The Global Carbon Balance and its Vulnerabilities

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Outline

1. Recent carbon-climate trends
2. The global carbon budget
3. Carbon source/sink processes
4. Sink processes
   - CO_2 fertilization effect
5. Source processes: vulnerabilities
   - Drought
   - Soil respiration

Recent Carbon-Climate Trends: Signs of Trouble

Fossil Fuel and Cement Emissions:

7.9 Pg C

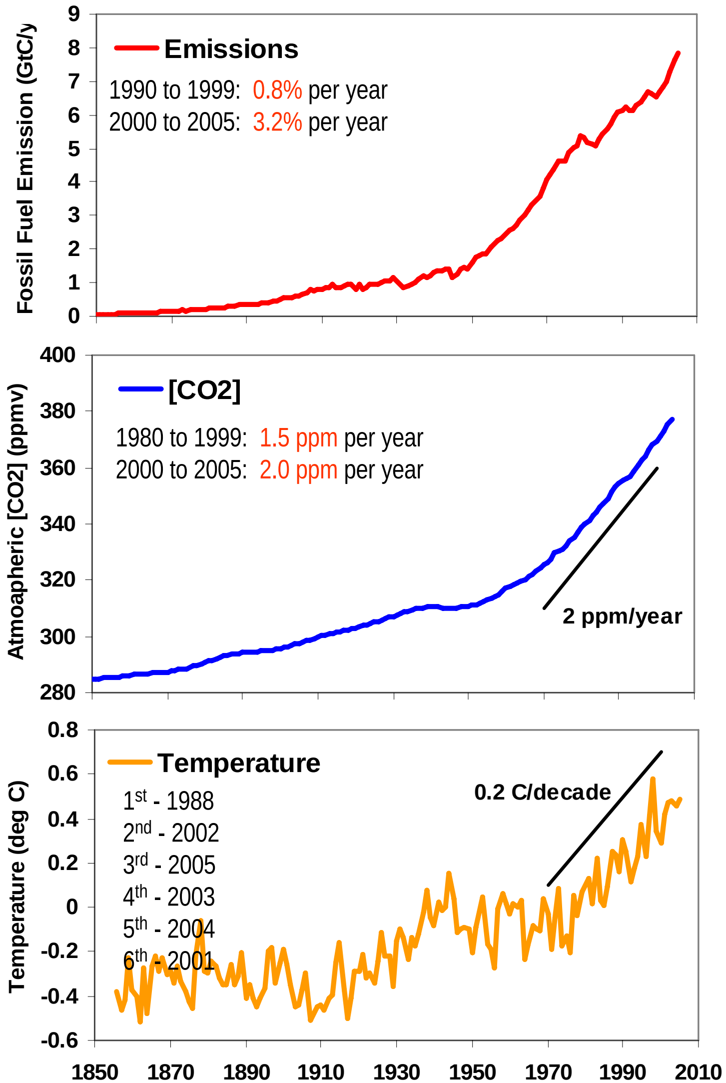
Atmospheric CO_2 concentration:

379 ppm

(36% above pre-industrial)

Global Temperature:

2nd-3rd hottest year



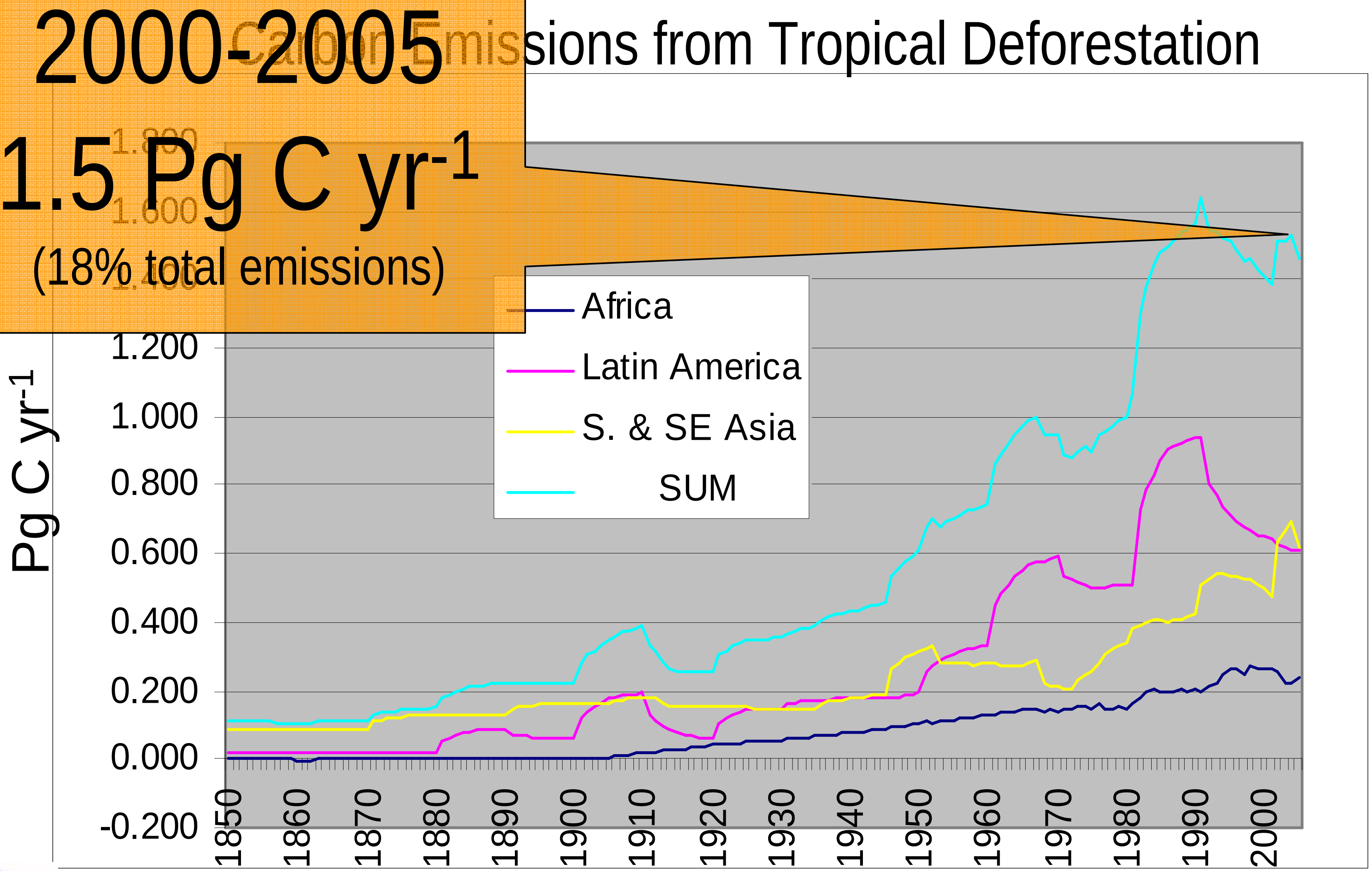
UNESCO/Scope-GCP Policy Briefing, 2006; Canadell et al 2006, submitted

Recent Carbon-Climate Trends: Signs of Trouble

2000-2005

1.5 Pg C yr^{-1}

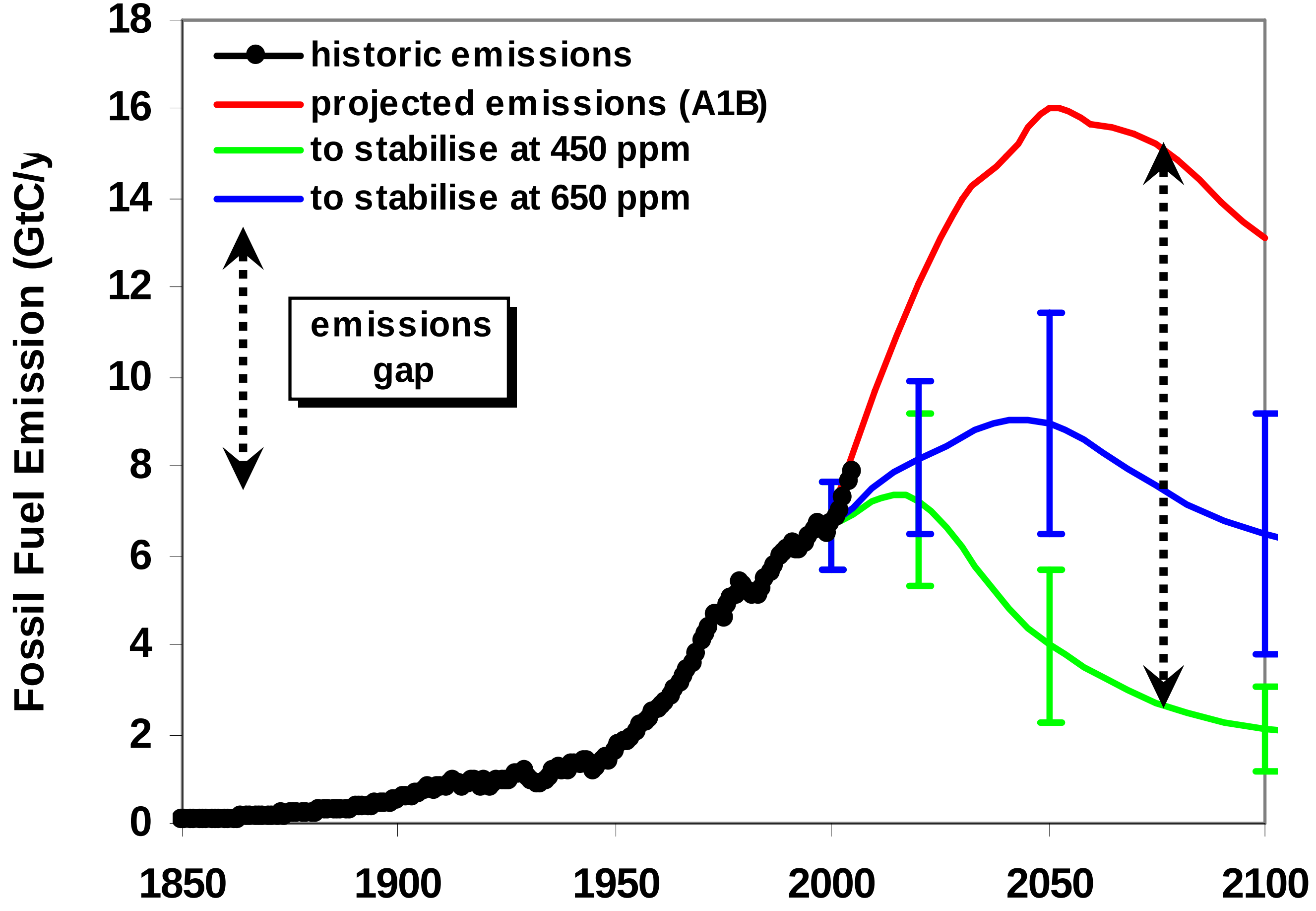
(18% total emissions)



Skee Houghton, unpublished

Trajectory of Global Fossil Fuel Emissions

- Emissions scenario (eg SRES A1B): based on a storyline for global development
- Stabilisation trajectory: an emissions consistent with stabilision at a given CO_2 level



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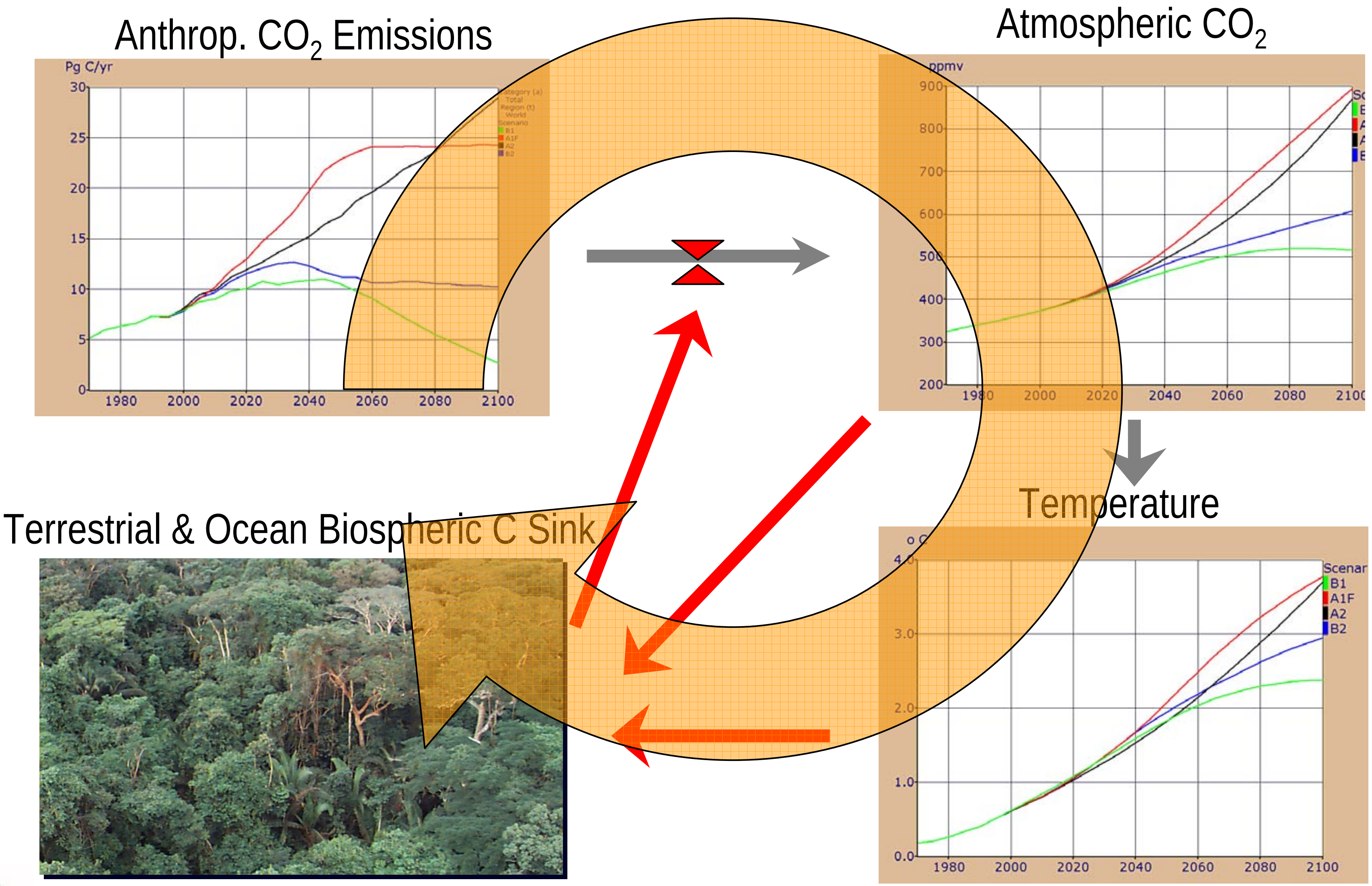
Earth System Science Partnership

Carbon-climate-human Interactions



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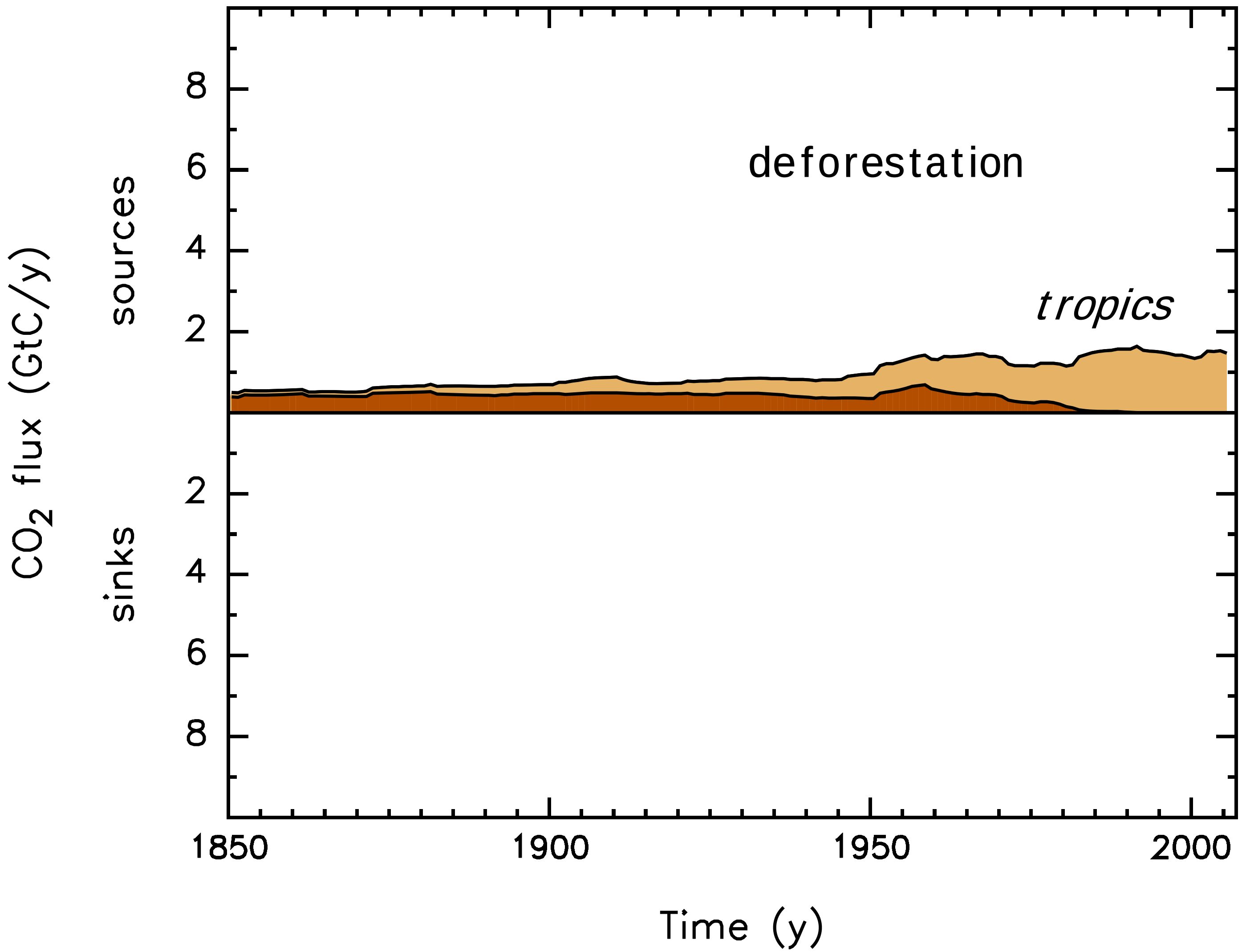
GLOBAL CHANGE

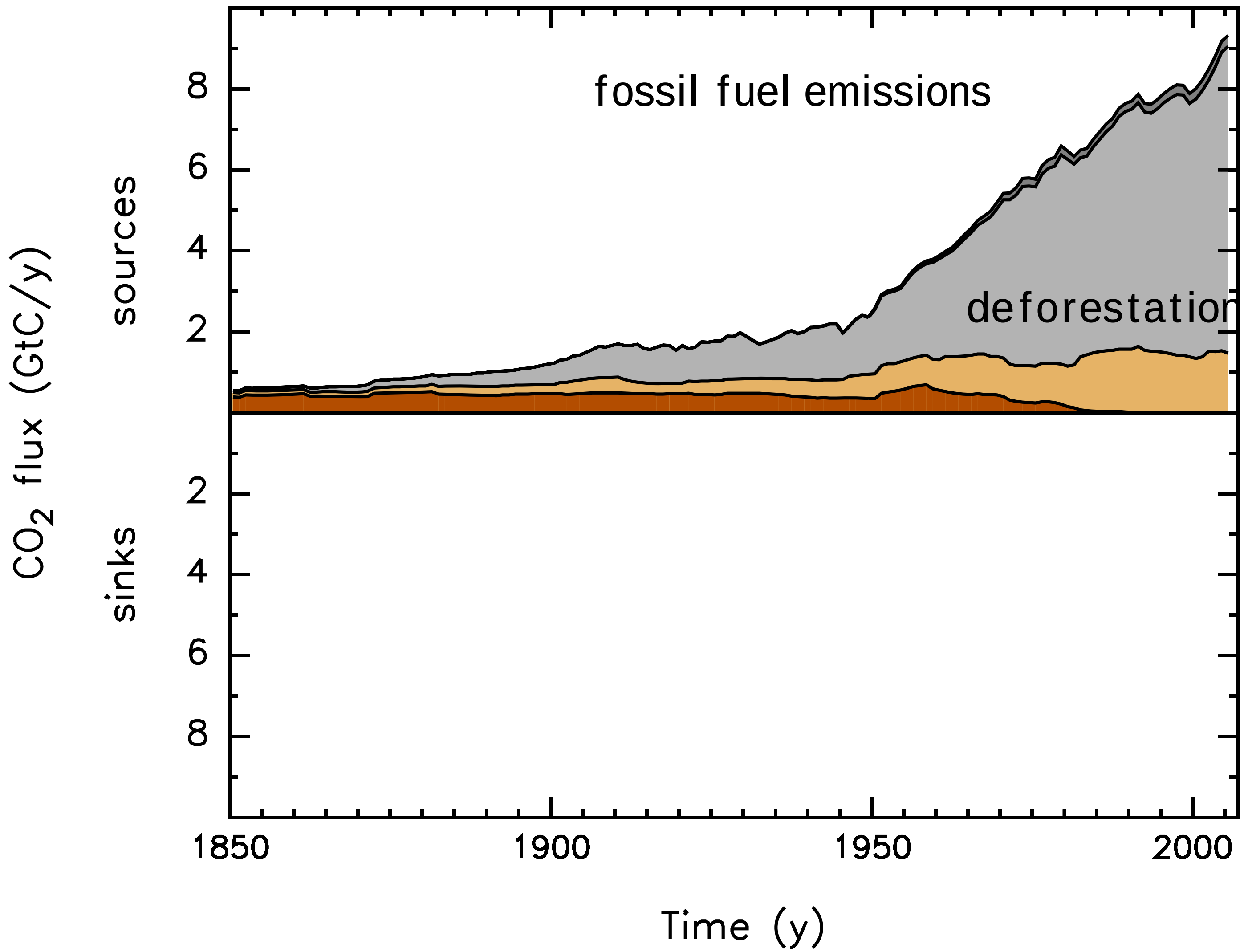
IHDP

Global Carbon Budget (1850-2005)



Le Quere, GCP 2007, in preparation

Global Carbon Budget (1850-2005)



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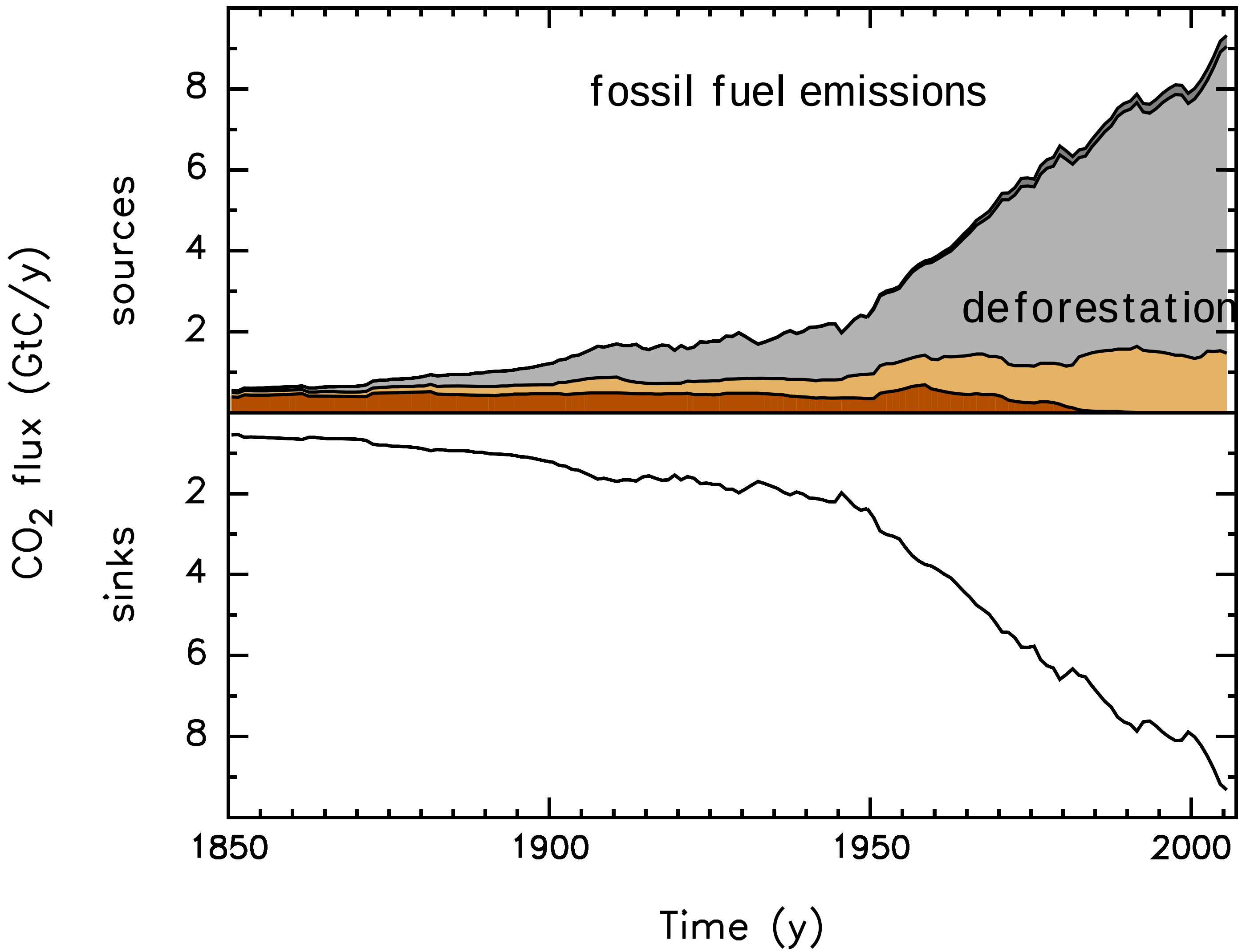

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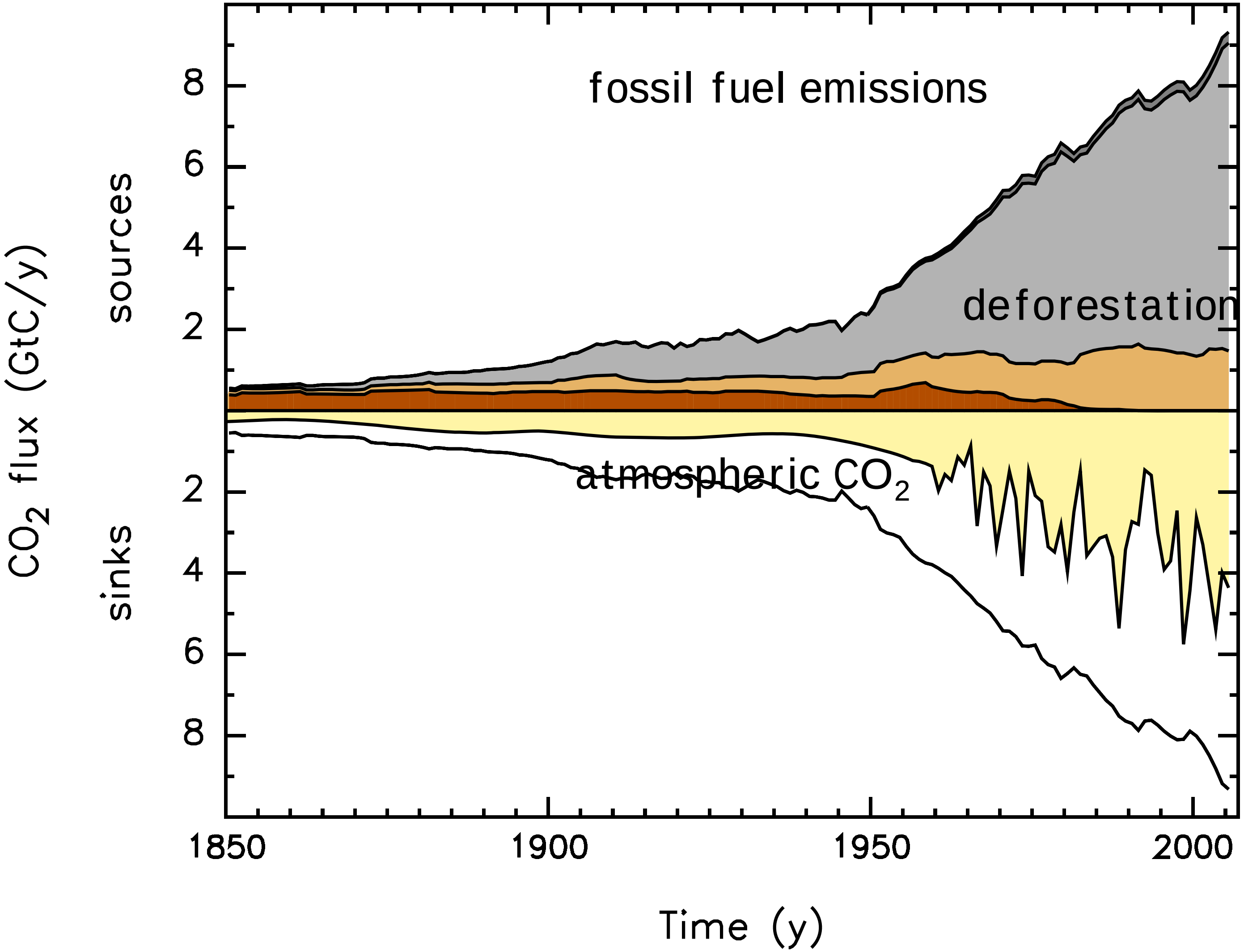

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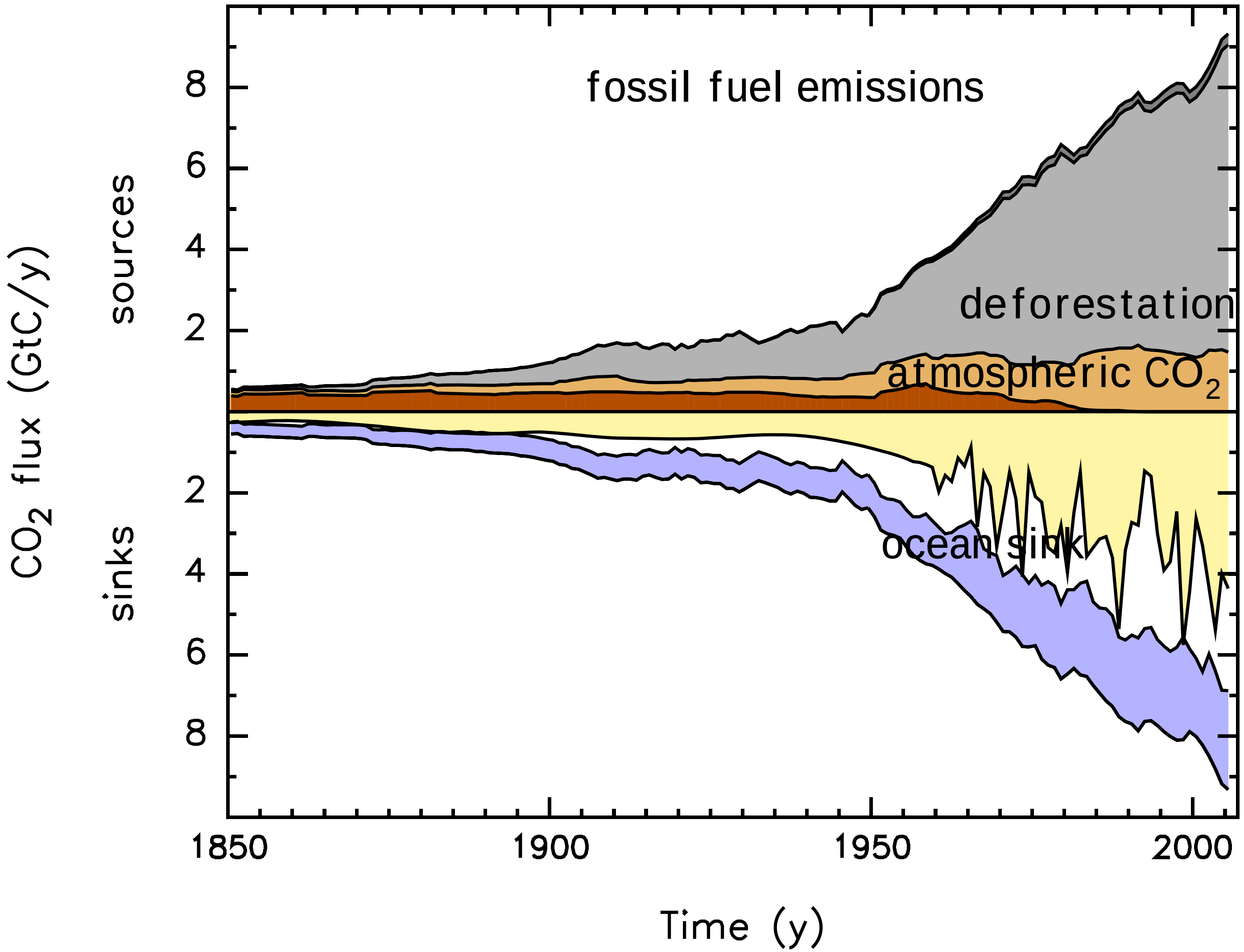
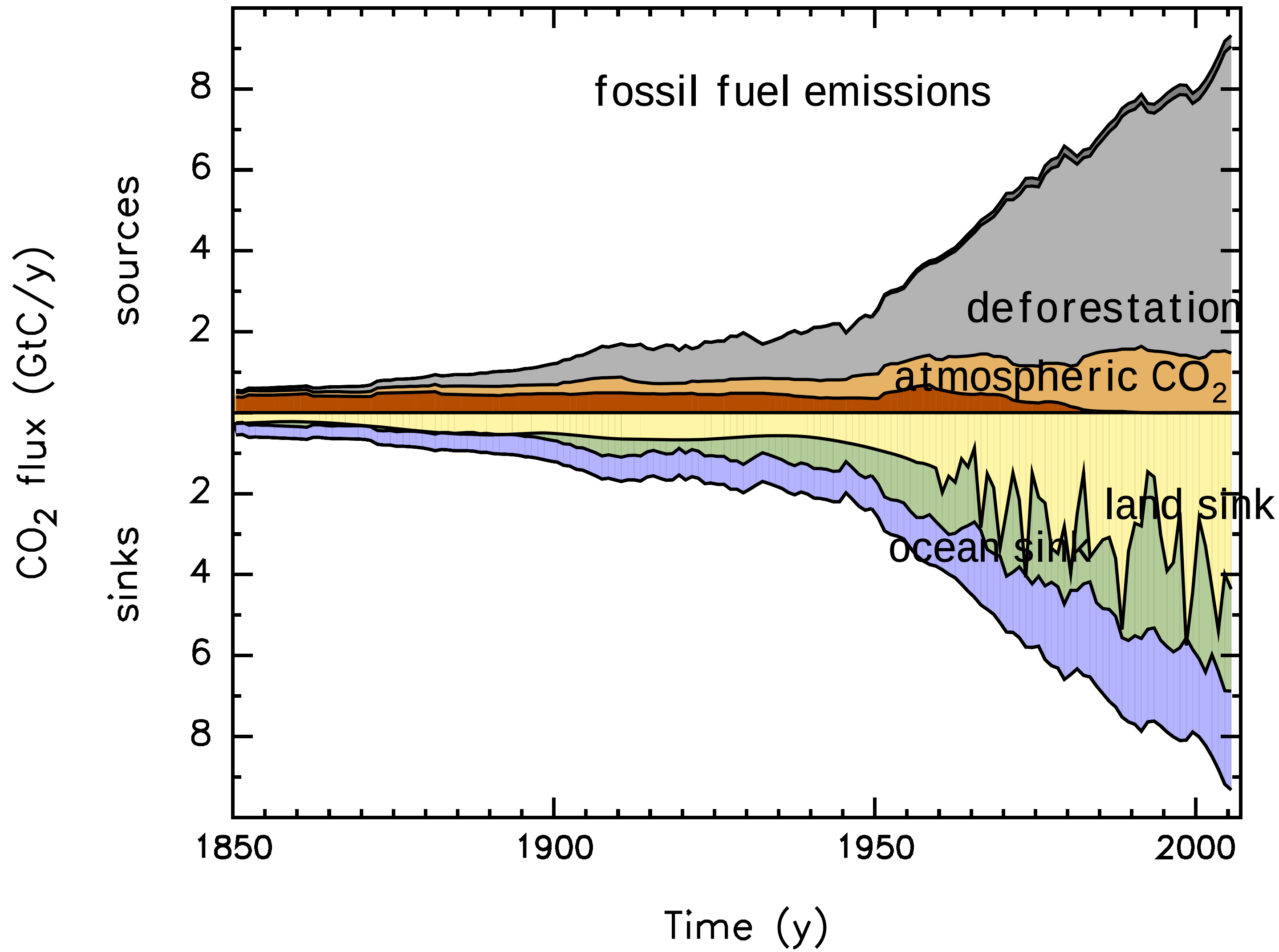


GCP 2006, in preparation

Global Carbon Budget (1850-2005)



Le Quere, GCP 2007, in preparation

Global Carbon Budget (2000-2005)

Anthropogenic Emissions (FF, cement)

+7.2 ± 0.6 Pg C/yr

→ +4.1 ± 0.2 PgC/yr - Atmosphere

→ -2.2 ± 0.5 PgC/yr - Oceans

→ -0.9 ± 0.7 PgC/yr - Terrestrial

Deforestation

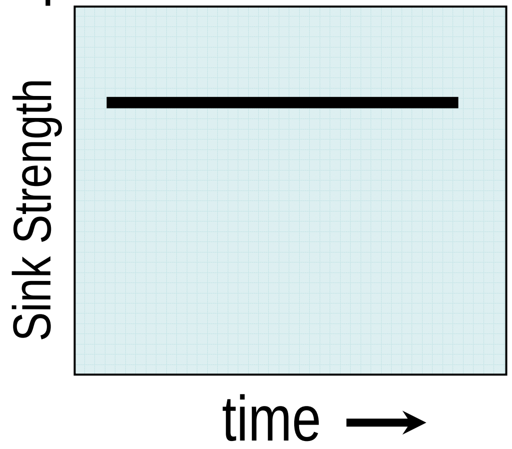
+1.5 Pg C/yr → – 2.4 +1.5 = -0.9

Biological Benefits

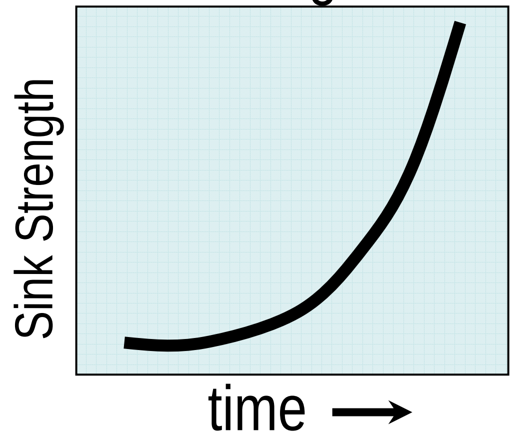
- Terrestrial and marine exchanges currently remove more than 4 Gt C yr^{-1} from the atmosphere (55% of anthropogenic emissions)
- This free service provided by the planet constitutes an effective 55% emissions reduction, worth Trillions of $$ per year if we had to provide it through mitigation measurements.

Carbon Sinks: How will they Behave in the Future

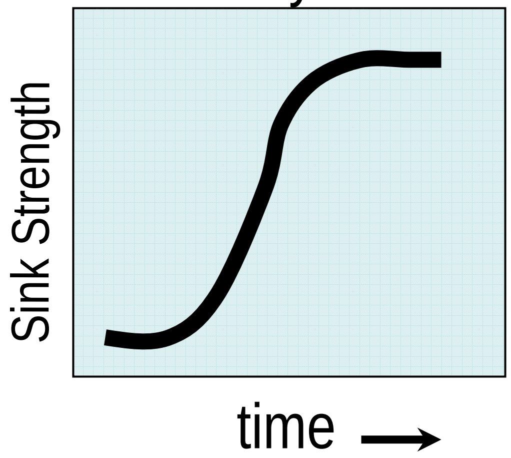
1. Are the sink mechanisms permanent features?



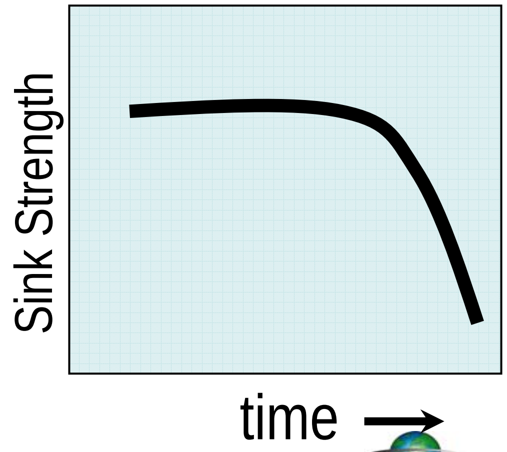
2. Will they increase in strength?



3. Will they saturate?



4. Will they disappear?



Carbon Sink Mechanisms (Globally and Australia)

Climate and Atmospheric Drivers:

- CO_2 fertilization and increased WUE
- Nitrogen fertilization
- NPP enhancement (or suppression) by climate change

Land Use Change Drivers:

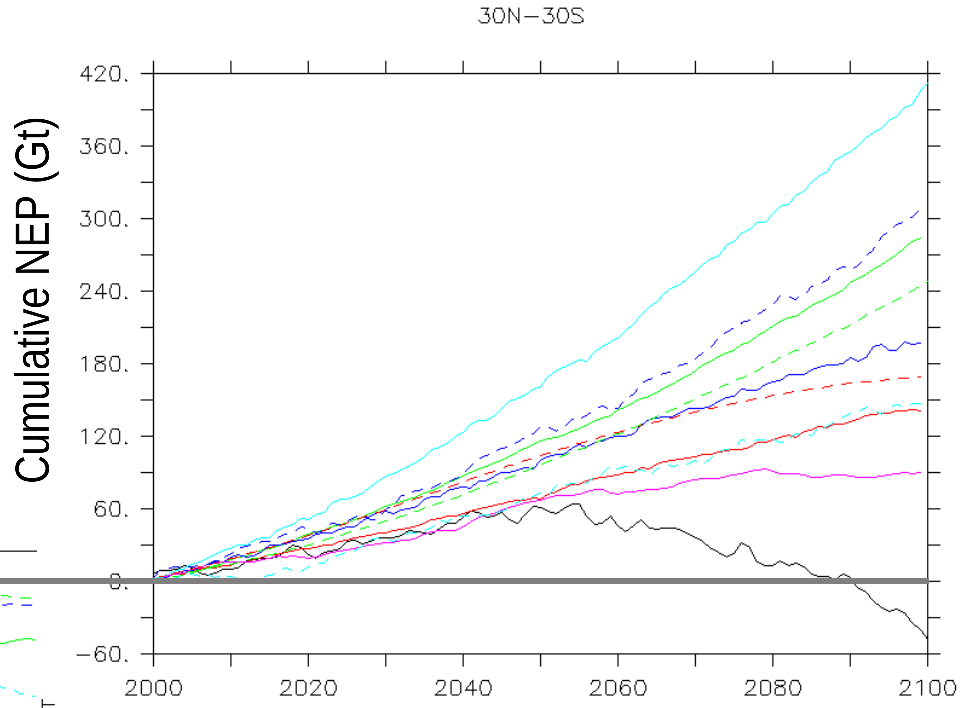
- Reforestation / Afforestation
- Regrowth in abandoned agricultural land
- Regrowth of previously disturbed forests (Fire, wind, insects, logging)
- Woody encroachment on grassland/savannas
- Forest thickening
- Improved agriculture
- Sediment burial
- Decreased deforestation
- Shifts in vegetation types
- Wood products and landfills.

Carbon Source Mechanisms

- Deforestation
- Wildfires
- Insect attacks
- Enhanced H_R in warmer and wetter conditions
- Soil depletion by agricultural practices
- Permafrost thawing, thermokarst processes, C decomposition, and vegetation dynamics
- Peatland hydrology, drainage and C decomposition, and vegetation dynamics
-
- Livestock methane production
- Fossil fuel emissions

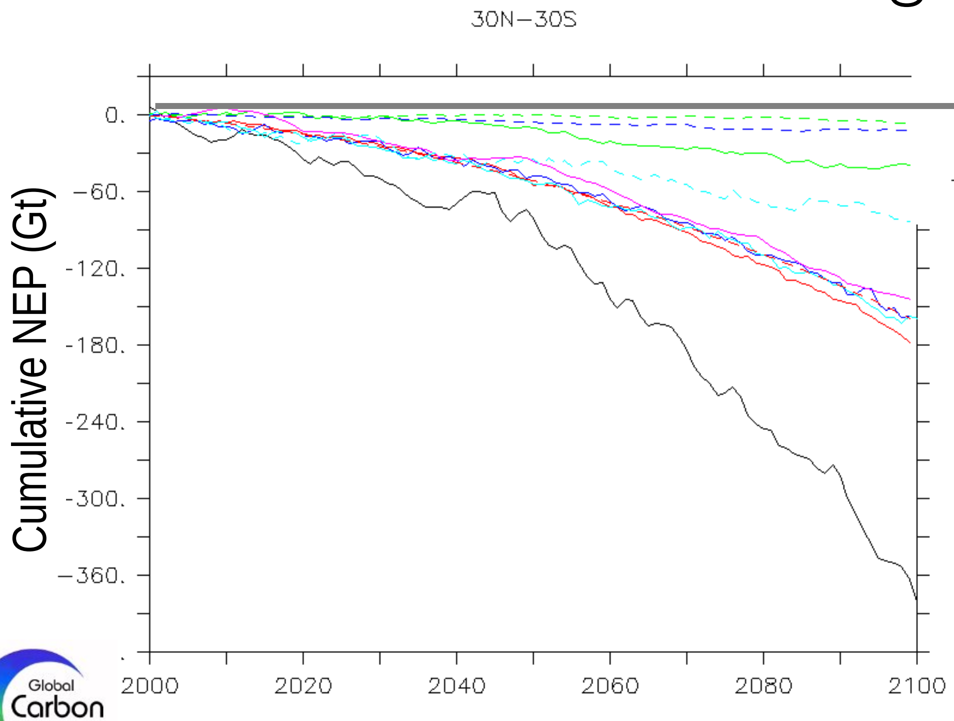
The Importance of the CO_2 Fertilization Effect

Tropical Regions (30N-30S)



Climate Change + CO_2 fertilization

Climate Change Only

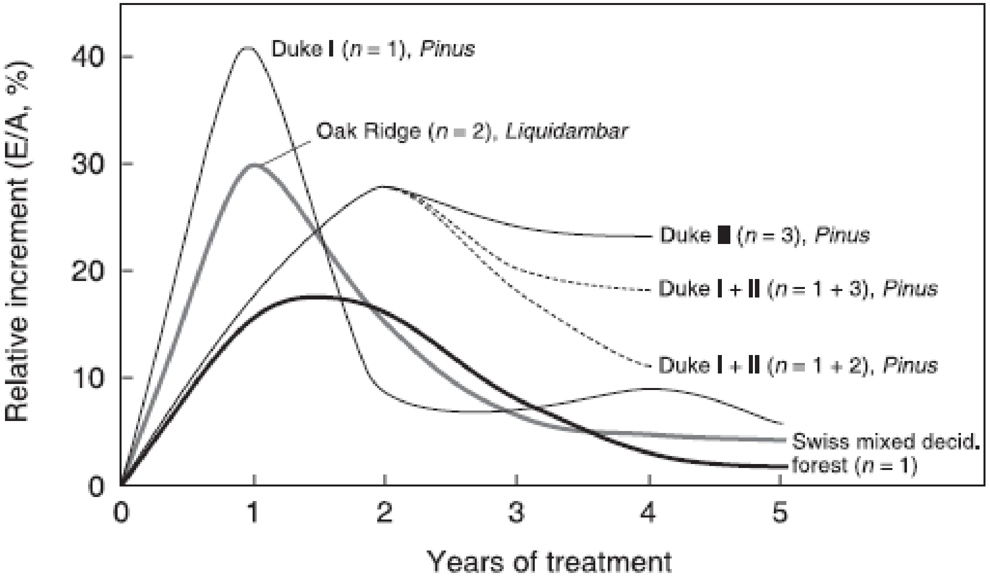


~23% increased NPP
at double CO_2

Friedlingstein et al, unpublish

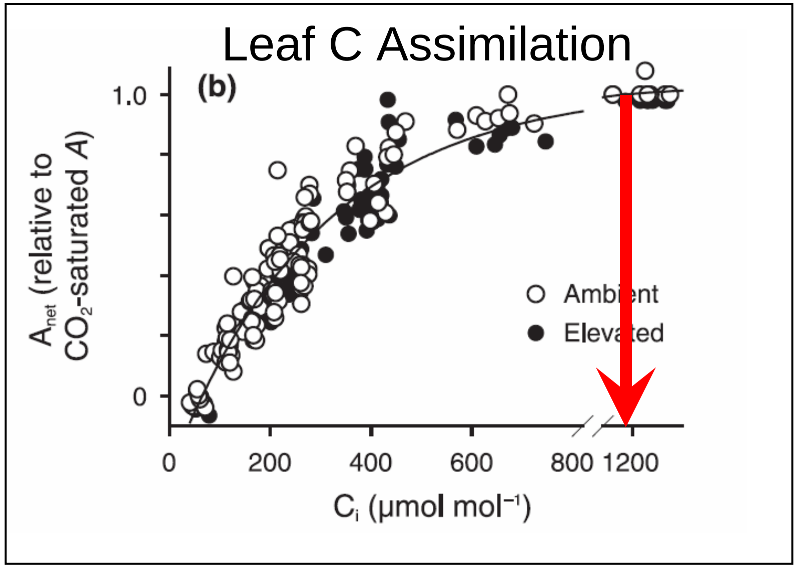
Fertilization Effect of 550 ppm of CO_2 on Forest Productivity

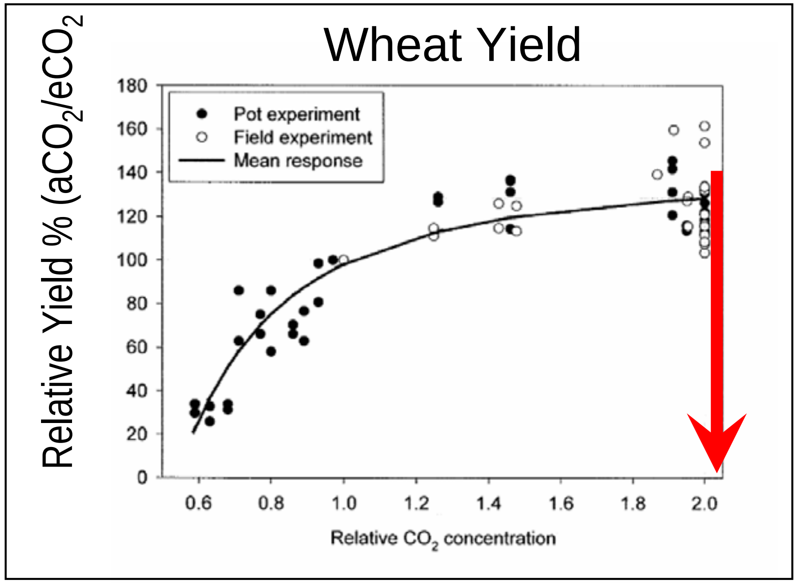
Basal Area or Biomass

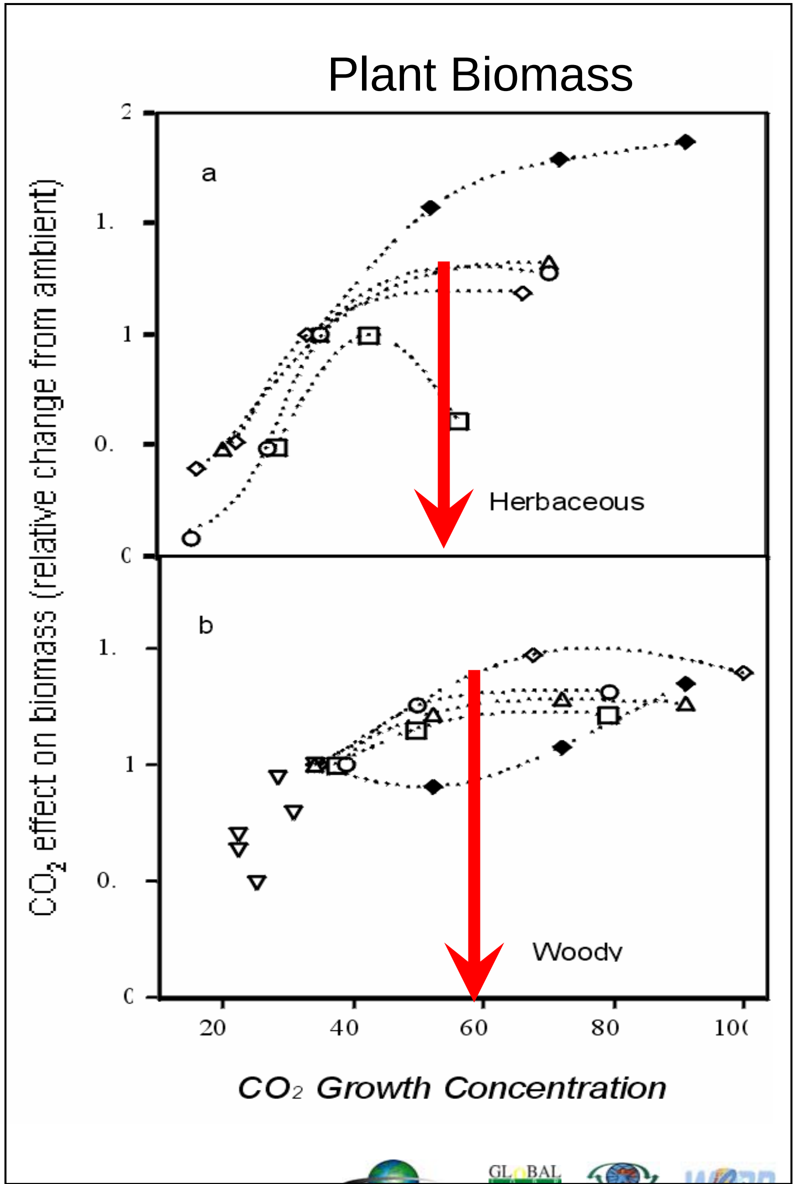


Koerner 2006

Saturation of CO_2 Fertilization Effect

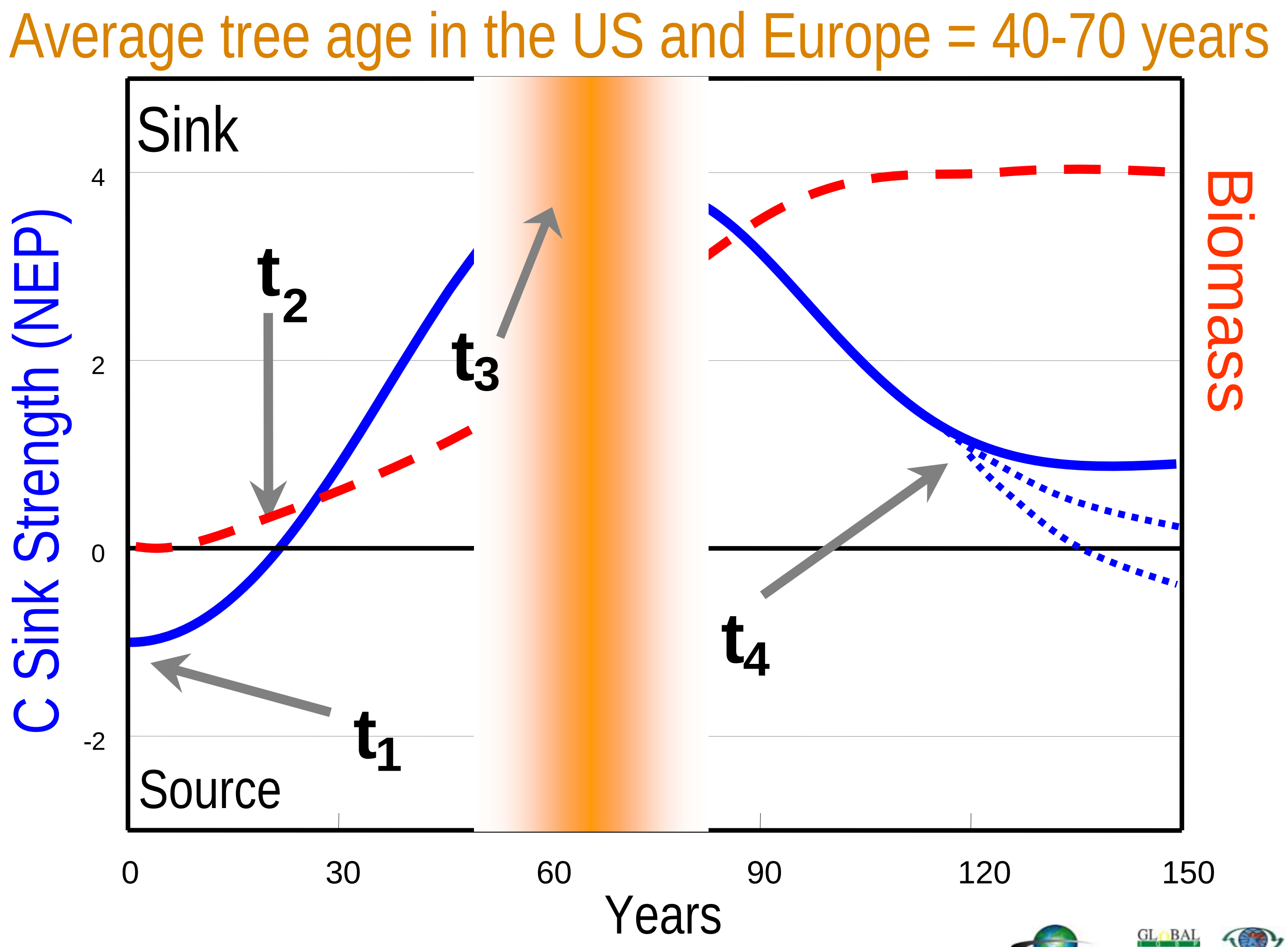






Canadell et al. 2007

Carbon Sinks from Forest Regrowth



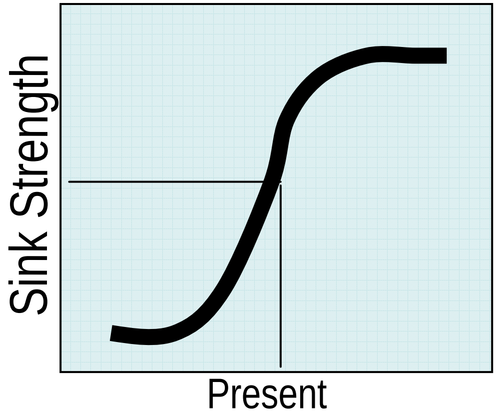
Canadell et al. 2007

If the current terrestrial carbon sink…

… is largely driven by

physiological responses

(CO_2 fertilization, N deposition)

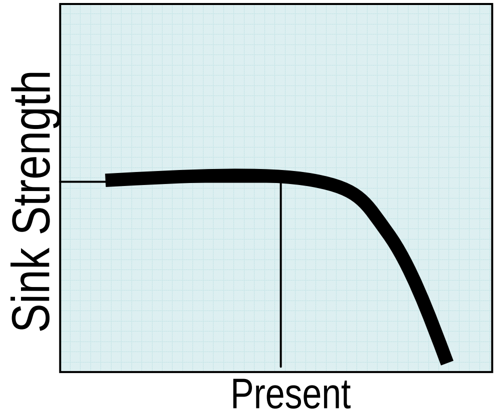


Climate will warm as predicted

…is largely driven by

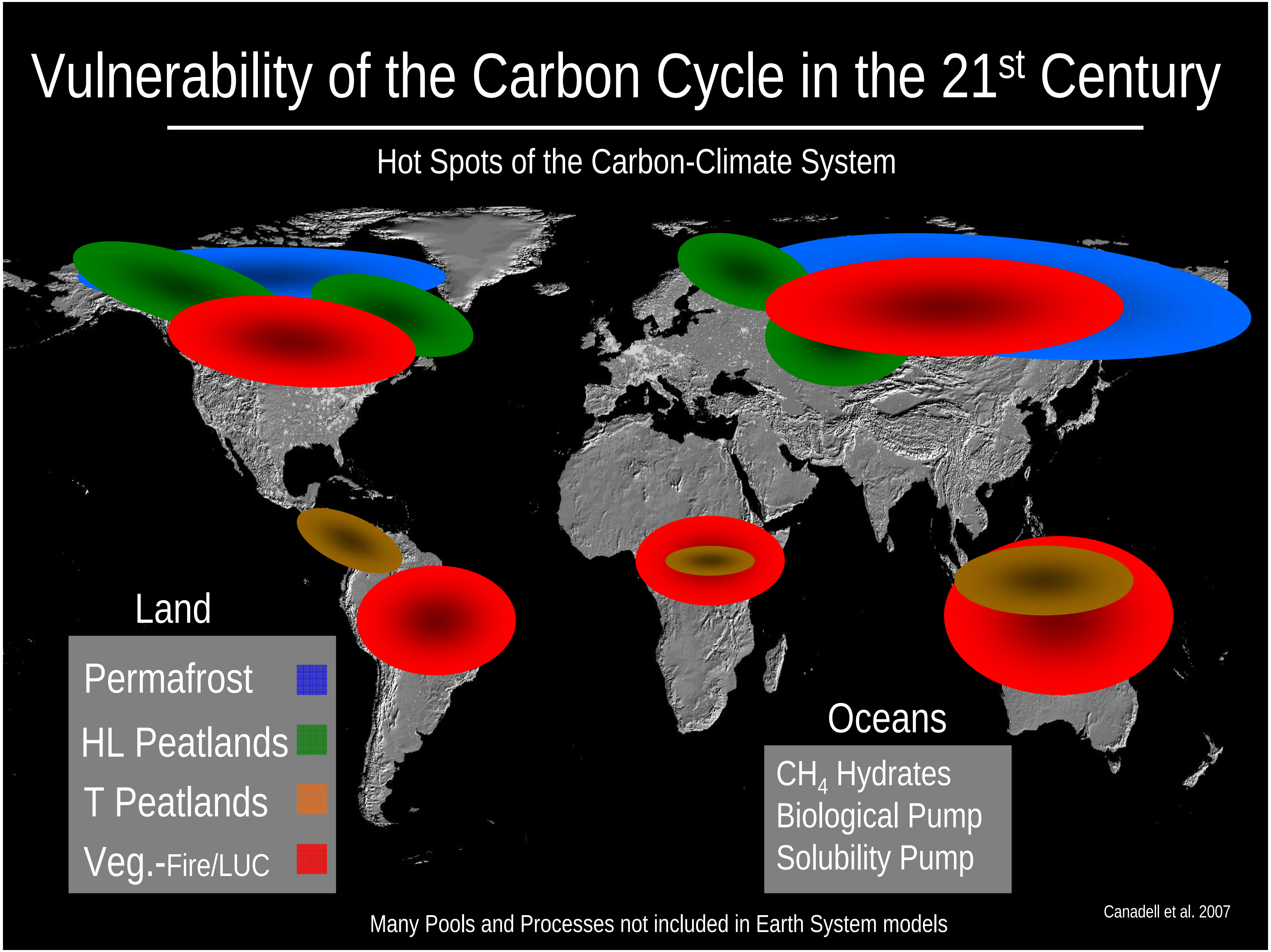
past and current land use change

(e.g., forest regrowth, thickening, woody encroachment)



Climate will warm more rapidly than predicted

Canadell et al. 2007


Vulnerability of the Carbon Cycle in the 21st Century
Hot Spots of the Carbon-Climate System
Land
Permafrost
HL Peatlands
T Peatlands
Veg.-Fire/LUC
Oceans
CH4 Hydrates
Biological Pump
Solubility Pump
Many Pools and Processes not included in Earth System models
Canadell et al. 2007

Vulnerability of the Carbon Cycle in the 21st Century

>200 Pg C
vegetation and soils
vulnerable to
drought x land use x fire

Perm
HL P
T Pe
Veg.-Fire/LUC

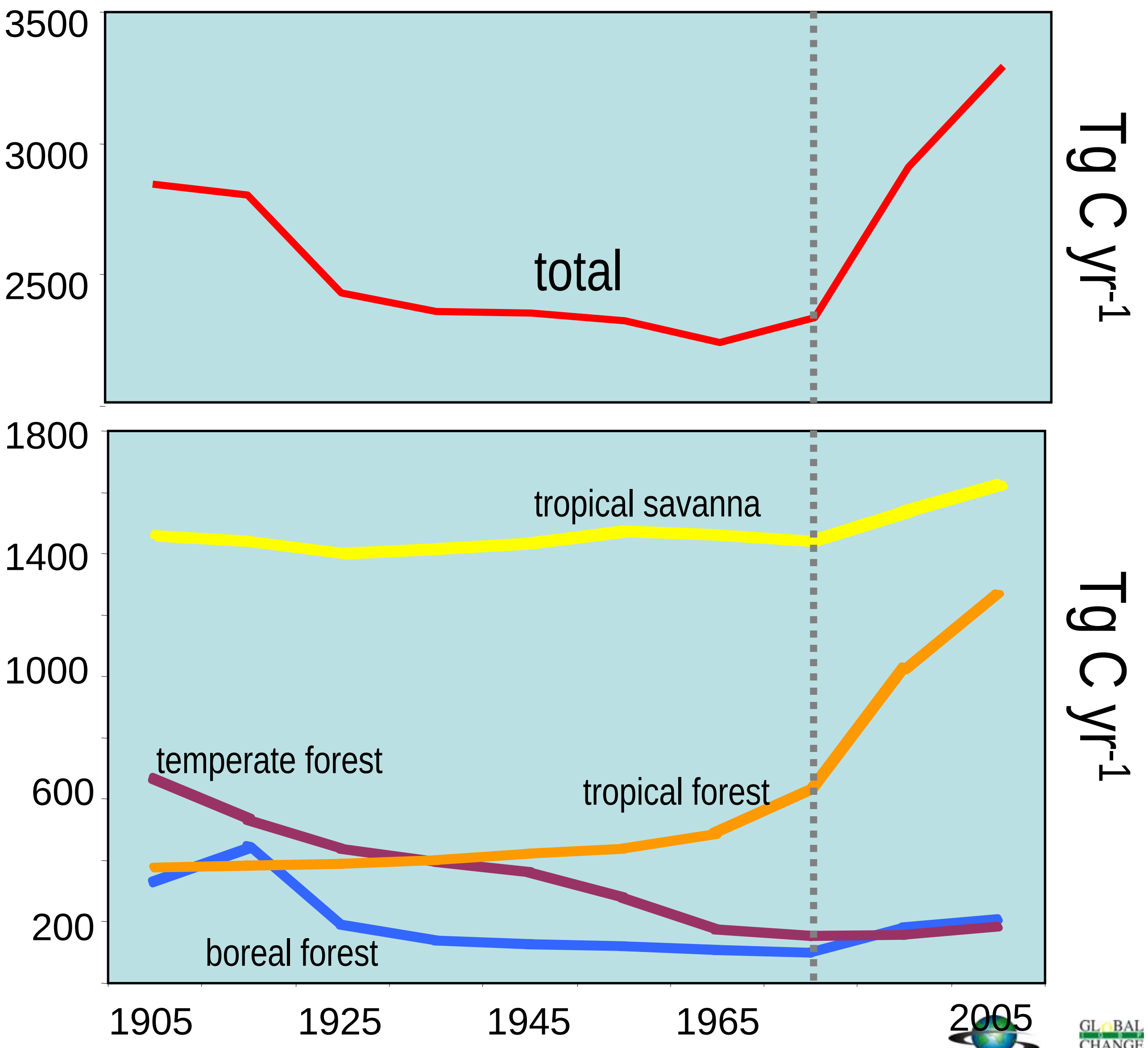
Oceans

CH_4 Hydrates
Biological Pump
Solubility Pump

Many Pools and Processes not in included in Earth System models

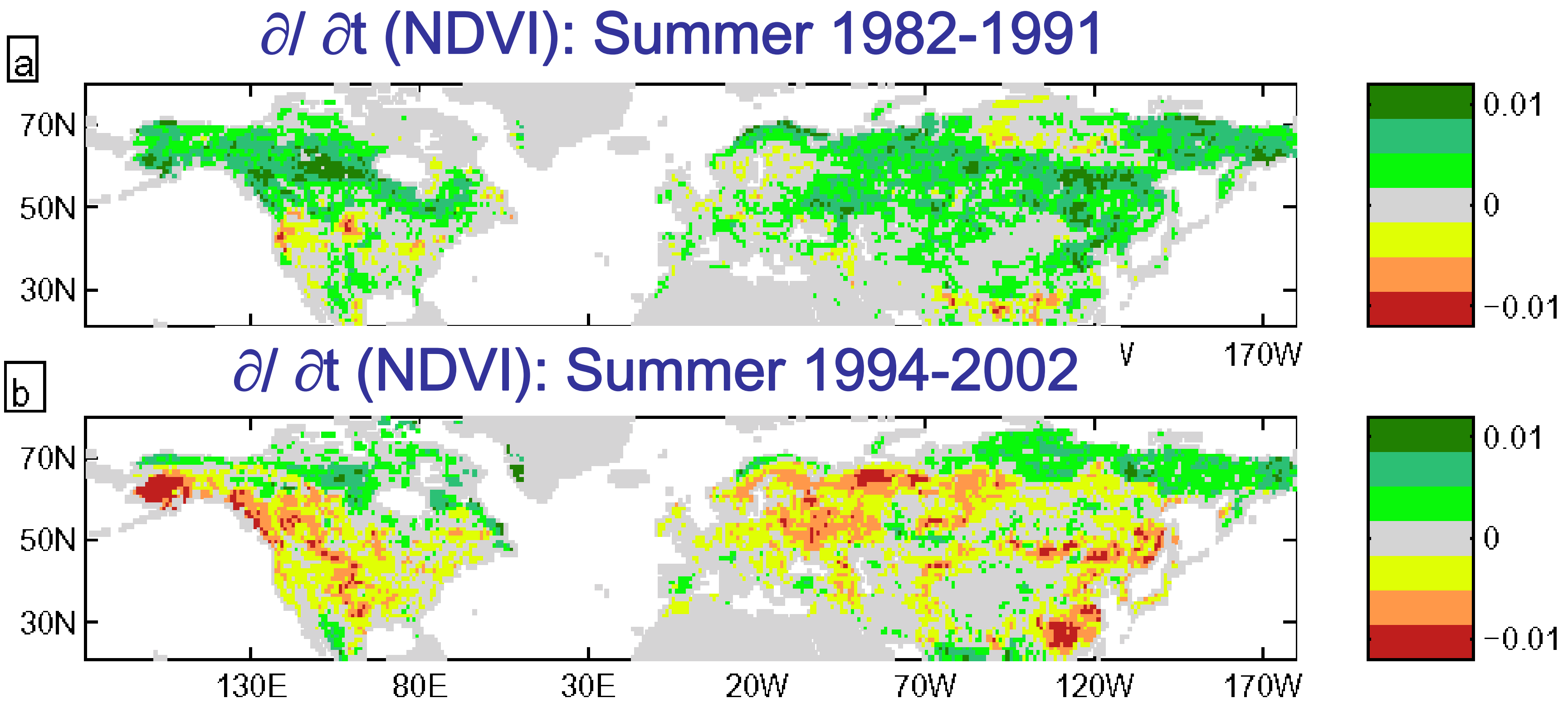
Field and Raupach 2004
Canadell et al. 2006

Trends in Carbon Emissions from Fires



Mouillot et al. 2006

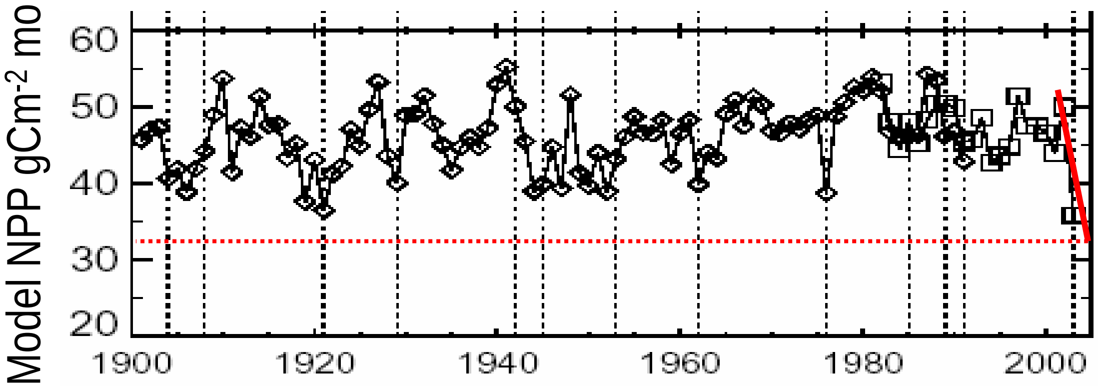
Drought Effects on the Mid-Latitude Carbon Sink



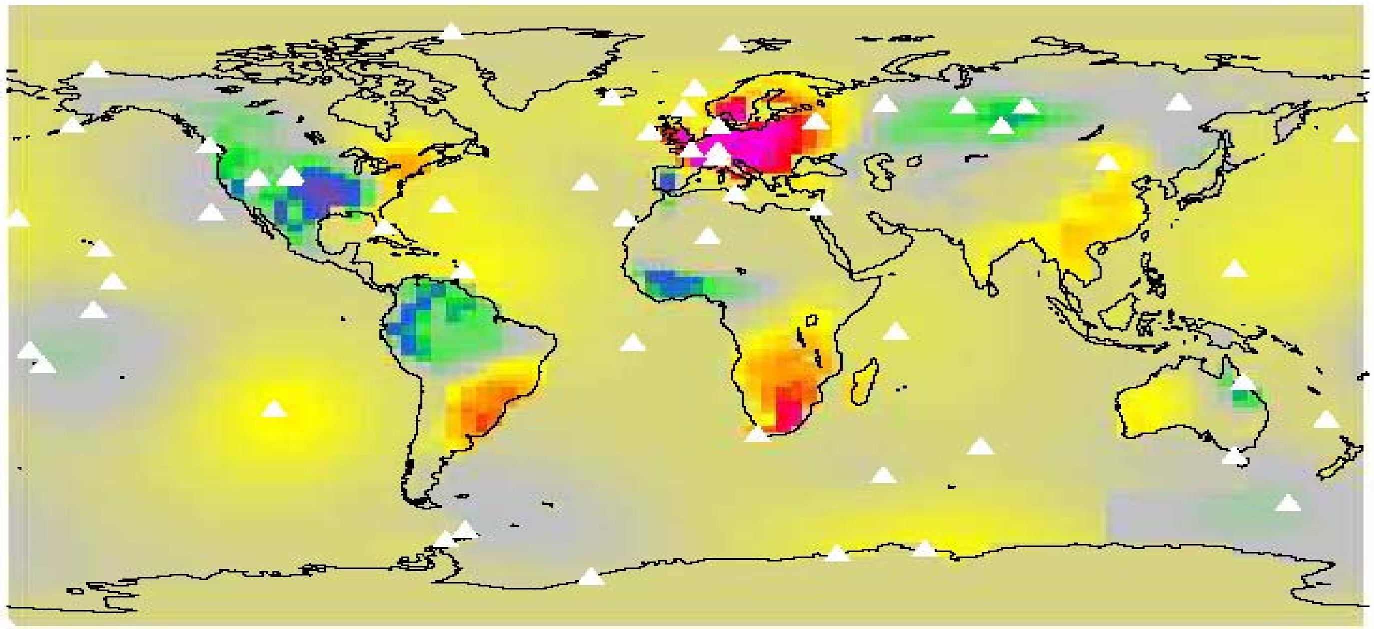
Angert et al. 2005

The 2003 Heat Wave in Europe

The largest productivity crash of the past 100 years



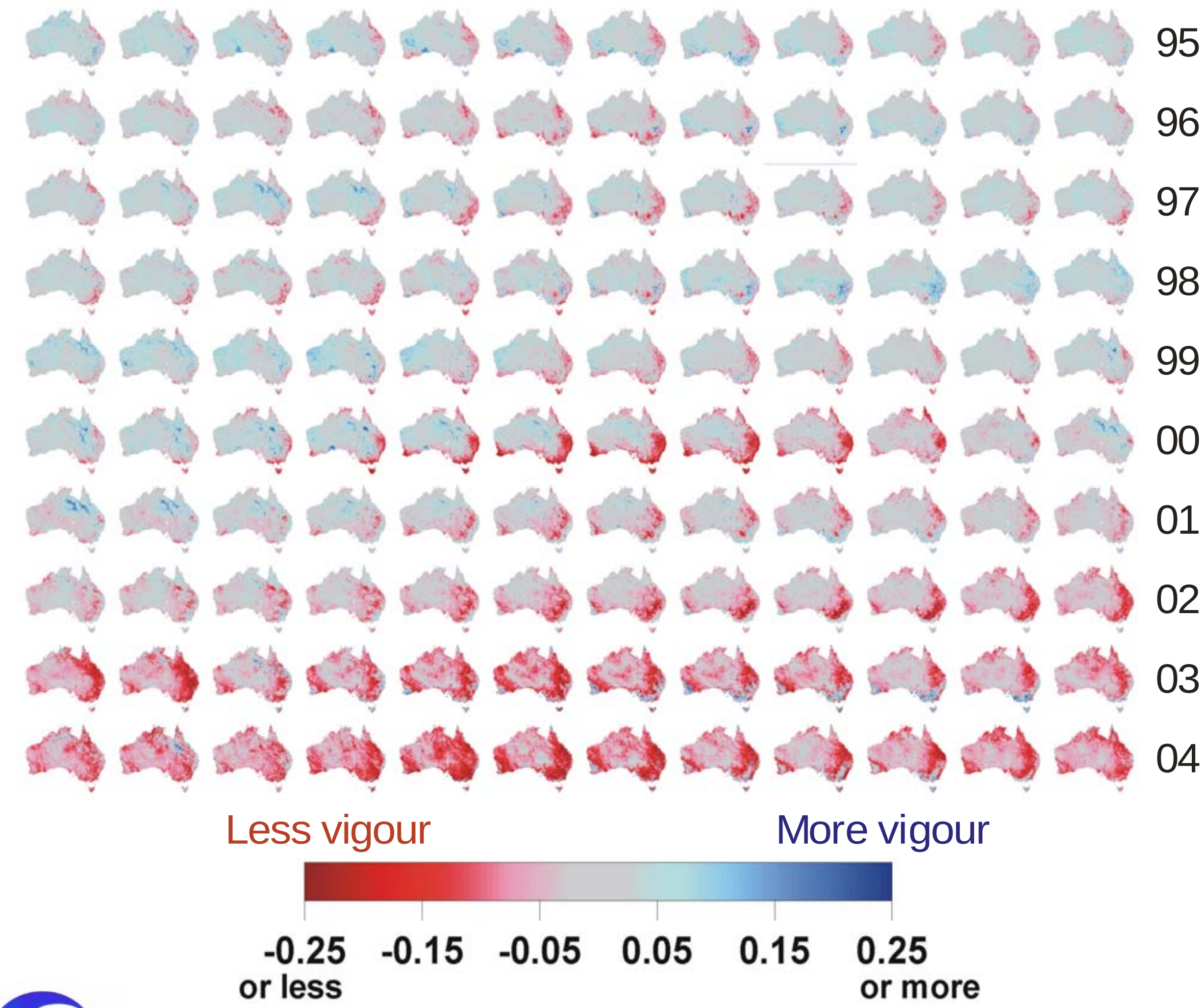
30%	Reduction of GPP
0.5PgC	Net source of CO_2
4years	Equivalent C sink



CO_2 Anomaly

Ciais et al. 2005, Peylin et al., unpublished

NDVI Anomaly - Monthly 1995-2004



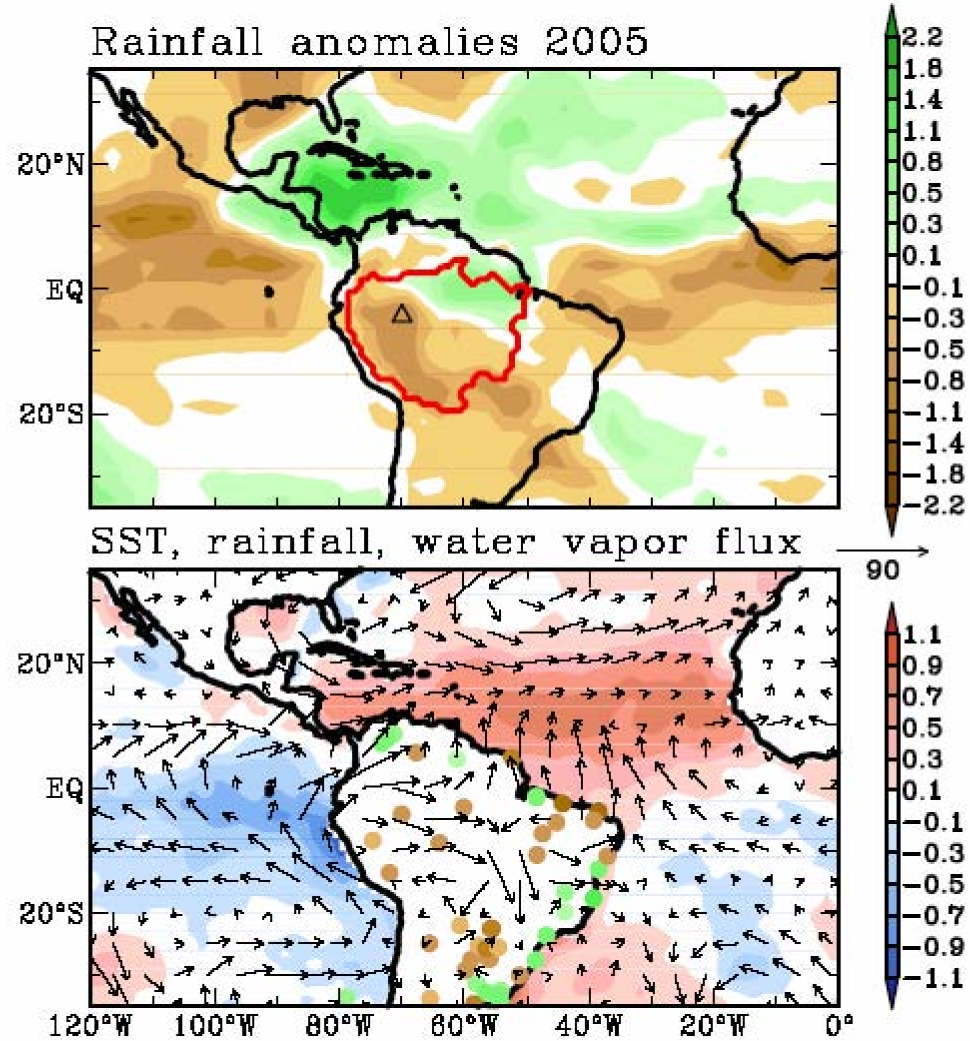
Drought related Emissions:
0.2 PgC
= 200 MtC
= 730 Mt CO_2

Compare with:

Australian GHG emissions (2002):
550 Mt CO_2eq

Raupach et al, 2006, unpublished

The 2005 Amazon Drought

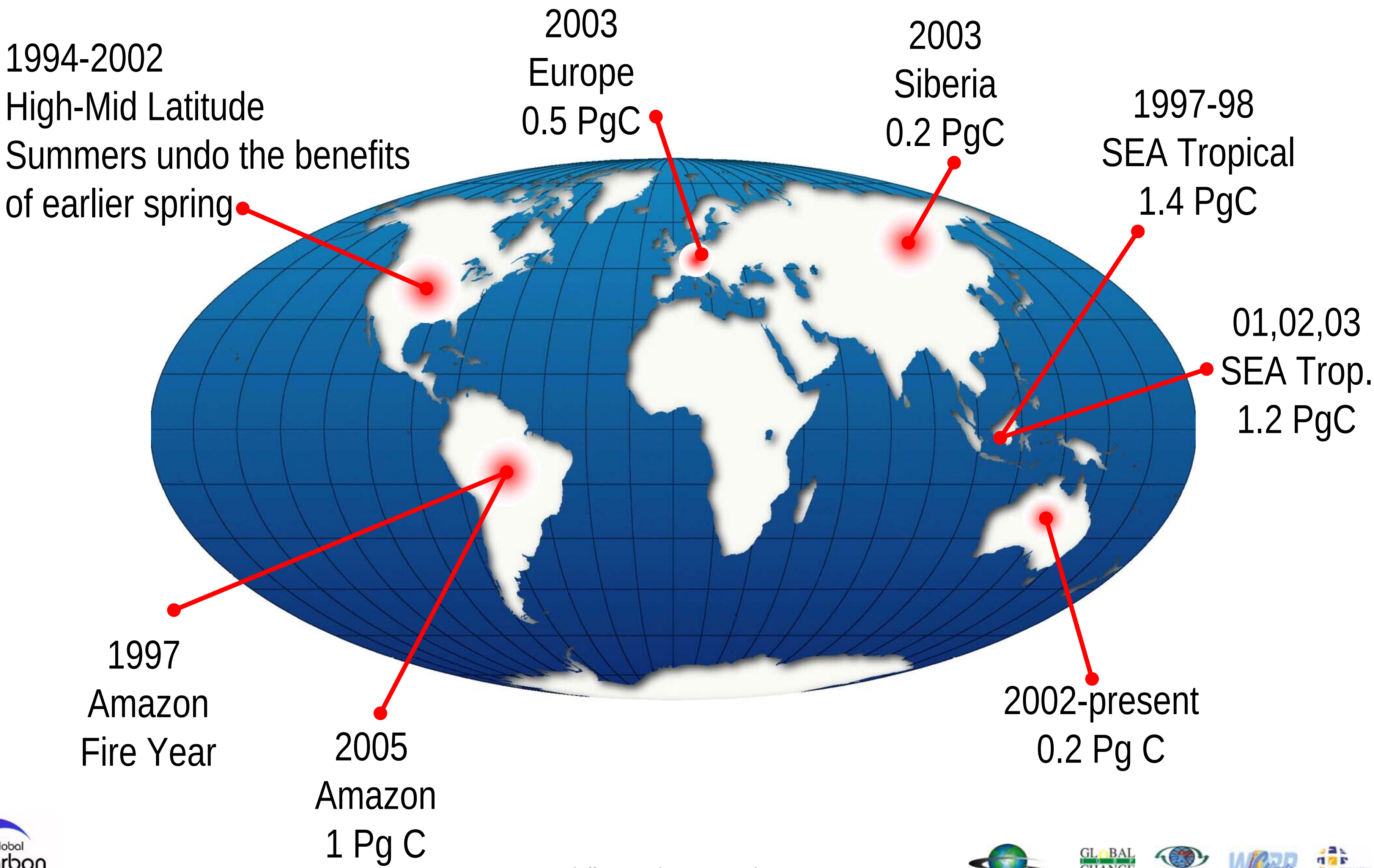


- The lowest river stage in the 25 year data period for the upper Amazon

- 1 Pg C released (equivalent to the sink of the world's tropics)

Ning et al. 2006, submitted; Nepstad et al. 2006, in preparation

Drought-Carbon Emissions (1994-2005)



Canadell 2007, in preparation

400 Pg C - frozen soils vulnerable to warming

>500 Pg C - frozen sediments vulnerable to warming (yedomas in Siberia)

Vulnerability of the Carbon Cycle in the 21st Century

Land

Permafrost

HL Peatlands

T Peatlands

Veg.-Fire/LUC

Oceans

CH_4 Hydrates

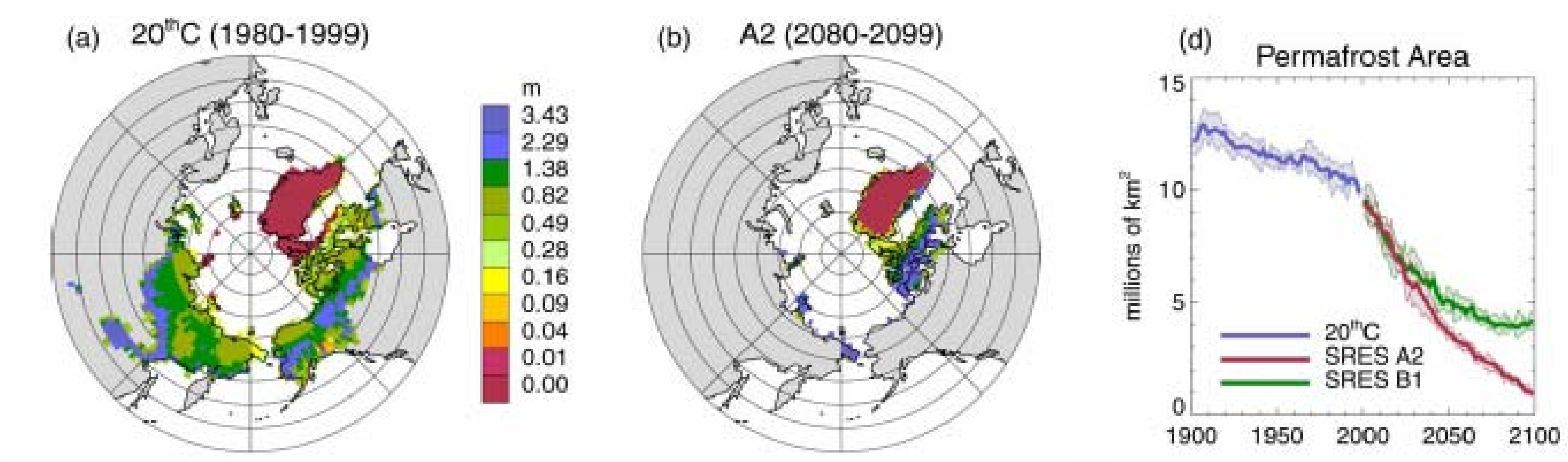
Biological Pump

Solubility Pump

Many Pools and Processes not in included in Earth System models

Field and Raupach 2004
Canadell et al. 2006

Permafrost Degradation in the 21st Century



Present extension:
10.5 Million km^2

2100 extension:
1 Million km^2

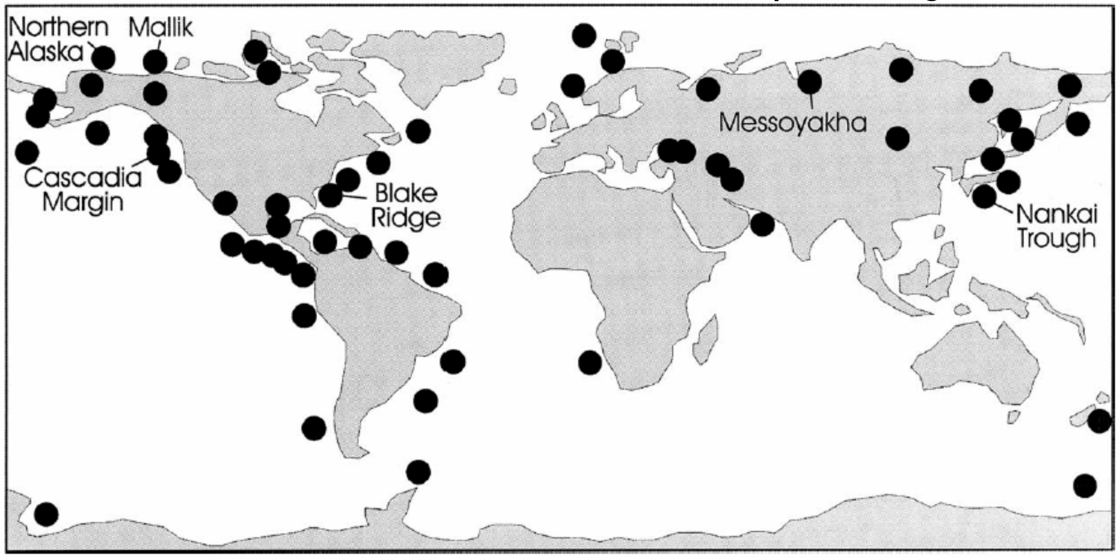
Carbon Emissions from thawing permafrost by 2100: 100 Pg C

Lawrence et al. 2005, Gruber et al. 2004

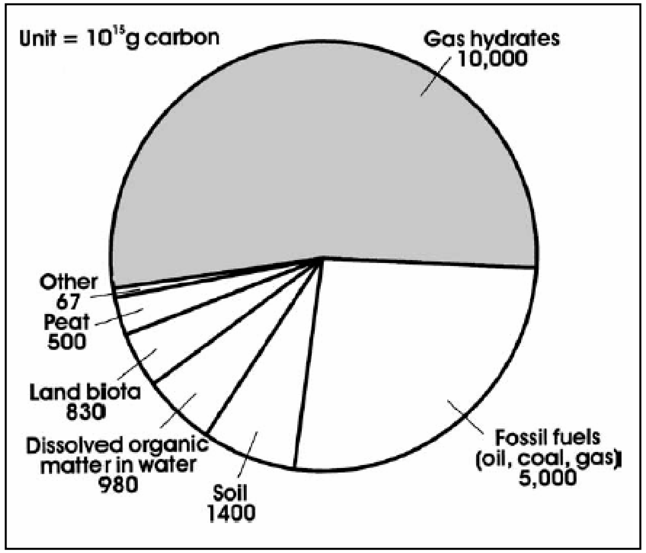
10,000 Pg C – gas hydrates in frozen ground and ocean sediments

The Vulnerability of Methane Hydrates

Occurrence: Beneath oceans and in polar regions



Carbon content



- Continental permafrost: is unlikely to be disturbed by surface warming by the end of this century
- Deep ocean deposits unlikely to be disturbed by surface warming and pressure changes
- Surprises? : Outburst of gas due to build up of pressure in the sediments

Biggest threat to climate:

If they contain enough natural gas, they will be exploited during the 21st century adding a new carbon source to the Fossil Fuel energy mix that can last for centuries.

Vulnerability of the Carbon Cycle in the 21st Century

400 Pg C – cold peatlands vulnerable to climate change

Land

Permafrost

HL Peatlands

T Peatlands

Veg.-Fire/LUC

100 Pg C – tropical peatlands vulnerable to land use and climate change

Many Pools and Processes not in included in Earth System models

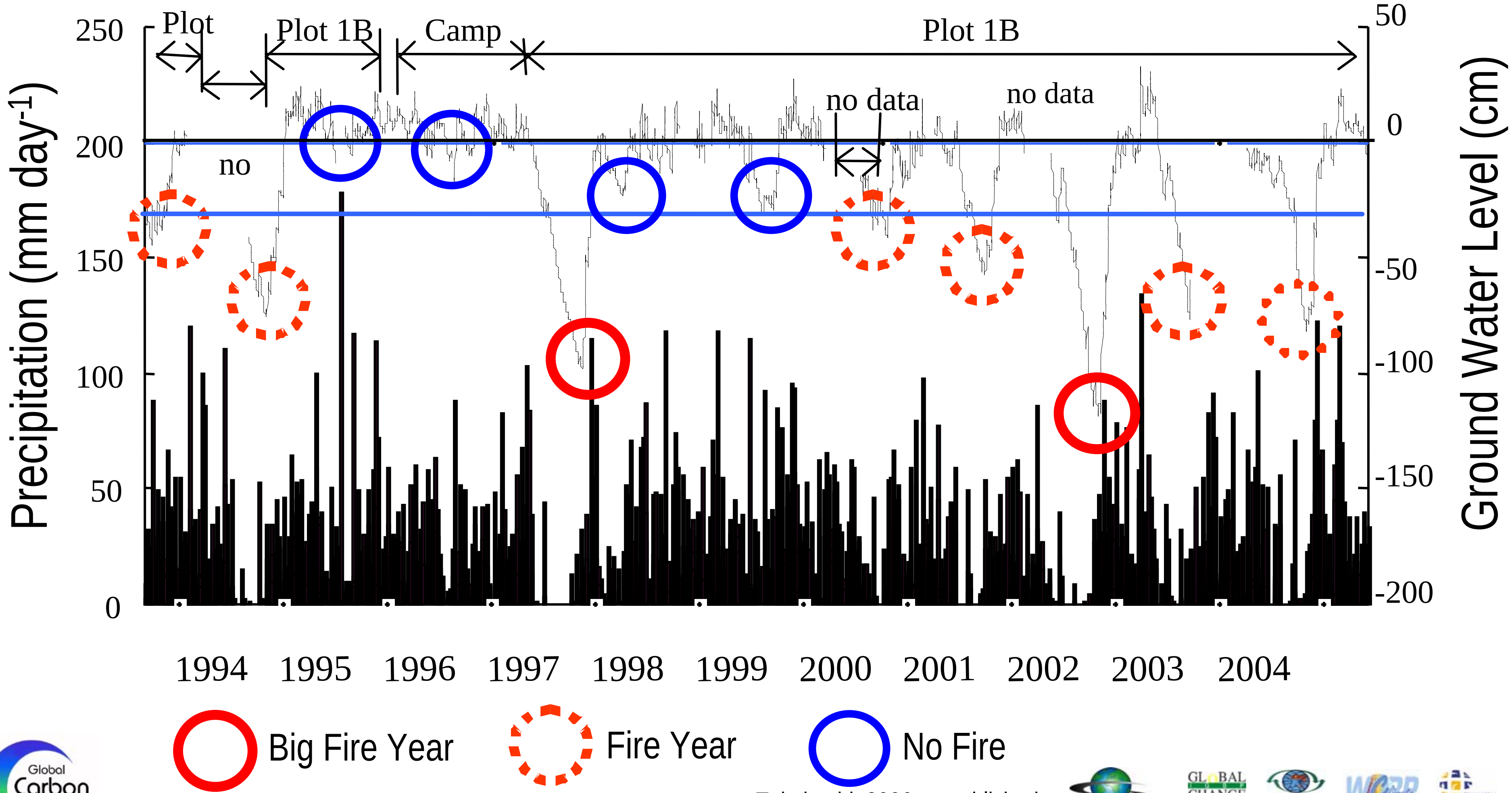
Canadell et al. 2005

Worm

Takashi Hirone

Ground water level modulates the intensity and spread of fires in the tropical peat swamp forest

South Kalimantan



Takahashi, 2006, unpublished

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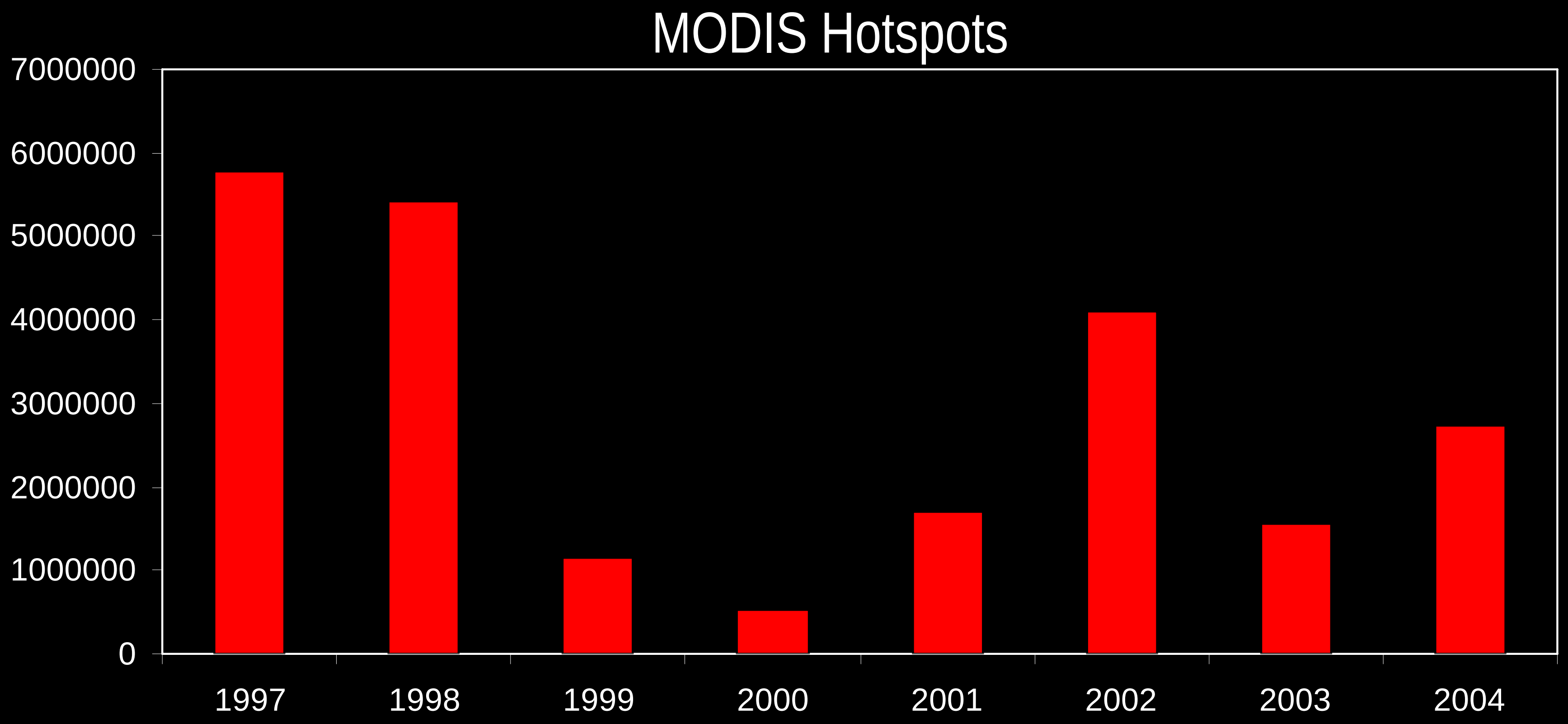
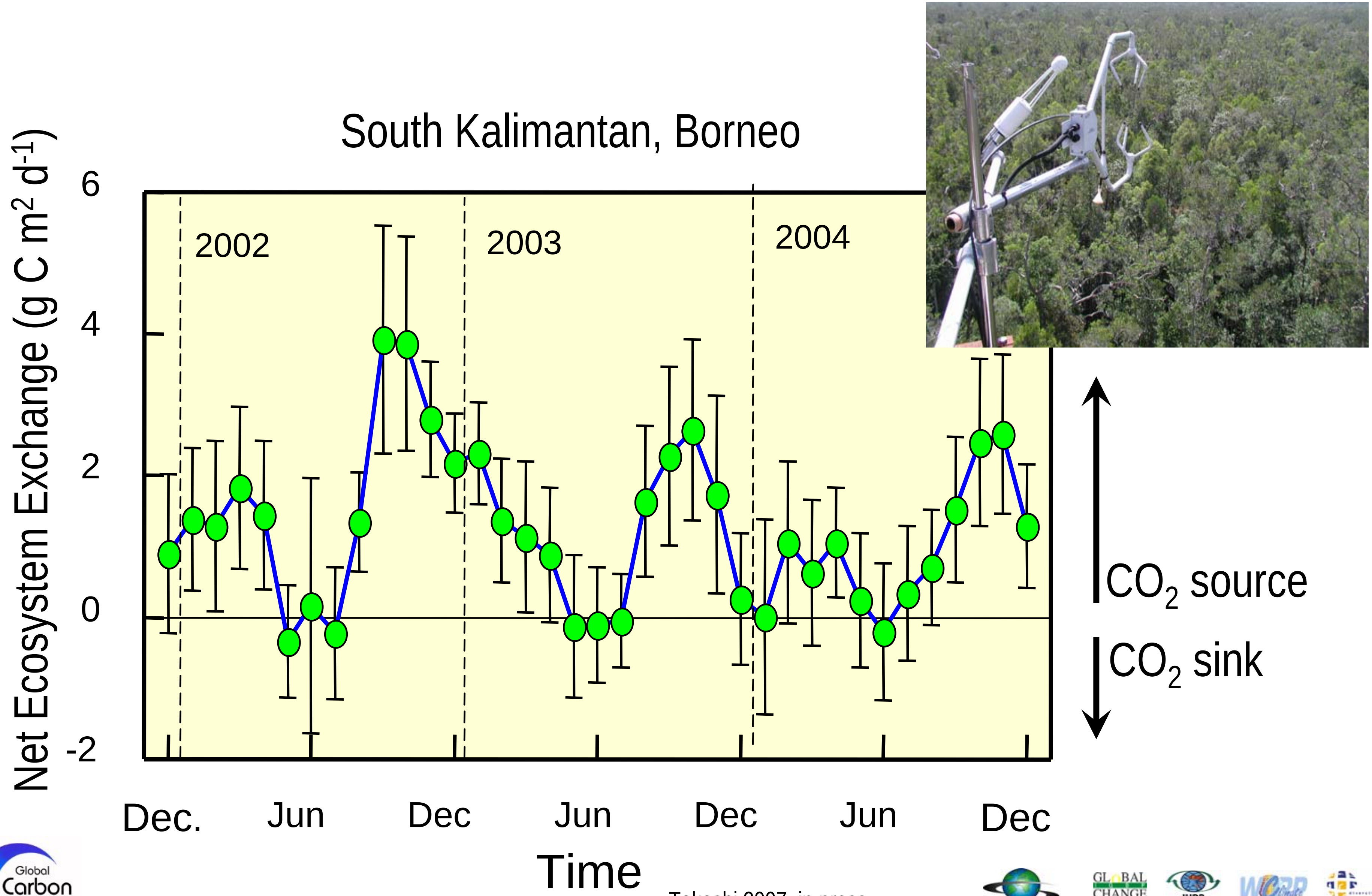
Fire occurrence on Borneo 1997-2004



Sum: 22 Million ha (22,950.949 ha)
33% burned more than once

MODIS hotspots: courtesy of MODIS fire team
NOAA AVHRR: courtesy of IFFM, JAICA
ATSR: courtesy of ESA

Source/Sink Dynamics of Drained Peatland Forests



Takashi 2007, in press

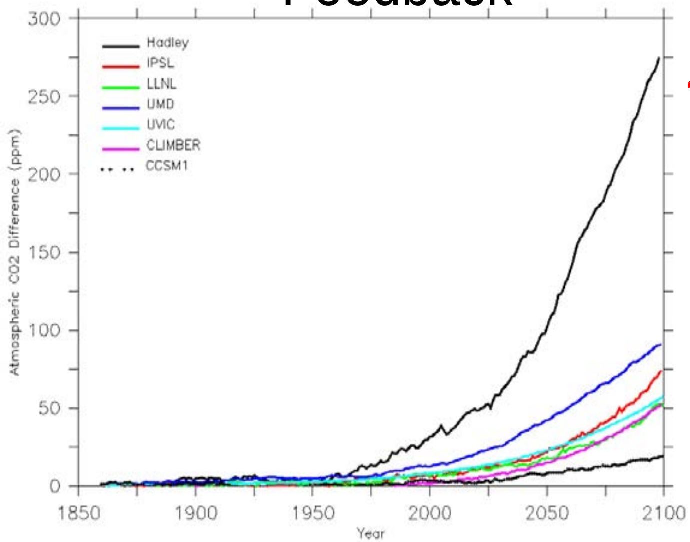
How many of the carbon sink/sources processes are part of Earth System models?

- <u>Sink</u>: CO_2 fertilization
- <u>Source</u>: Heterotrophic respiration

- Nitrogen fertilization and limitation (and P)
- Wildfires
- Regrowth (age structure)
- Shifts in vegetation types
- Land use and Cropland management
- Permafrost thawing, C decomposition, vegetation dynamics
- Peatland drainage, C decomposition, vegetation dynamics

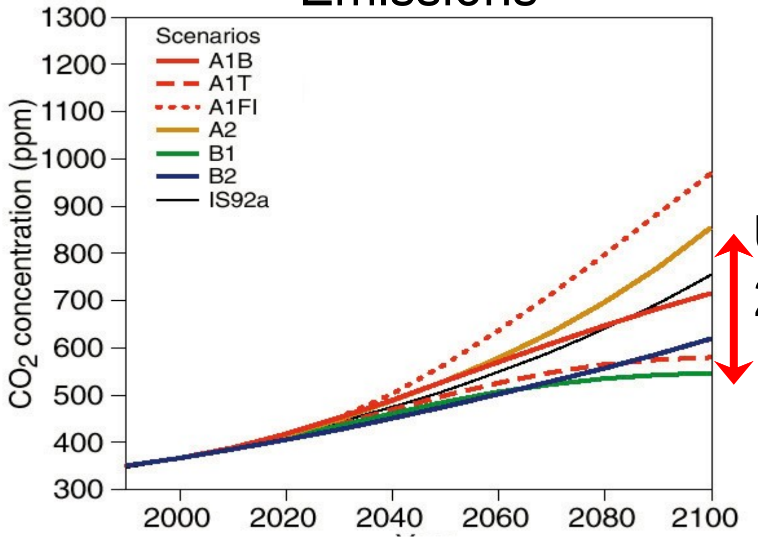
Vulnerability of the Carbon Cycle in the 21st century

Biospheric-Carbon-Climate Feedback



Up to 200 ppm

Anthropogenic Carbon Emissions



Up to 250 ppm

IPCC SRES 2000; Friedlingstein et al. 2006 www.globalcarbonproject.org