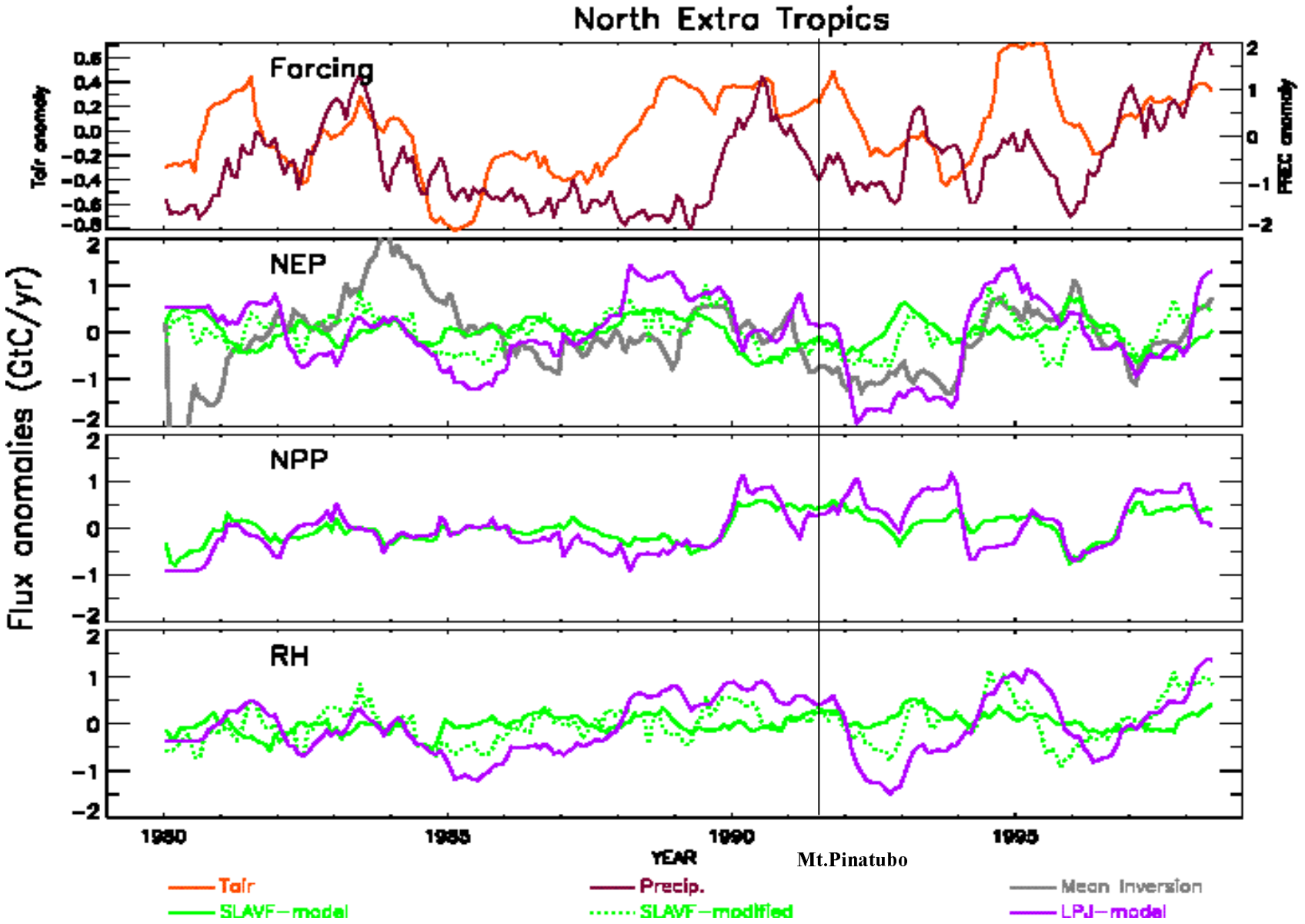

Tropical Land
ANOMALIES (GtC/yr)
2
0
−2
−4
1980
1985
1990
1995
LPJ
Inversion
Multivariate ENSO Index
3
2
1
0
-1
-2
1980
1985
1990
1995
El Nino
La Nina



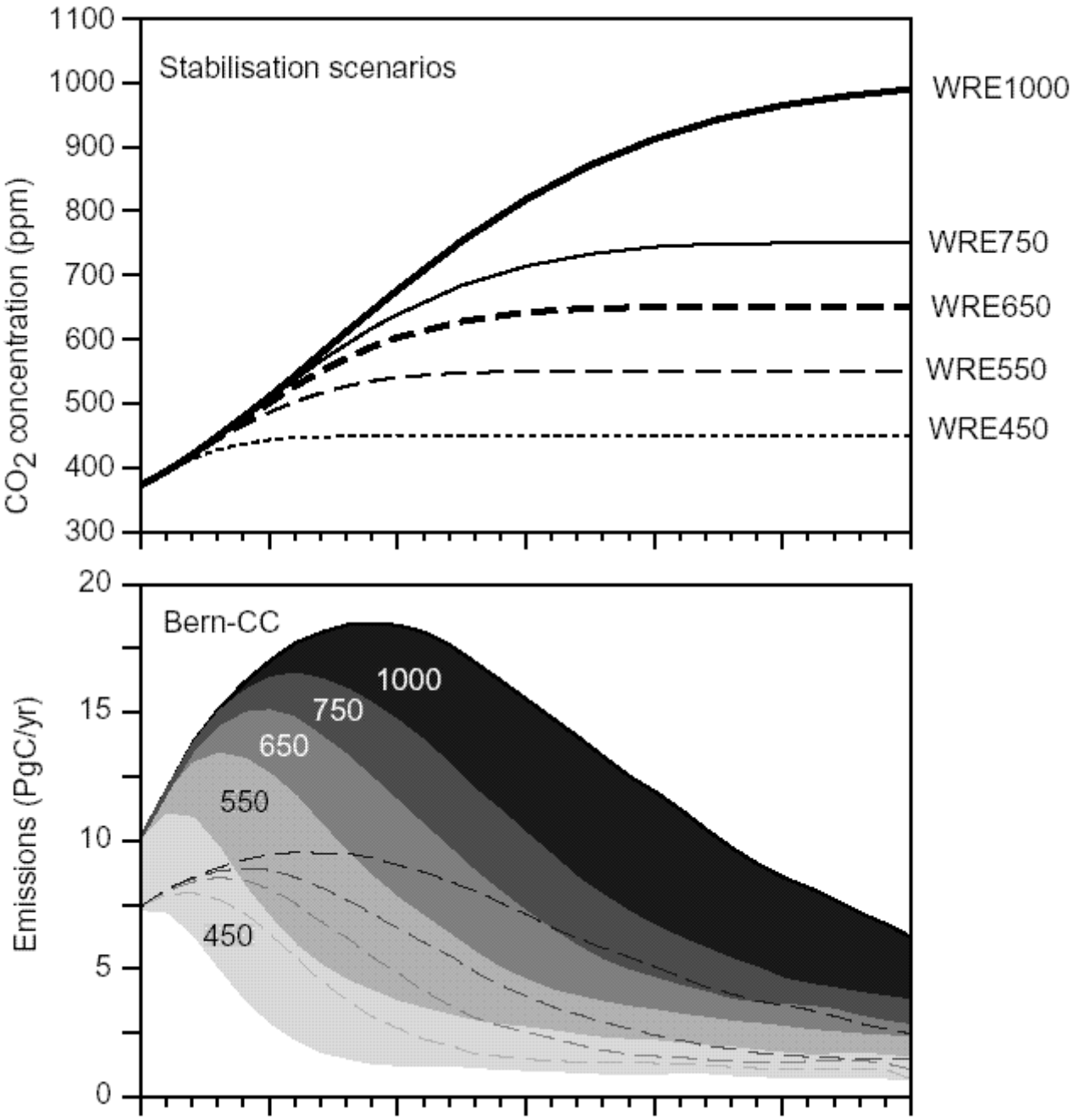
El Niño– High Temperatures, Reduced Precipitation

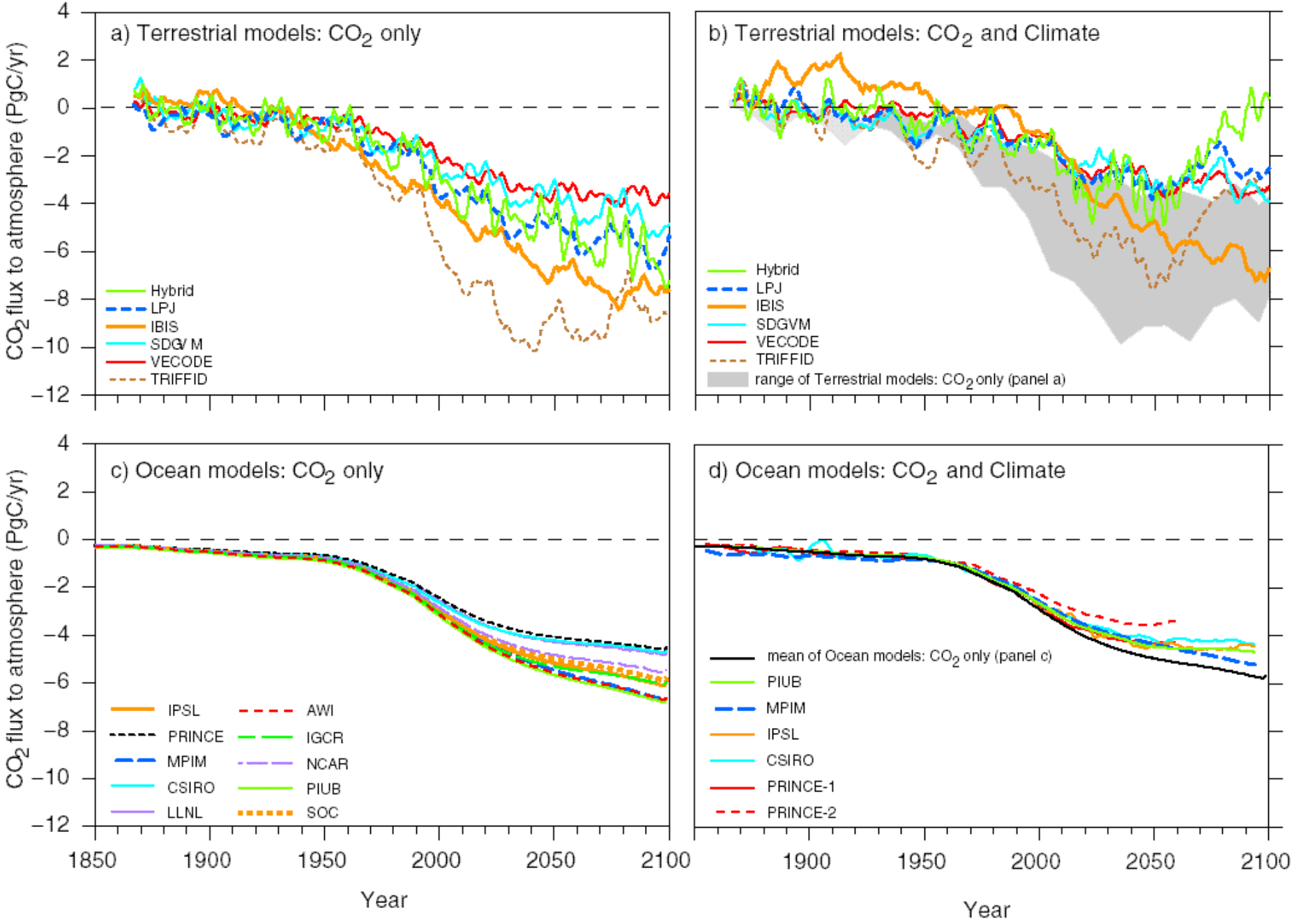
Process: Decrease NPP, increase Rh, +ve NEP anomaly (NEP=Rh-NPP)

Uncertainty: Rh=f(T)g(h_2O)

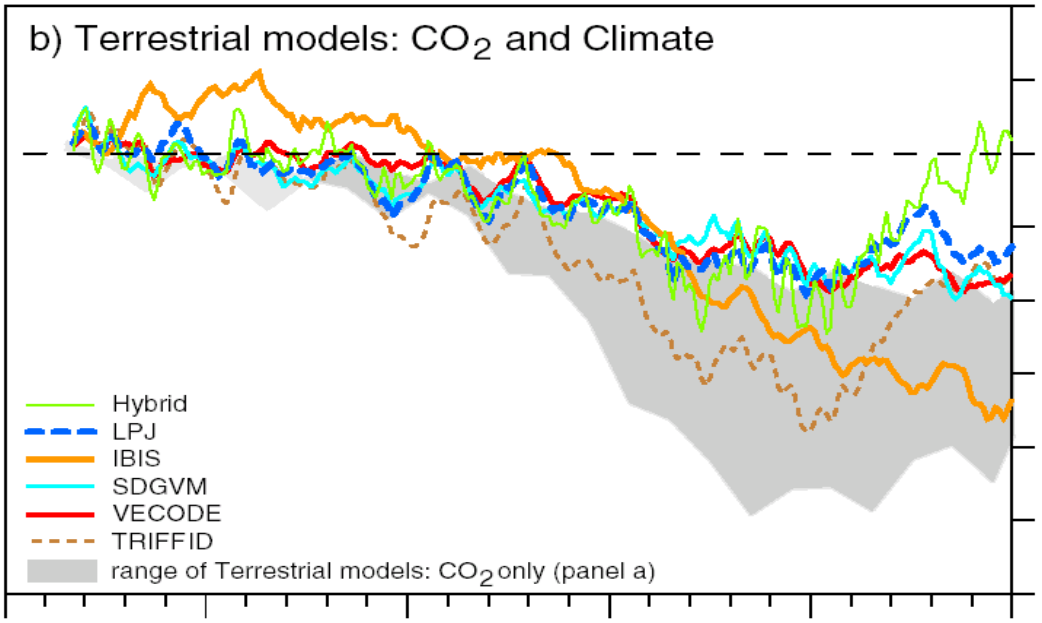


Mt. Pinatubo– Reduced Northern Hemisphere Temperatures **Process**: Decrease Rh, -ve NEP anomaly (NEP=Rh-NPP) **Uncertainty**: Rh=f(T)g(h_2O)

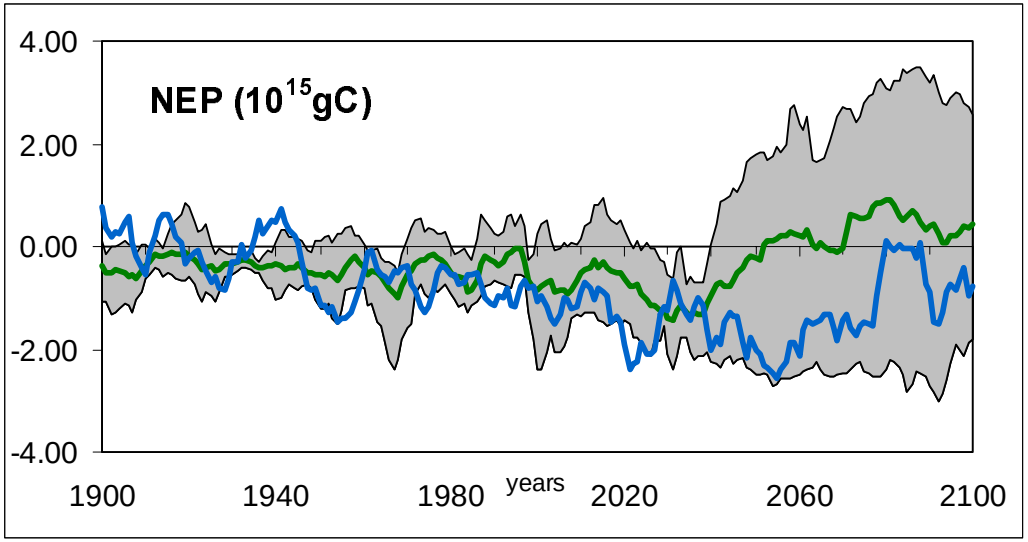

Stabilisation scenarios
WRE1000
WRE750
WRE650
WRE550
WRE450
CO_2 concentration (ppm)
1100
1000
900
800
700
600
500
400
300
Bern-CC
1000
750
650
550
450
Emissions (PgC/yr)
20
15
10
5
0

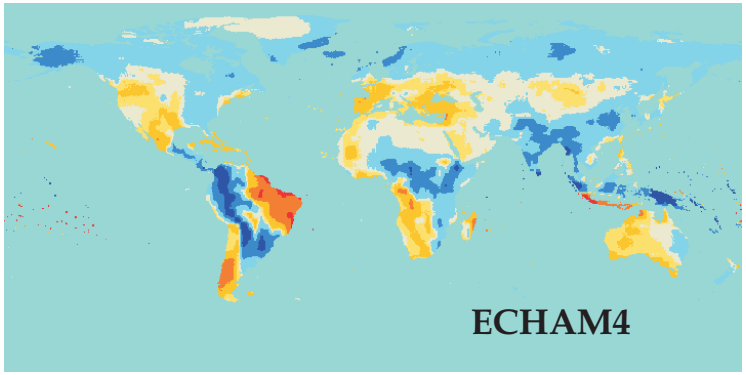

a) Terrestrial models: CO_2 only
b) Terrestrial models: CO_2 and Climate
c) Ocean models: CO_2 only
d) Ocean models: CO_2 and Climate
CO_2 flux to atmosphere (PgC/yr)
Year
Hybrid
LPJ
IBIS
SDGVM
VECODE
TRIFFID
range of Terrestrial models: CO_2 only (panel a)
IPSL
PRINCE
MPIM
CSIRO
LLNL
AWI
IGCR
NCAR
PIUB
SOC
mean of Ocean models: CO_2 only (panel c)
PRINCE-1
PRINCE-2

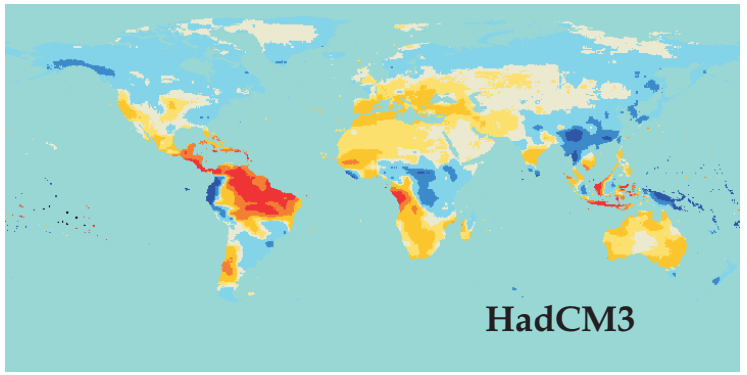
Uncertainties: One Climate Model, 6 Terrestrial Models

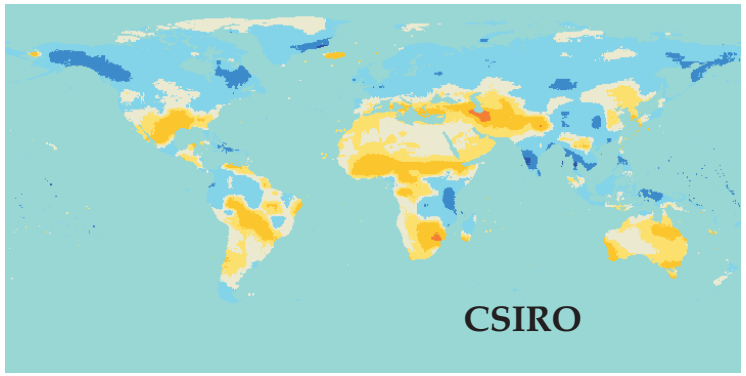


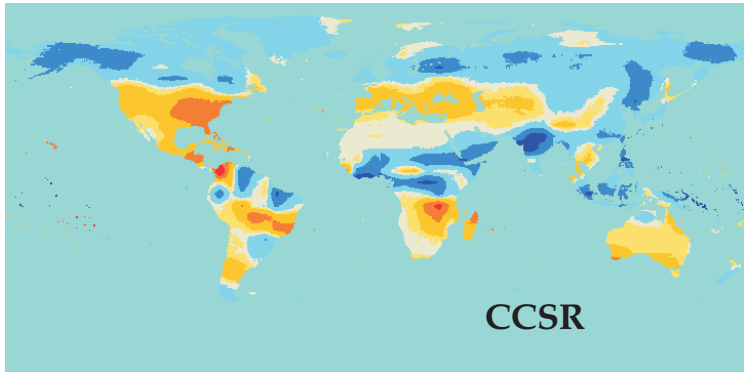
One Terrestrial Model, 5 Climate Models

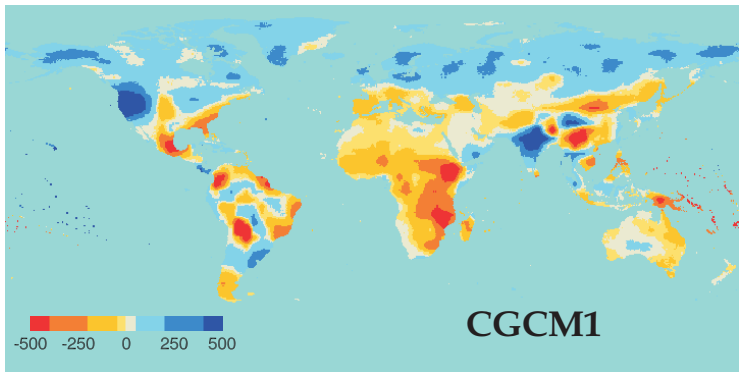






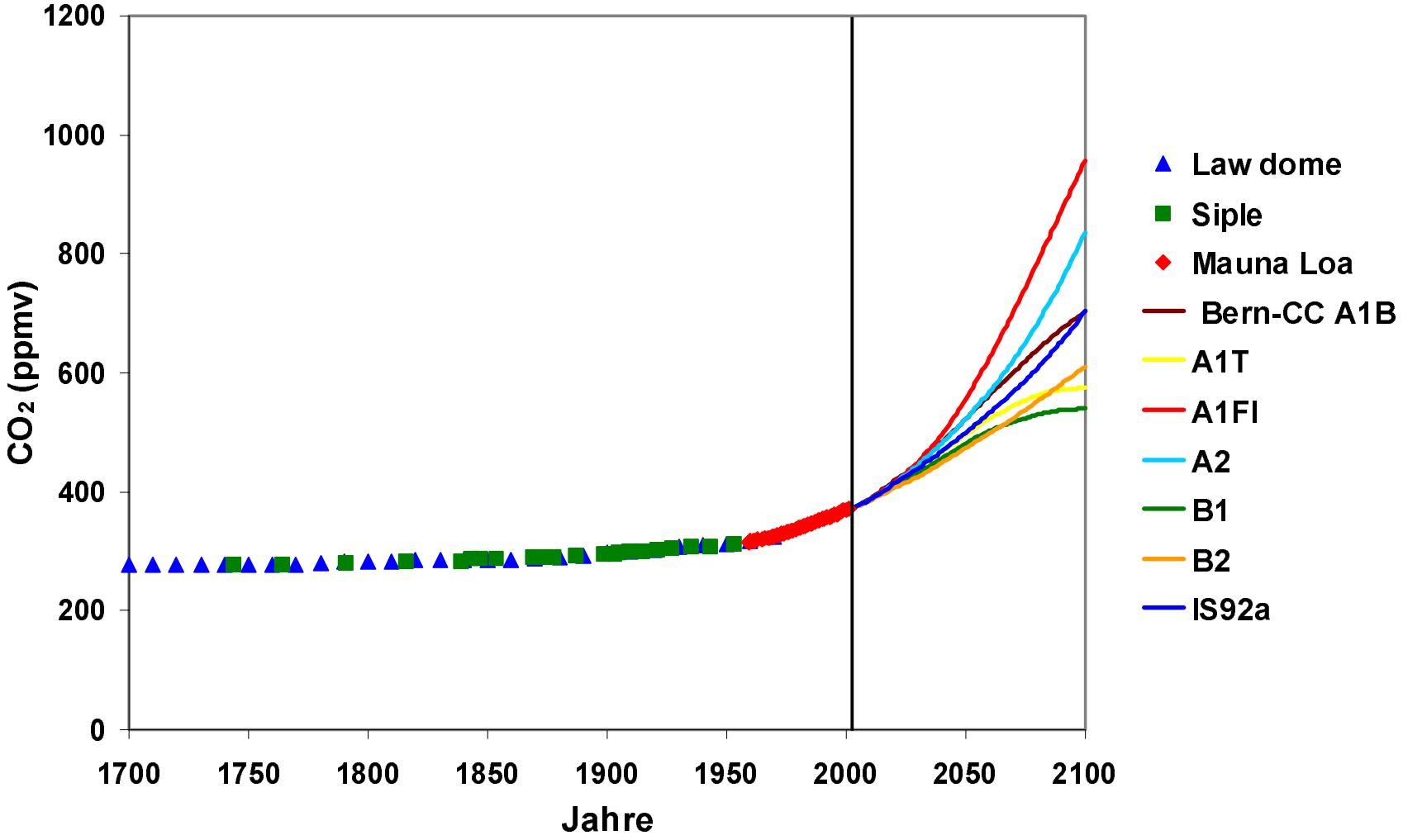


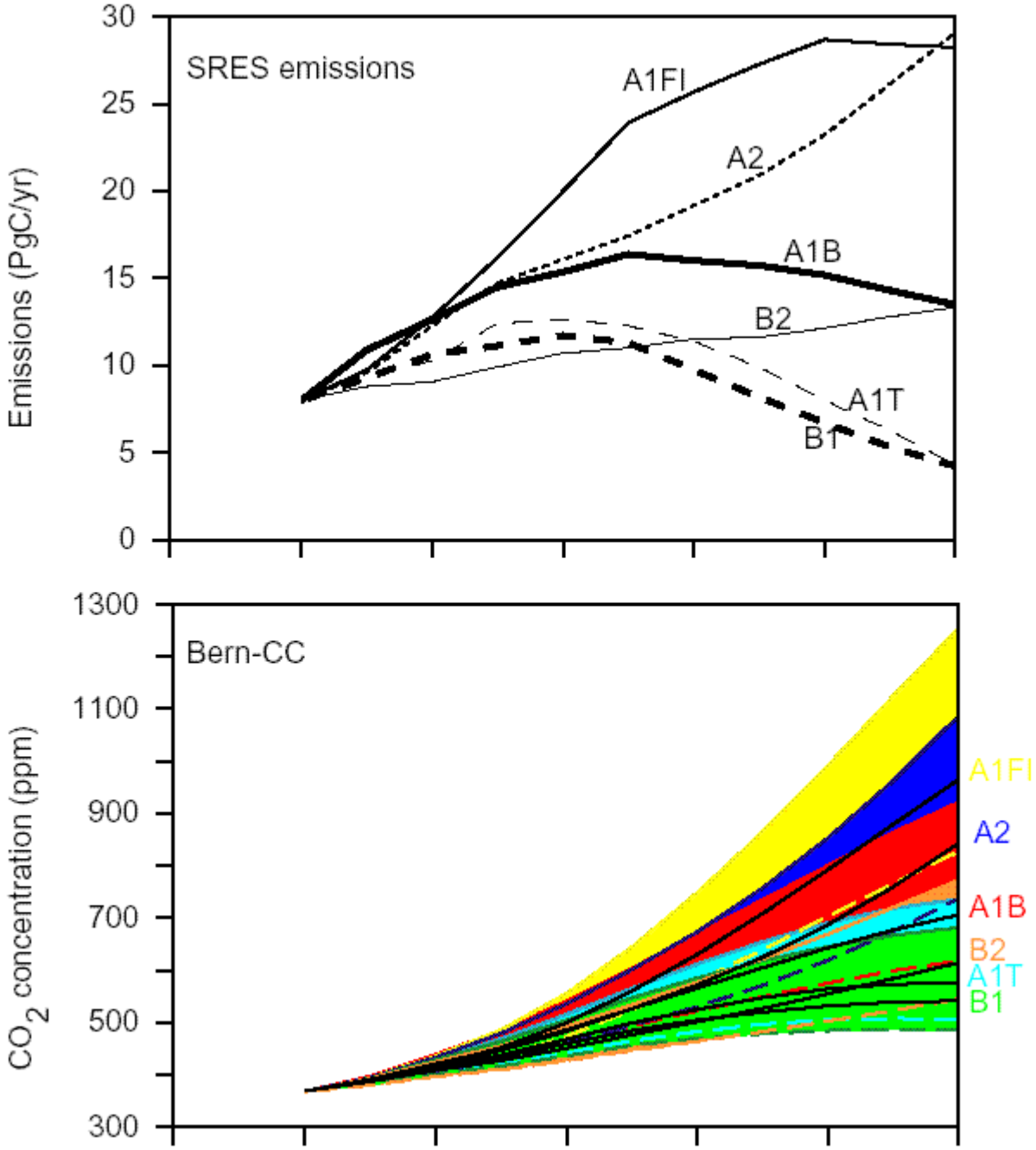


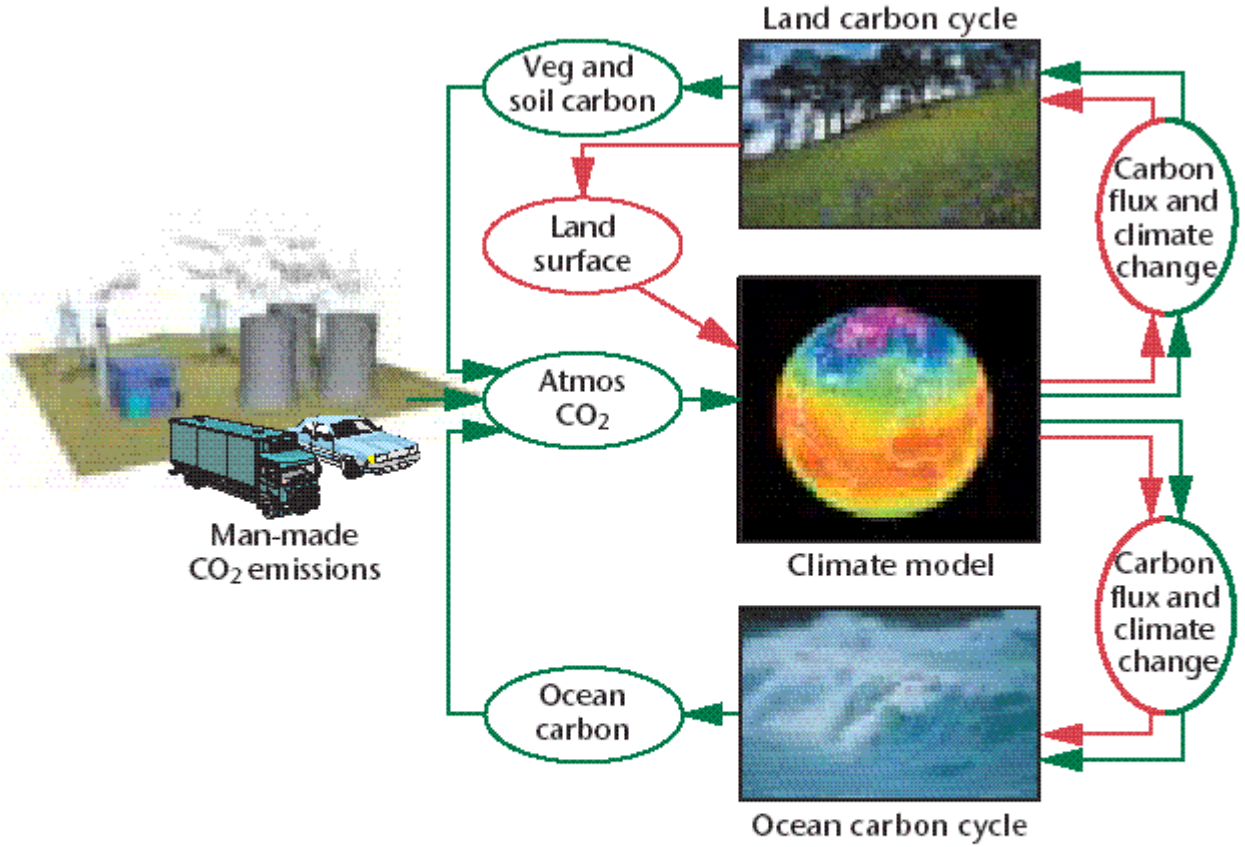


precipitation anomalies 2000 to 2100 (30-y. av.)

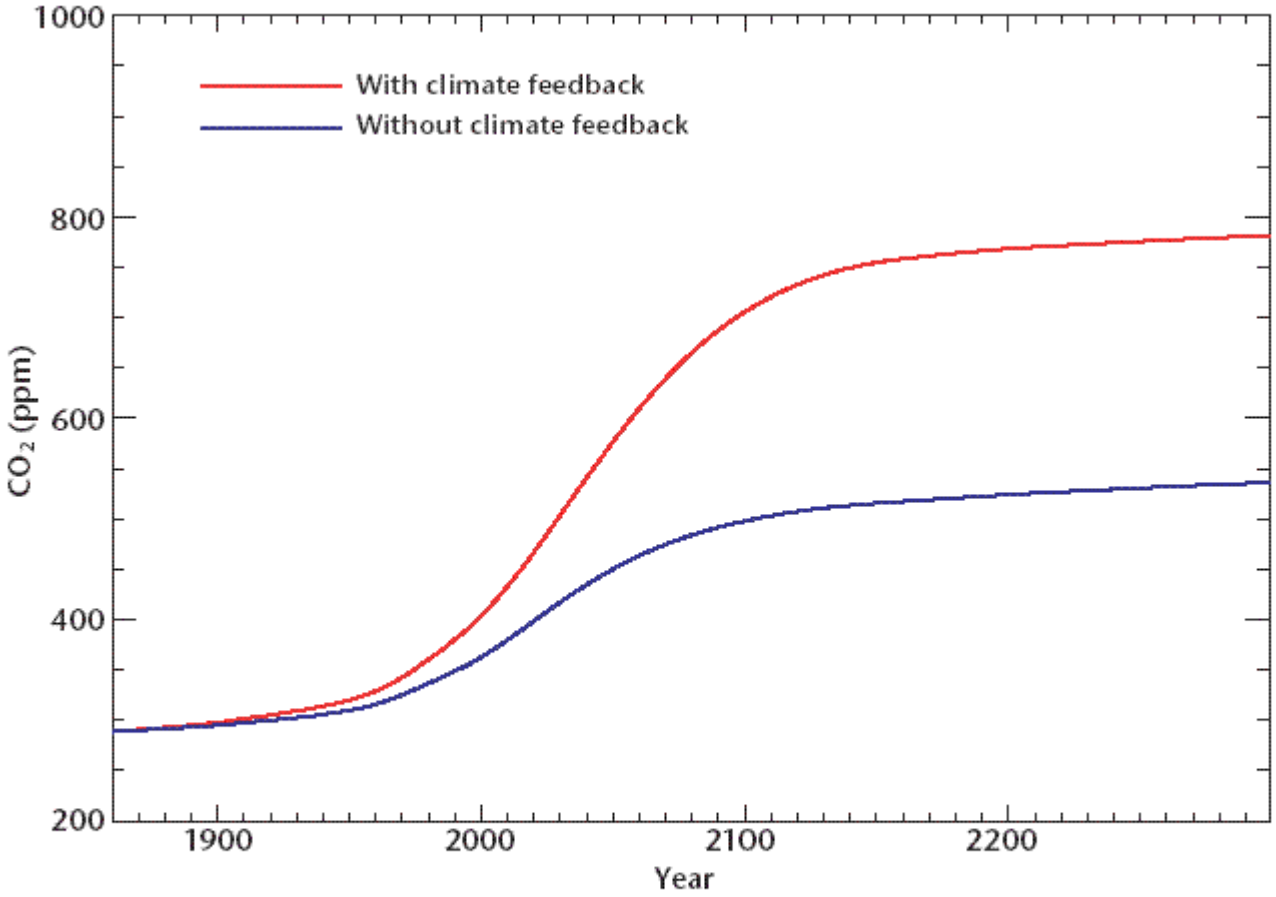
Future CO_2 scenarios



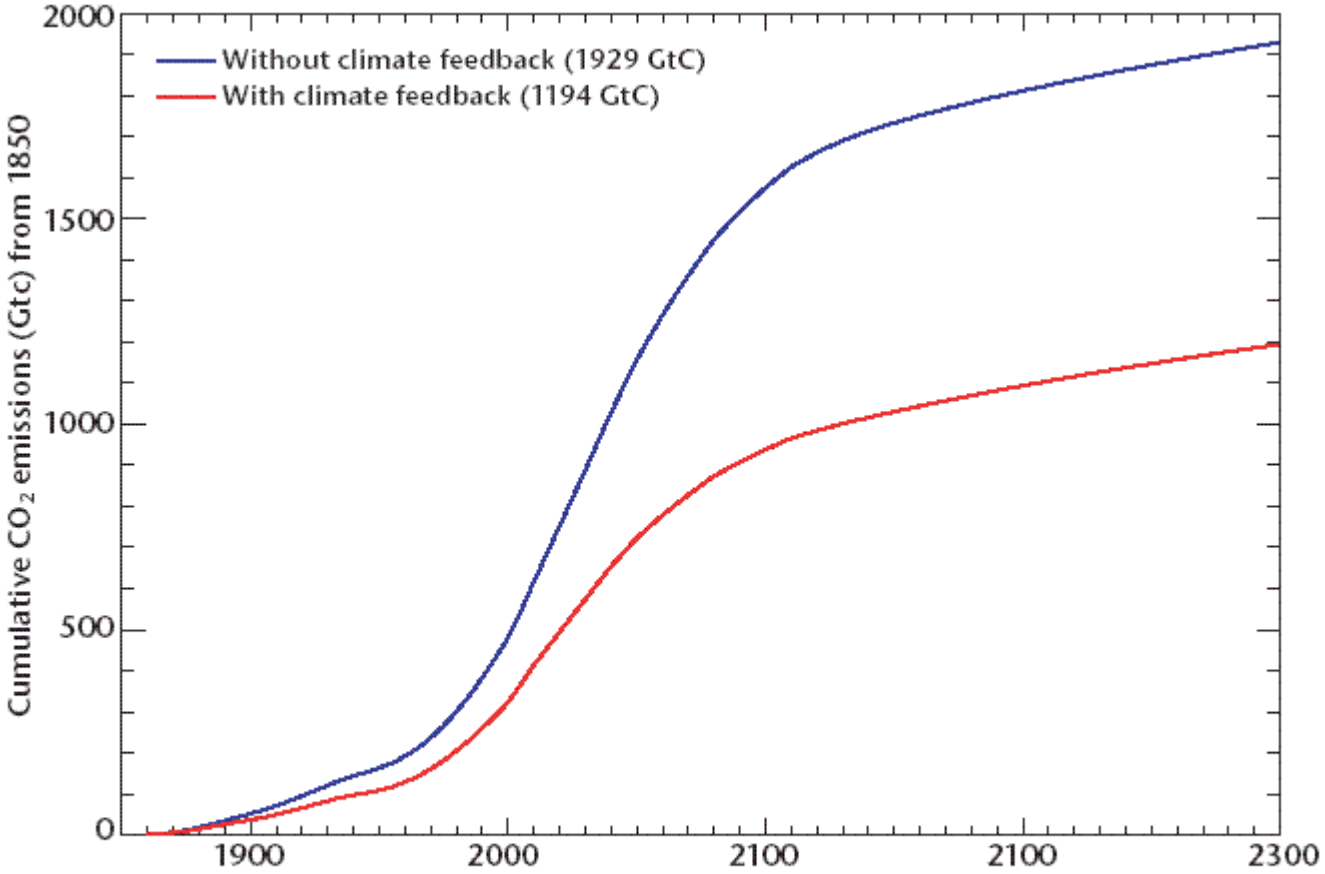

SRES emissions
A1FI
A2
A1B
B2
A1T
B1
Emissions (PgC/yr)
30
25
20
15
10
5
0
Bern-CC
CO_2 concentration (ppm)
1300
1100
900
700
500
300
A1FI
A2
A1B
B2
A1T
B1



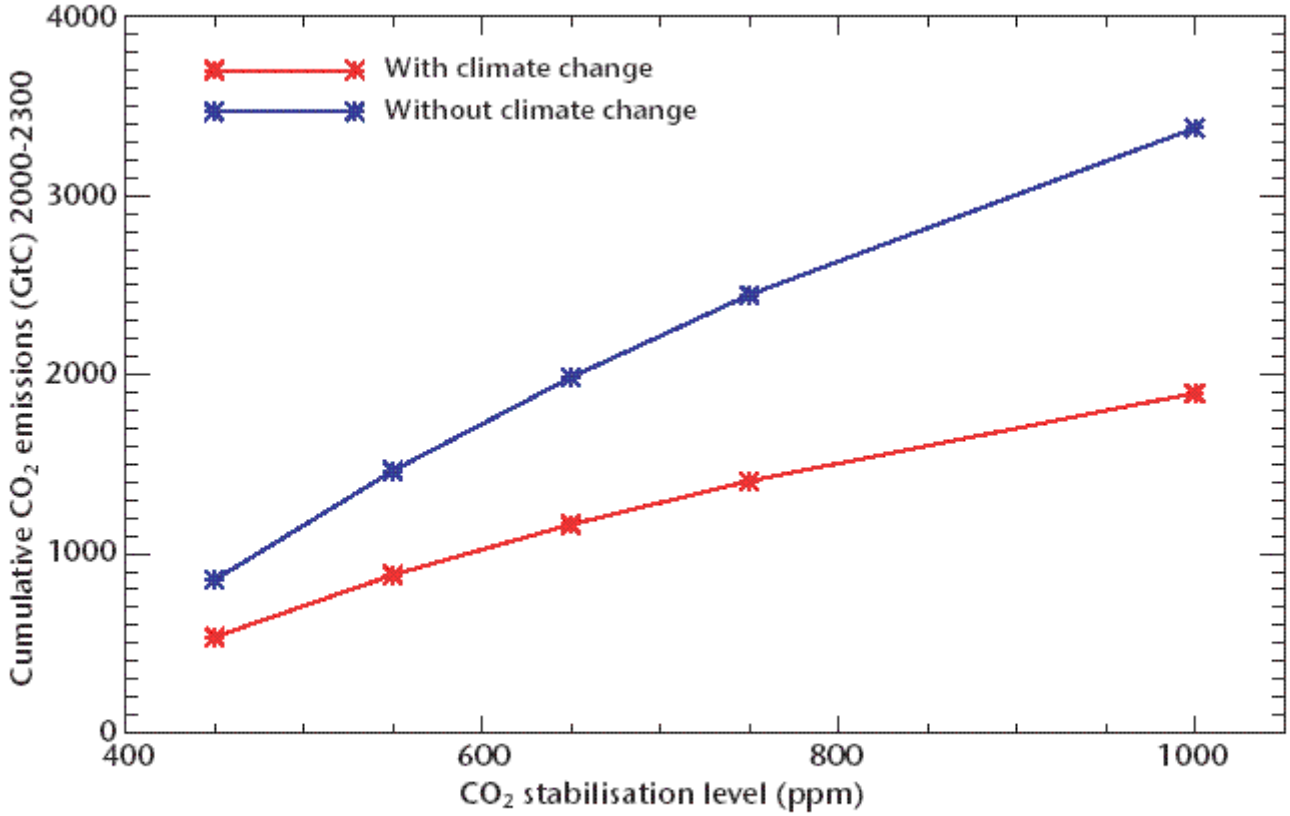
Schematic of a coupled climate–carbon cycle model. Green lines indicate carbon fluxes while red lines indicate physical changes and climate change.



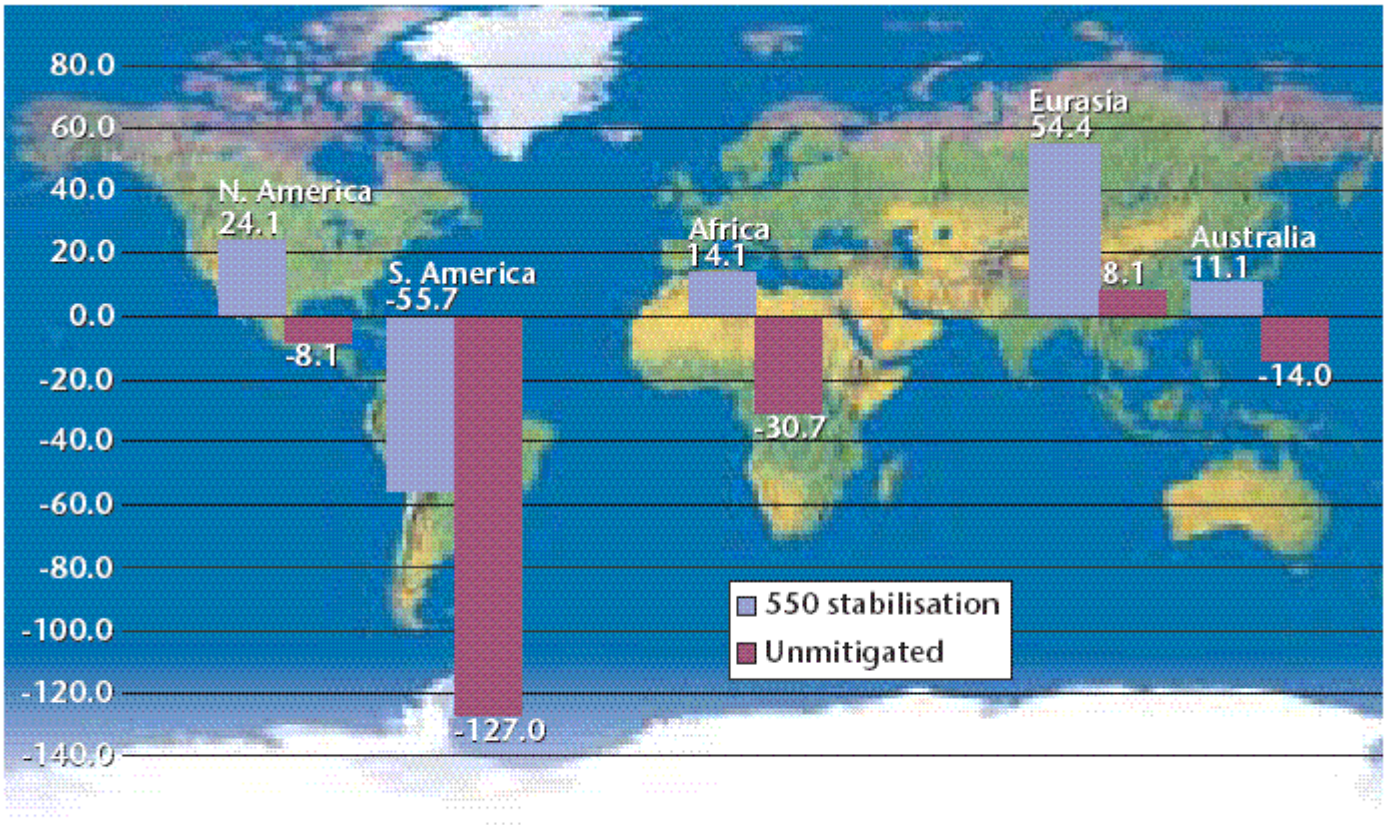
Impact of carbon cycle feedbacks on CO_2 stabilisation concentration for WRE550 emissions.



Cumulative emissions that are consistent with the WRE550 CO_2 concentration scenario.



Impact of carbon cycle feedbacks on stabilisation levels.

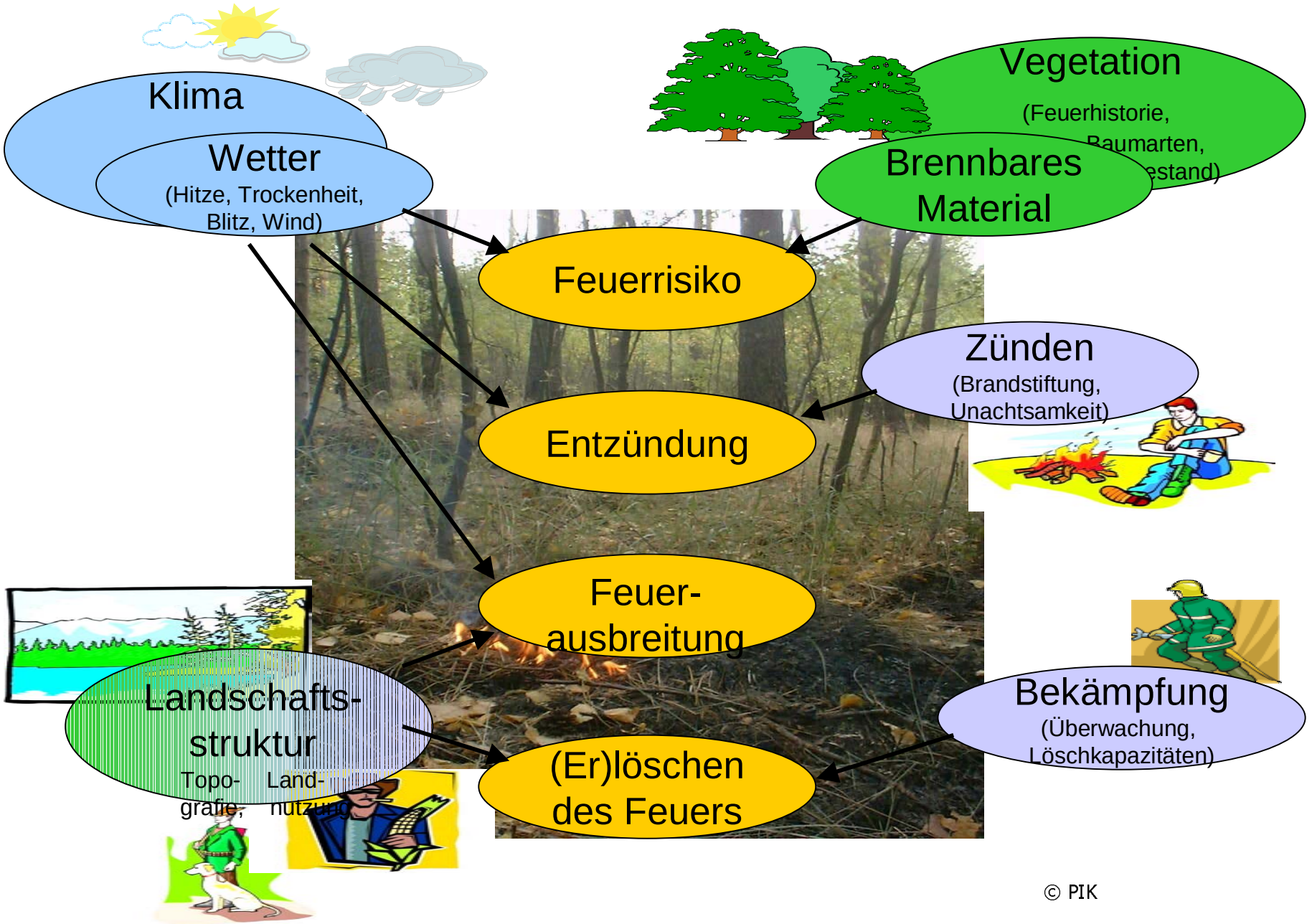


Change in land carbon storage with climate carbon cycle feedbacks between 2000 and 2100.

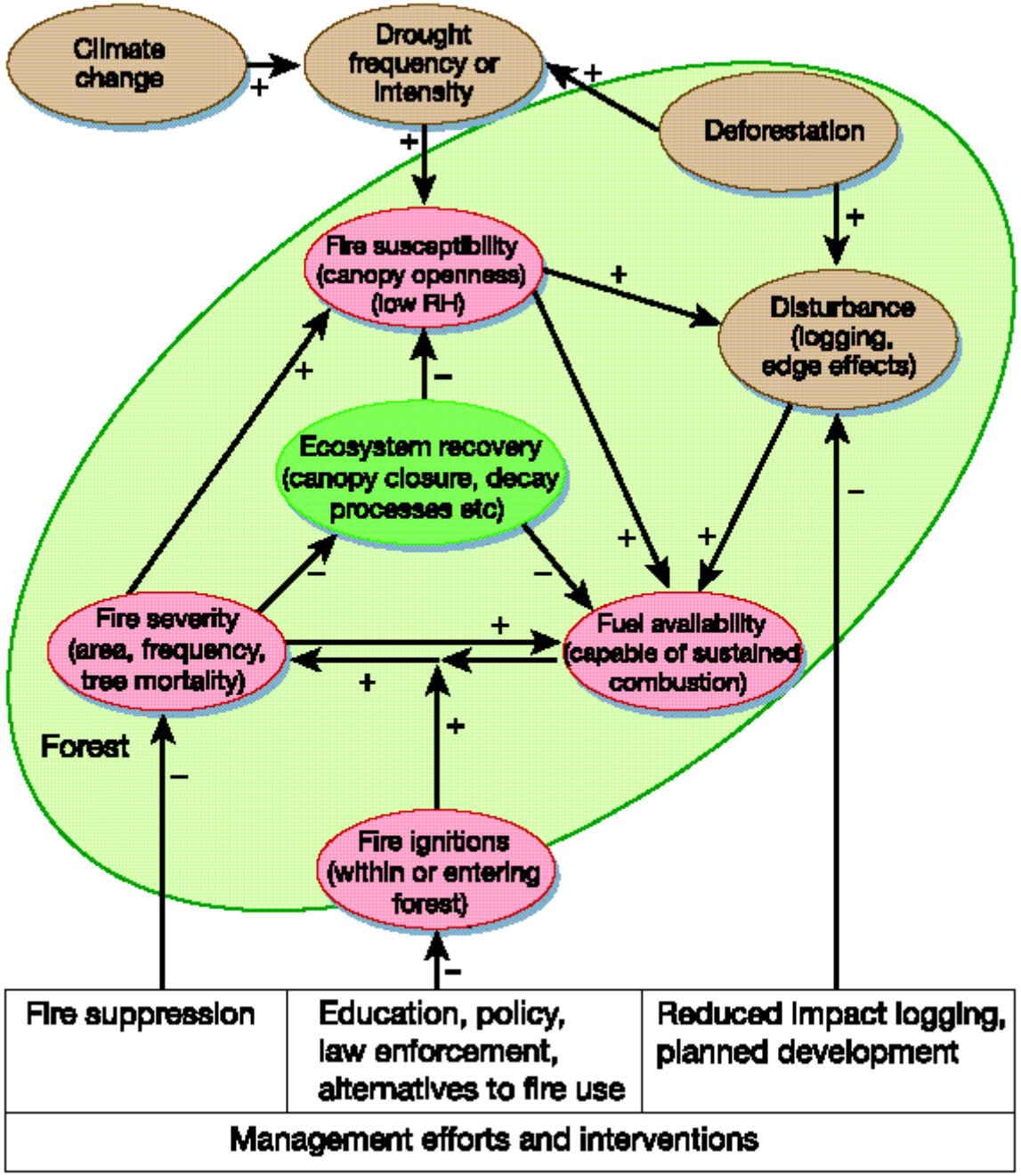
Conclusions

- LPJ simulates the regional interannual CO_2 fluxes in broad agreement with those derived from Inverse modelling- both phase and amplitude
- In the Northern Extra-tropics,
  - Equal magnitude response of NPP and Rh to climate variability, hence both determine interannual NEP
  - Largest Uncertainty in the temperature response of Rh
- In the tropics,
  - NPP shows the greatest variability in response to El Niño climate variability
  - Largest uncertainty in the moisture response of Rh

- The greatest model uncertainty is in the Rh formulation !


Klima
Wetter
(Hitze, Trockenheit,
Blitz, Wind)
Vegetation
(Feuerhistorie,
Baumarten,
estand)
Brennbares
Material
Feuerrisiko
Zünden
(Brandstiftung,
Unachtsamkeit)
Entzündung
Feuer-
ausbreitung
Landschafts-
struktur
Topo-
grafie,
Land-
nutzung
Bekämpfung
(Überwachung,
Löschkapazitäten)
(Er)löschen
des Feuers

© PIK


Climate change
Drought frequency or intensity
Deforestation
Fire susceptibility (canopy openness) (low RH)
Disturbance (logging, edge effects)
Ecosystem recovery (canopy closure, decay processes etc)
Fire severity (area, frequency, tree mortality)
Fuel availability (capable of sustained combustion)
Forest
Fire ignitions (within or entering forest)
Fire suppression
Education, policy, law enforcement, alternatives to fire use
Reduced impact logging, planned development
Management efforts and interventions

Conclusions

- Better understanding of terrestrial biosphere functioning on the interannual – decadal timescale; Rh representation most uncertain
- Improved hydrology, including validation
- Progress in implementing major crop types.
- Progress in Fire modelling, including, *Application of the regional fire model to human-dominated ecosystems.* [Venevsky et al. 2002 GCB 8, 984-998]
- First coupled Climber2-LPJ results
- Major uncertainties in the role of the terrestrial biosphere in a changing climate remain.