Trends and vulnerabilities in the carbon cycle

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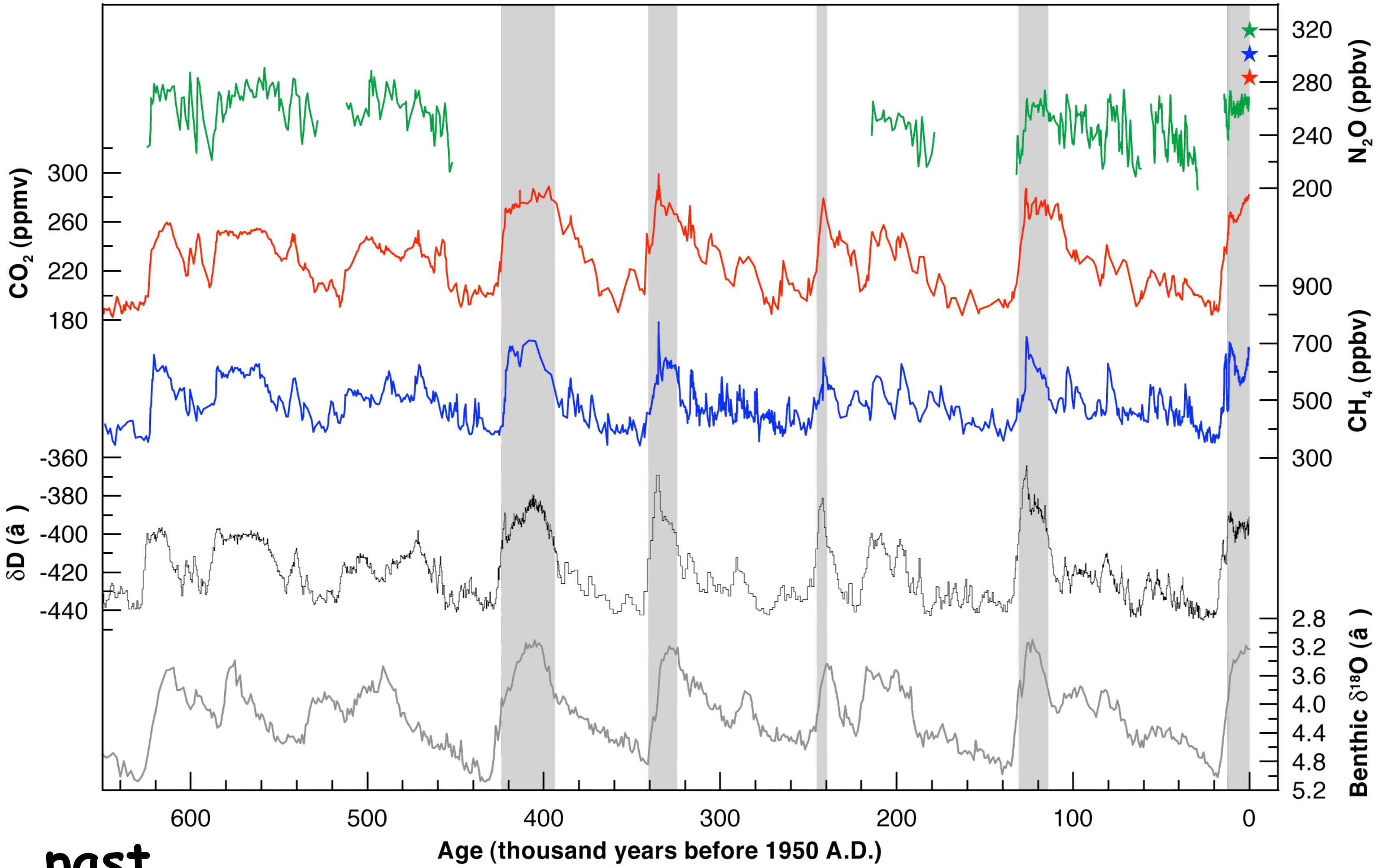
LSCE - Gif sur Yvette

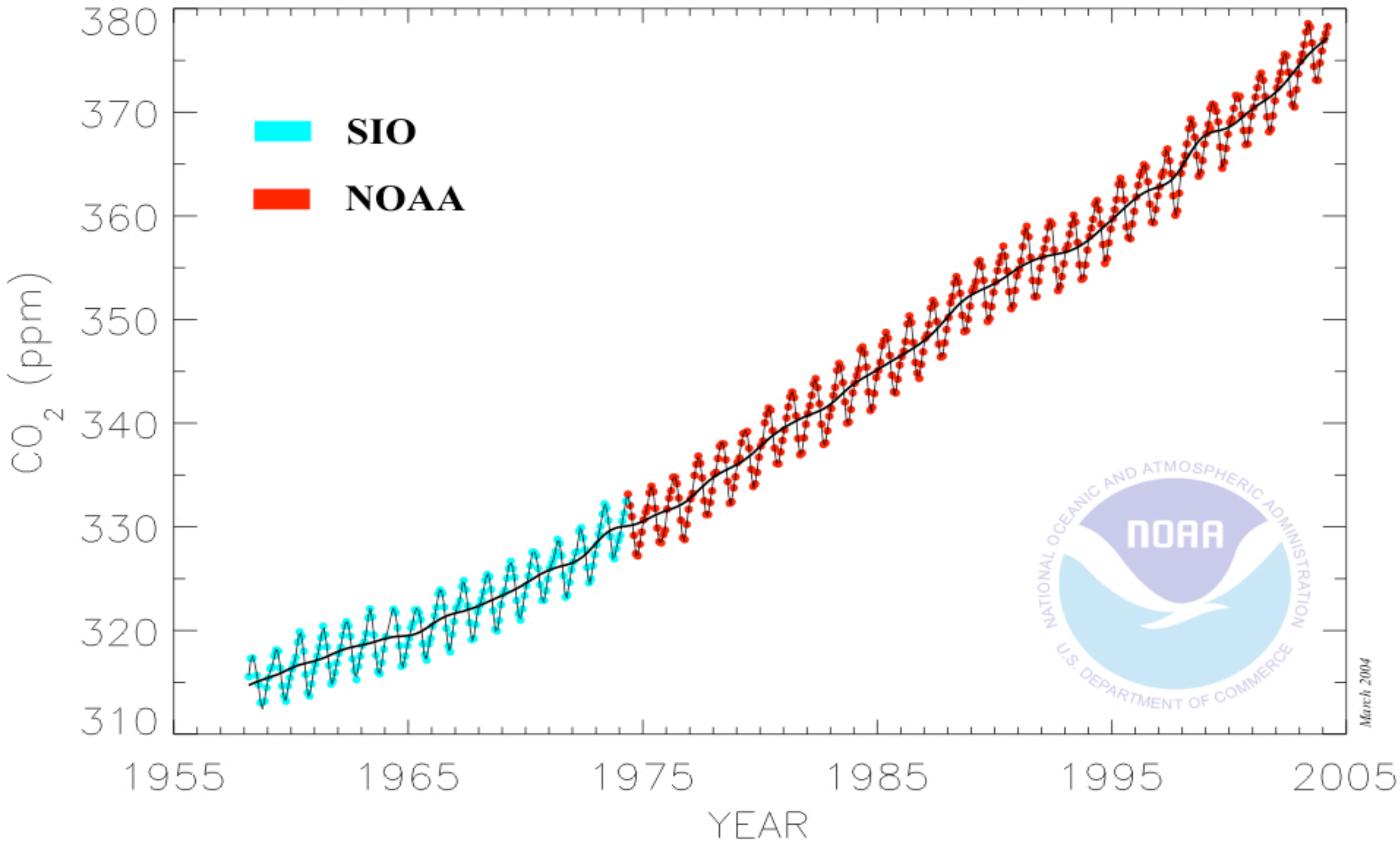
Late quaternary history of climate and greenhouse gases



past

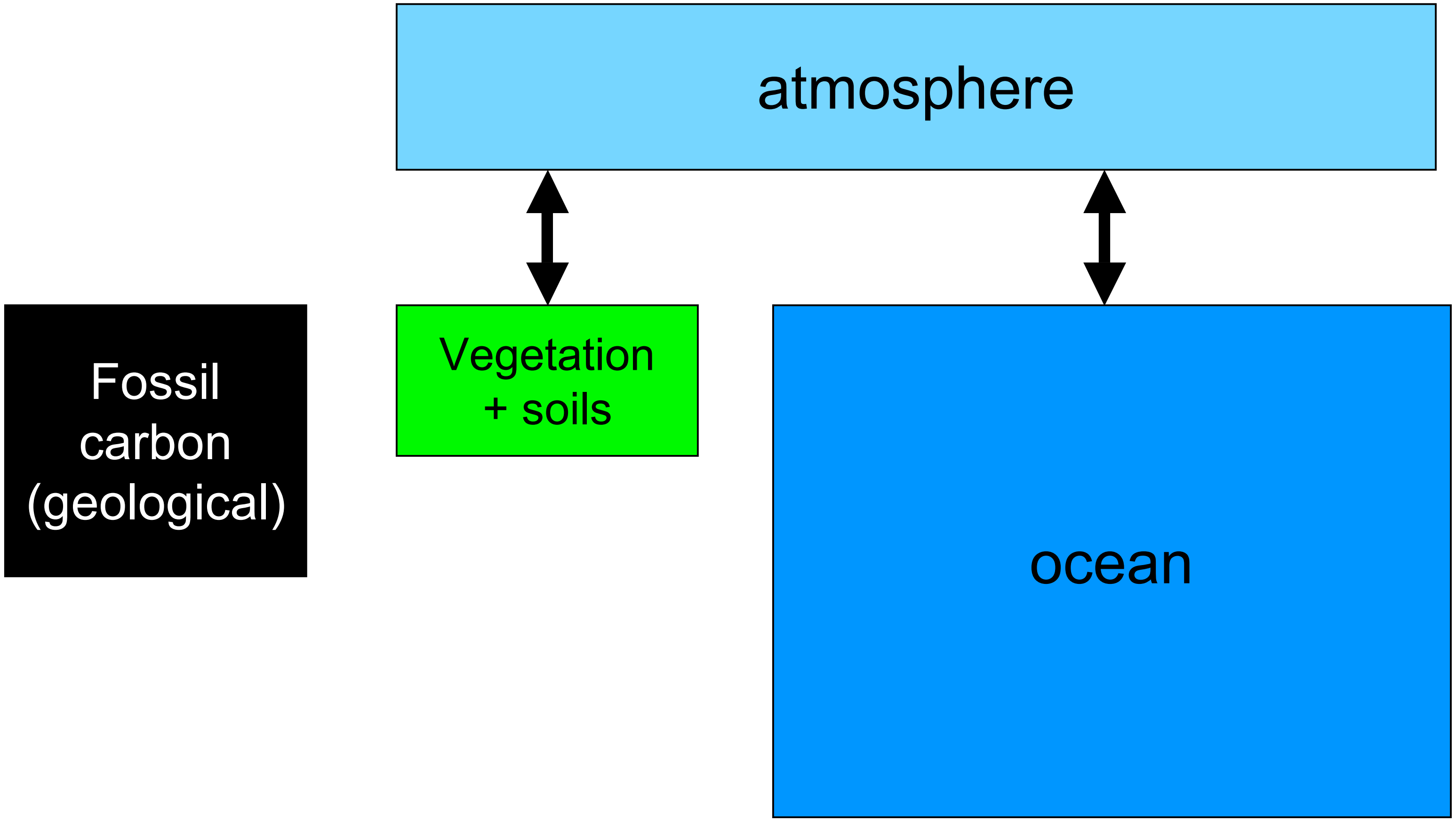
present

Mauna Loa Monthly Mean Carbon Dioxide

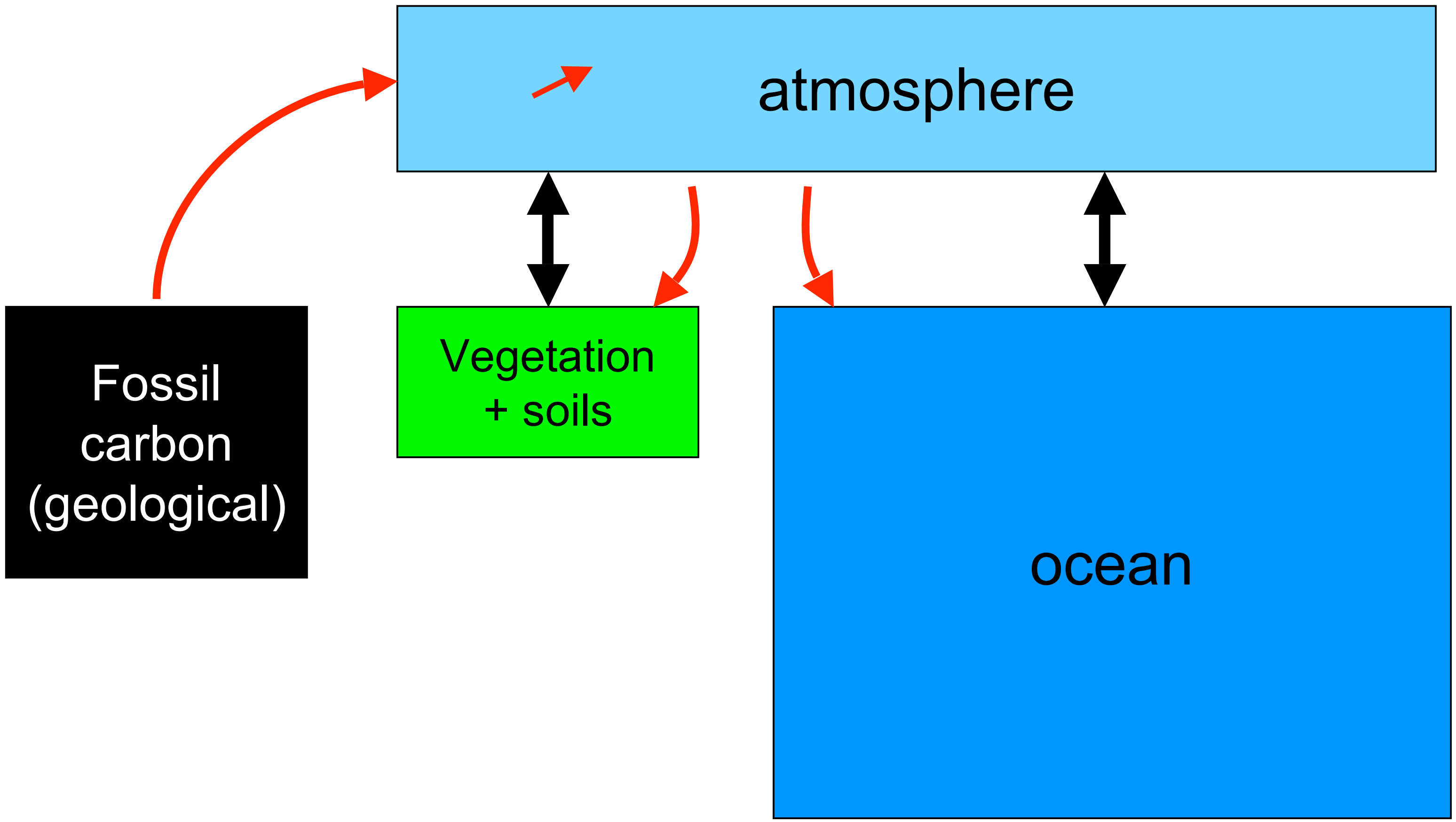


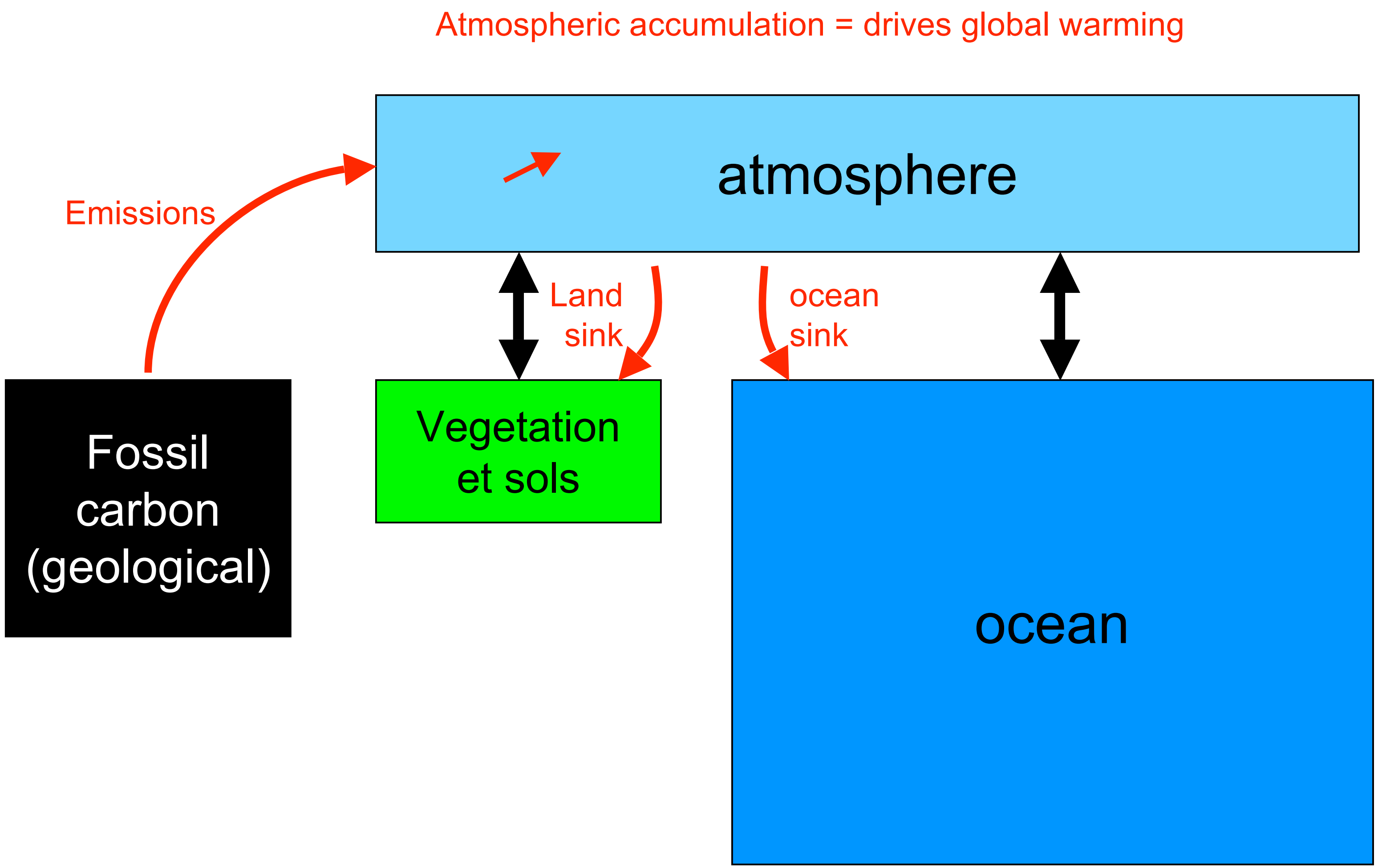
Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Principal investigators: Dr. Pieter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, and Dr. Charles D. Keeling, SIO, La Jolla, California, (616) 534-6001, cdkeeling@ucsd.edu.

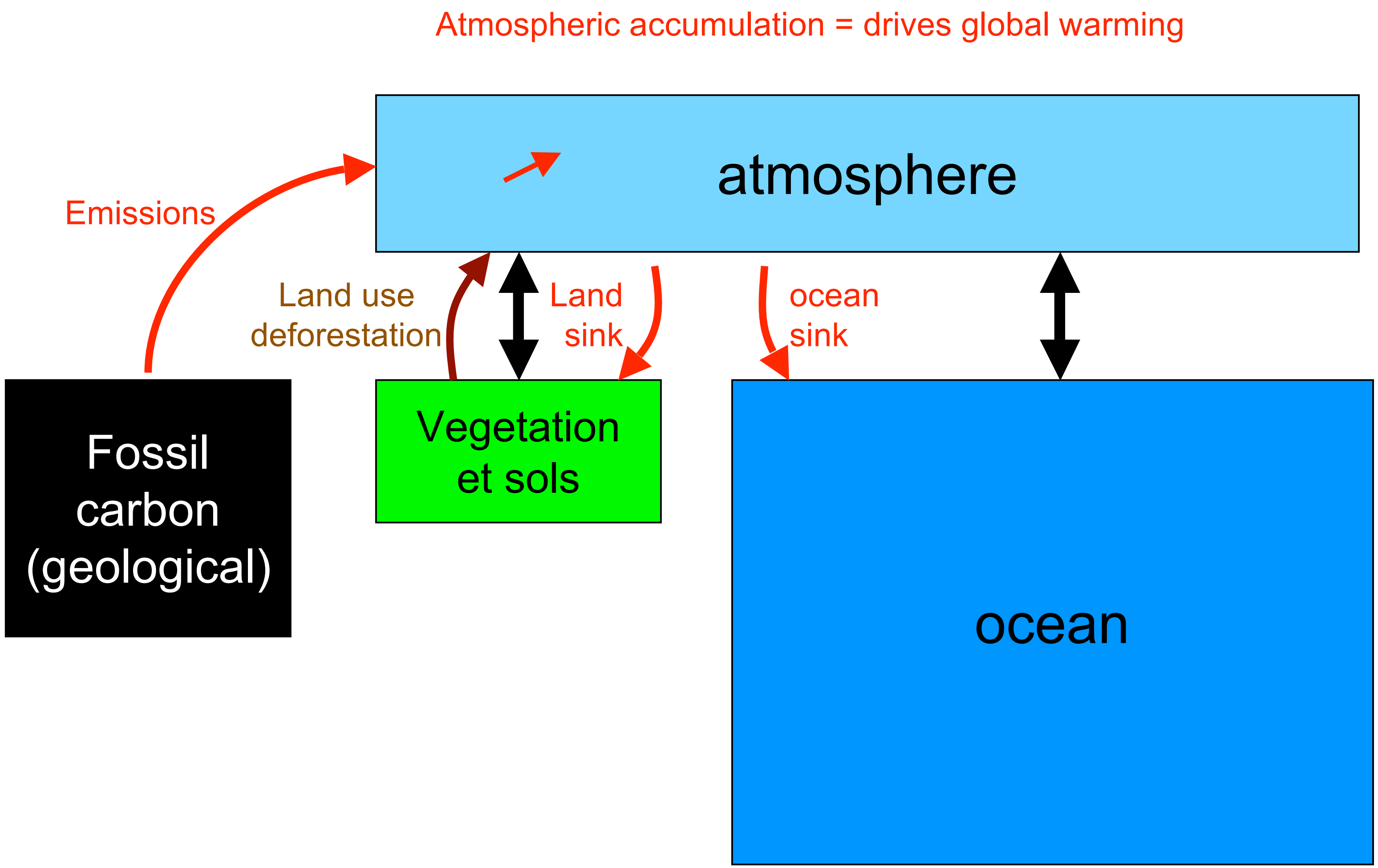
A stable carbon cycle during the Holocene



Humans mine fossil C and perturb the natural cycle

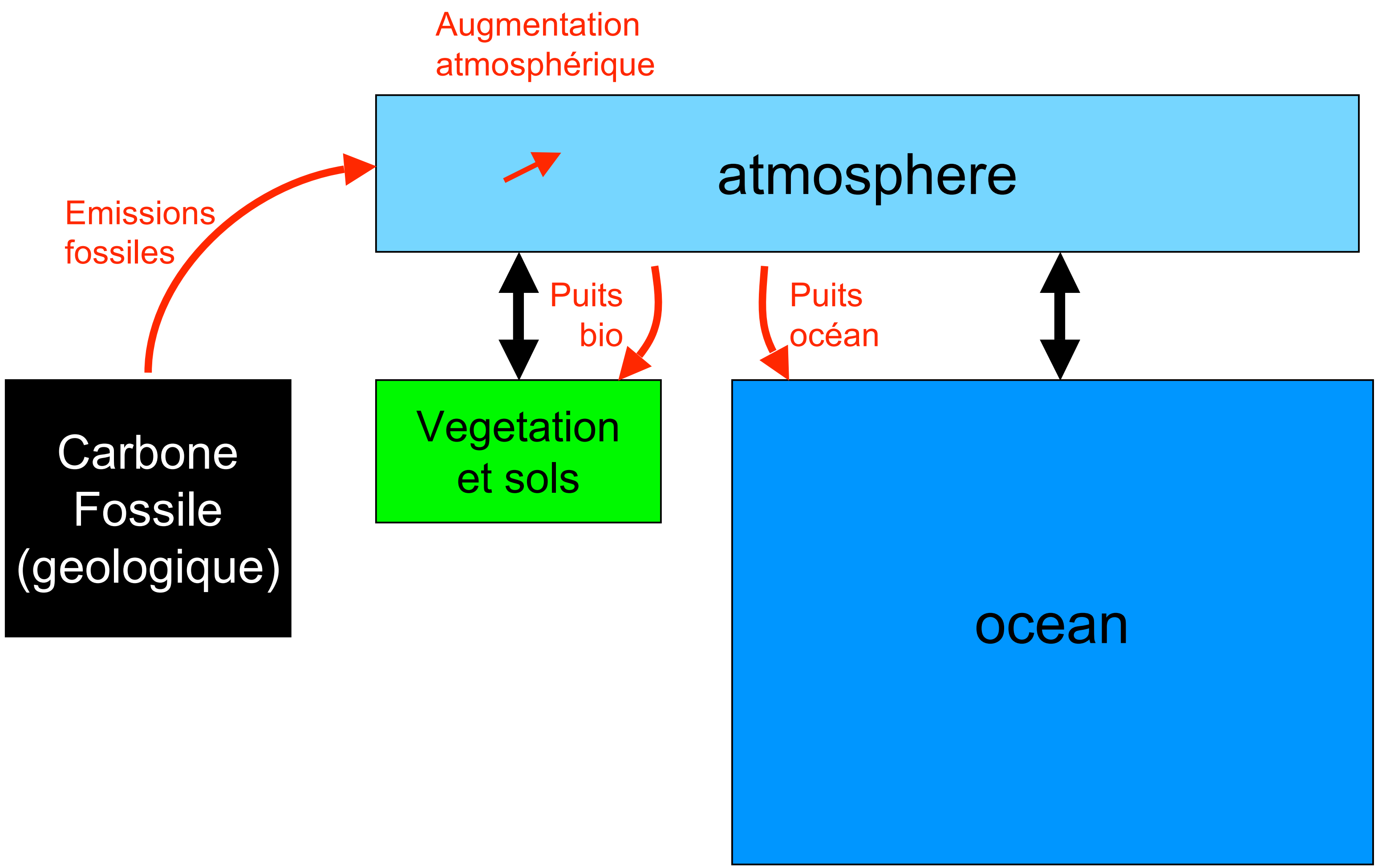



Atmospheric accumulation = drives global warming
atmosphere
Emissions
Land
sink
ocean
sink
Fossil
carbon
(geological)
Vegetation
et sols
ocean

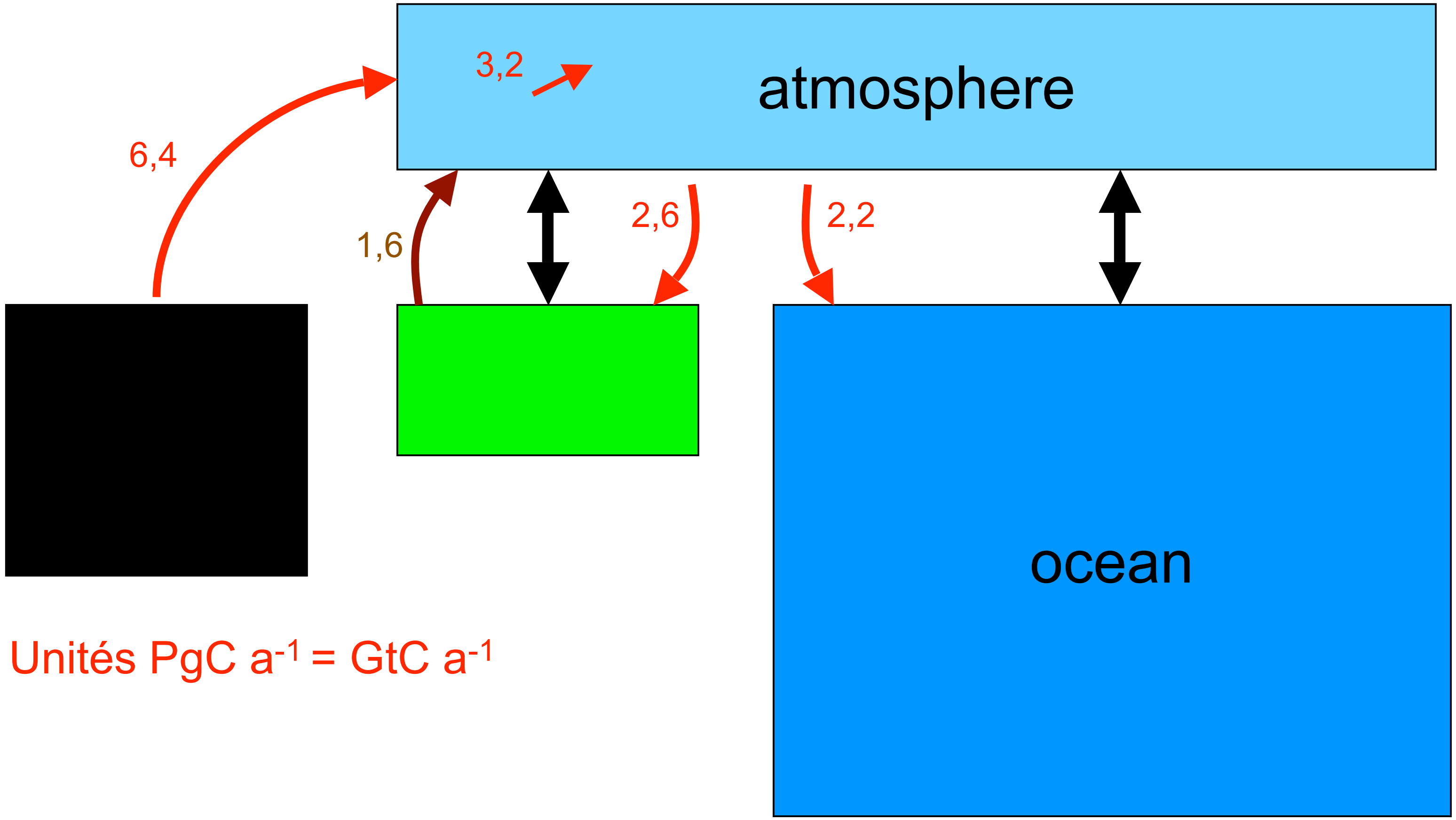


Atmospheric accumulation = drives global warming
atmosphere
Emissions
Land use
deforestation
Land
sink
ocean
sink
Fossil
carbon
(geological)
Vegetation
et sols
ocean

Le cycle du carbone pendant l'Anthropocène



The carbon cycle offers a discount of 50% on the additional greenhouse effect



Where does the fossil carbon go ? (2000-2006)

45% of all CO_2 emissions accumulate in the atmosphere

The Airborne Fraction

The fraction of the annual anthropogenic emissions that remains in the atmosphere

55% were removed by natural sinks

Ocean removes _ 24%

Land removes _ 30%

Canadell et al. 2007, PNAS

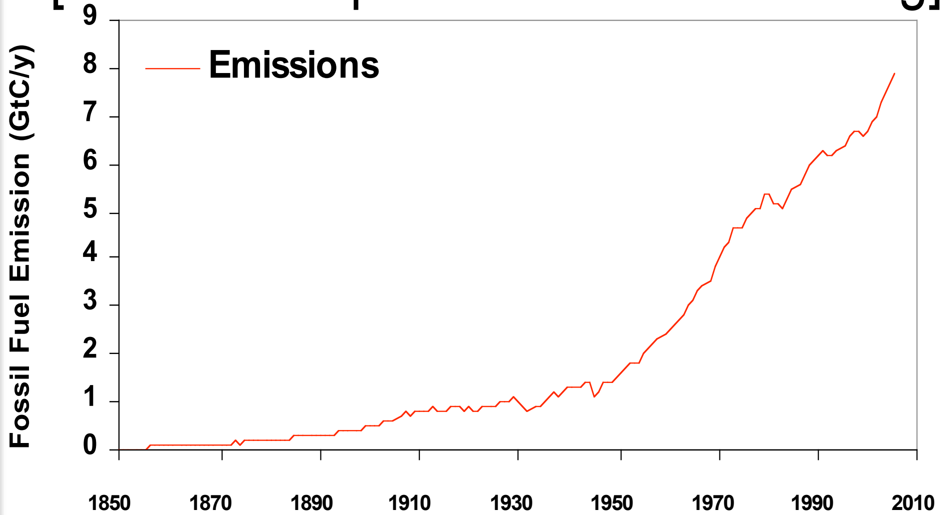
Big issues

- Where does the fossil carbon go ?
- What are the physical / chemical / biological processes
- Where will the fossil carbon go in the the future

Anthropogenic C Emissions: Fossil Fuel

2006 Fossil Fuel: 8.4 Pg C

[Total Anthrop.Emis.:8.4+1.5 = 9.9 Pg]

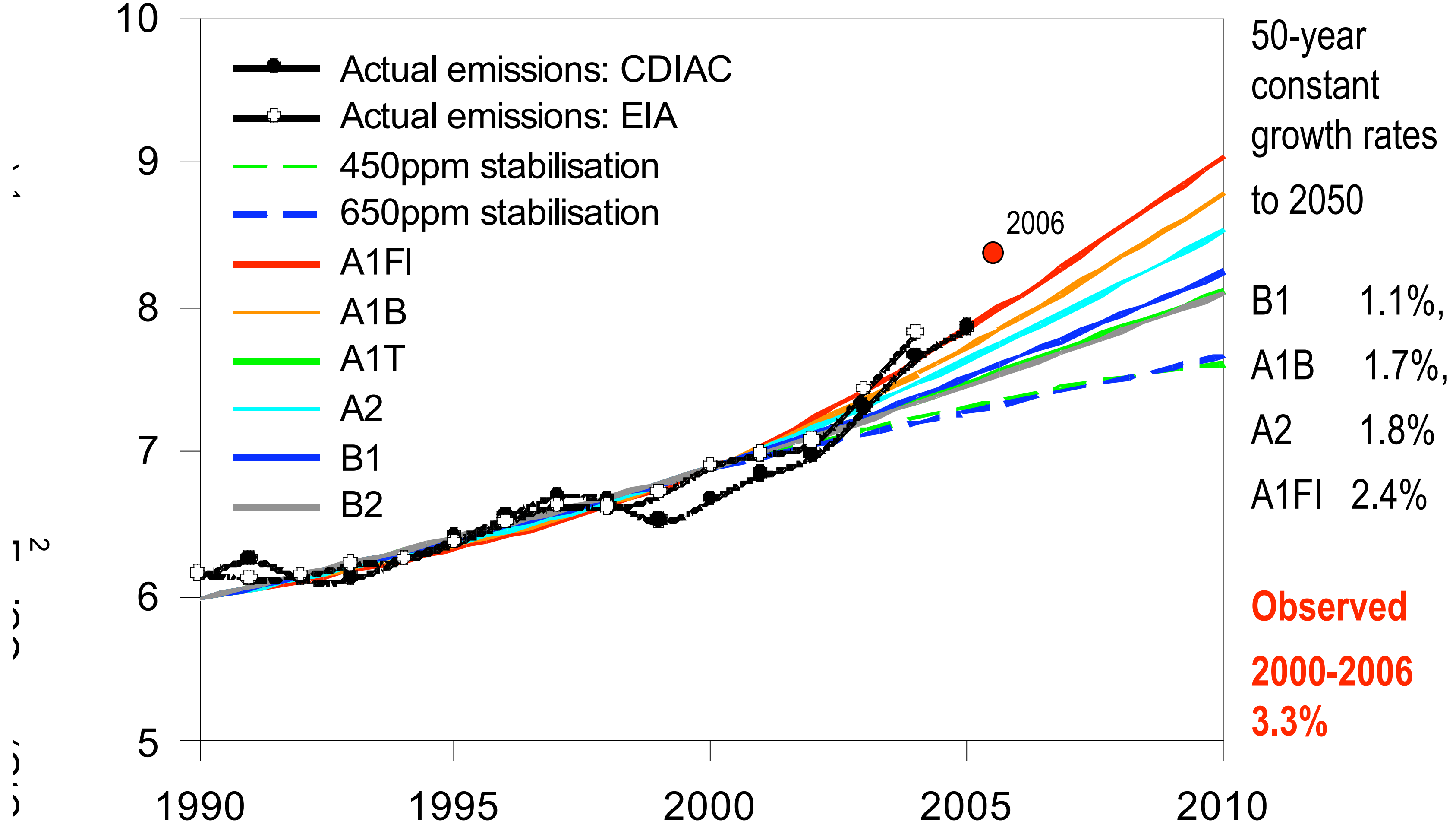


1990 - 1999: 1.3% y^{-1}

2000 - 2006: 3.3% y^{-1}

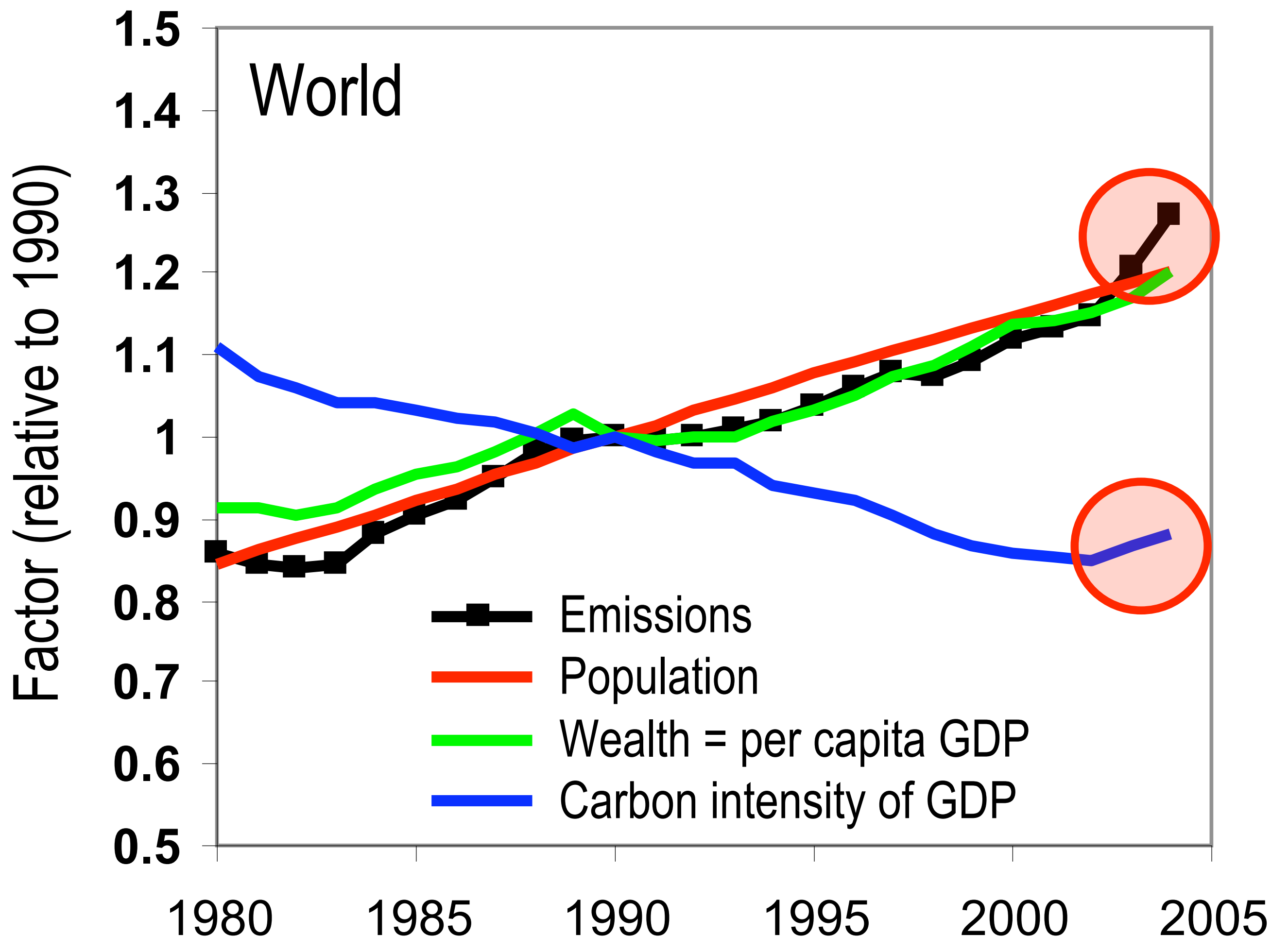
Raupach et al. 2007, PNAS; Canadell et al 2007, PNAS

Trajectory of Global Fossil Fuel Emissions



Raupach et al. 2007, PNAS; Canadell et al. 2007, PNAS

Anthropogenic C Emissions: Carbon Intensity of GDP



Raupach et al 2007, PNAS

Anthropogenic C Emissions: Land Use Change

Borneo. Courtesy: Viktor Boehm

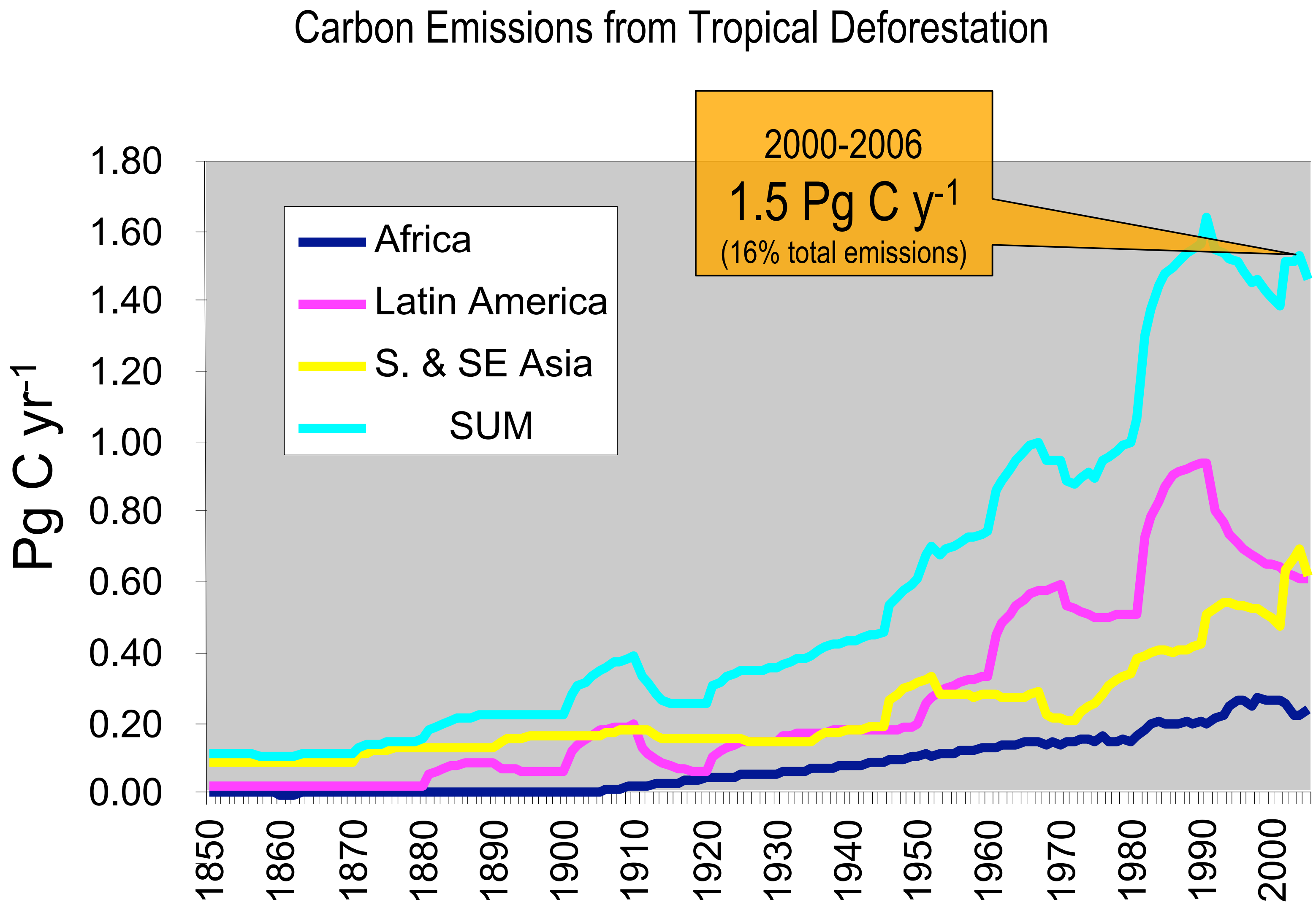
Tropical deforestation

13 Million hectares each year

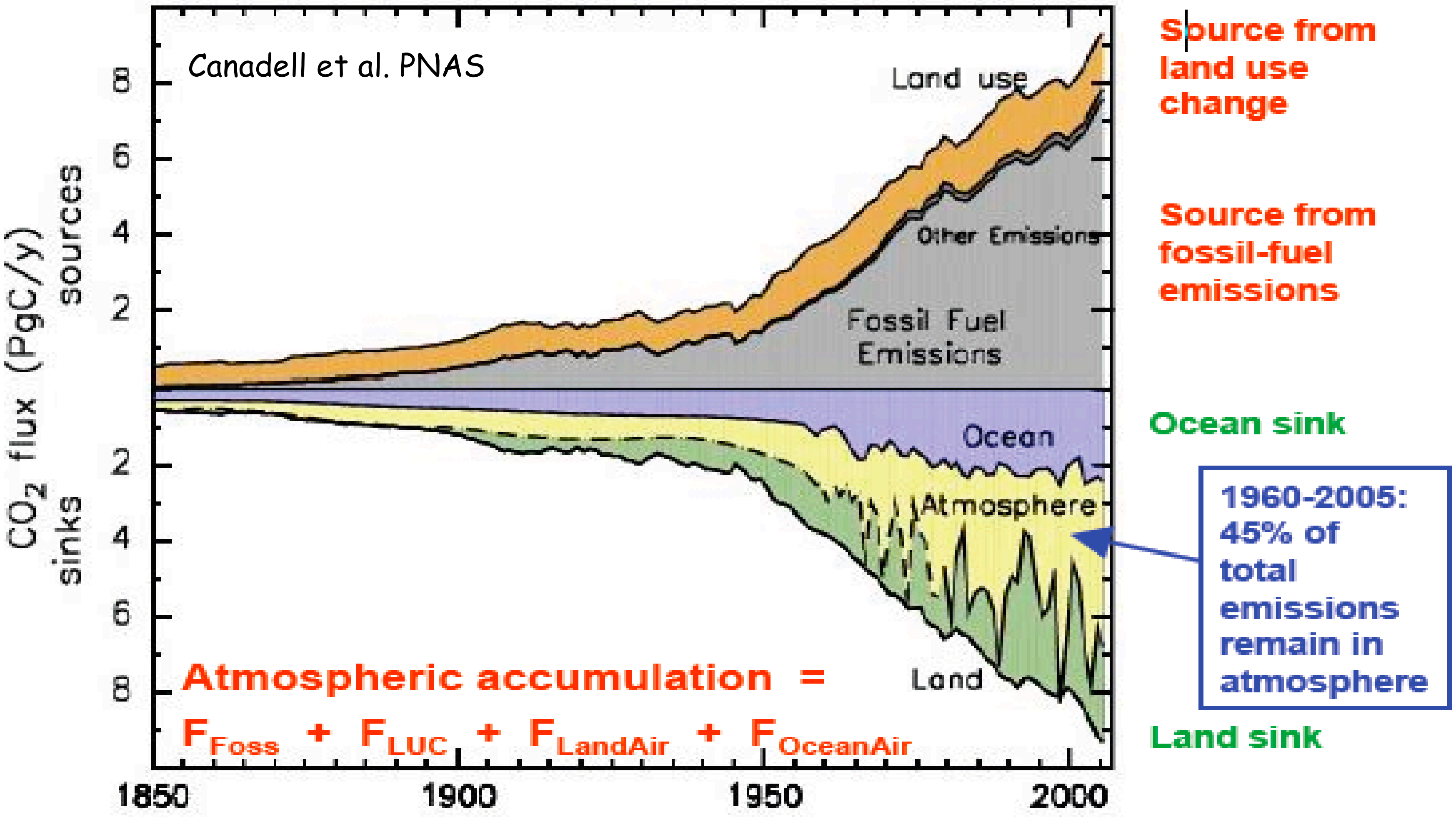
	2000-2005
Tropical Americas	0.6 Pg C y^{-1}
Tropical Asia	0.6 Pg C y^{-1}
Tropical Africa	0.3 Pg C y^{-1}
	1.5 Pg C y^{-1}

FAO-Global Resources Assessment 2005; Canadell et al. 2007, PNAS

Anthropogenic C Emissions: Land Use Change



Houghton, unpublished



Airborne fraction AF = atm accumulation / (F_{fos} + F_{LUC})

Mean increase in AF of 1% per 1958 - 2006

The Airborne Fraction (2000-2006)

45% of all CO_2 emissions accumulated in the atmosphere

The Airborne Fraction

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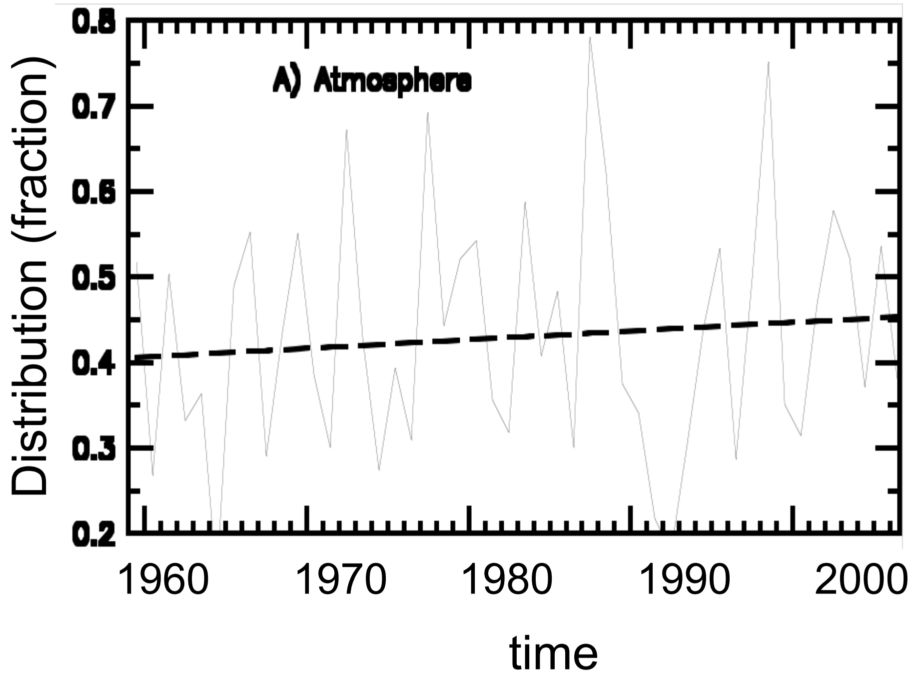
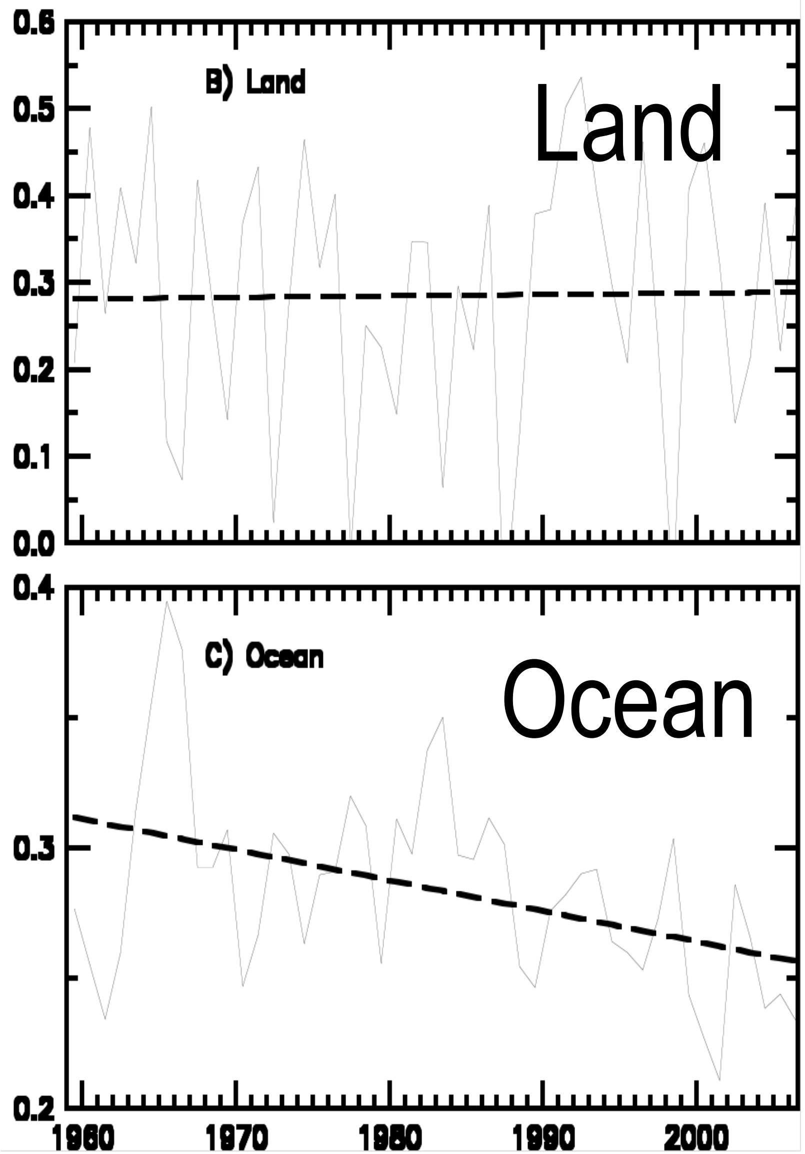
Canadell et al. 2007, PNAS

Time Dynamics of the Airborne Fraction, Land and Ocean Fractions



Observed
Airborne Fraction
10% Increase
(p = 0.89)



Canadell et al. 2007, PNAS, in press

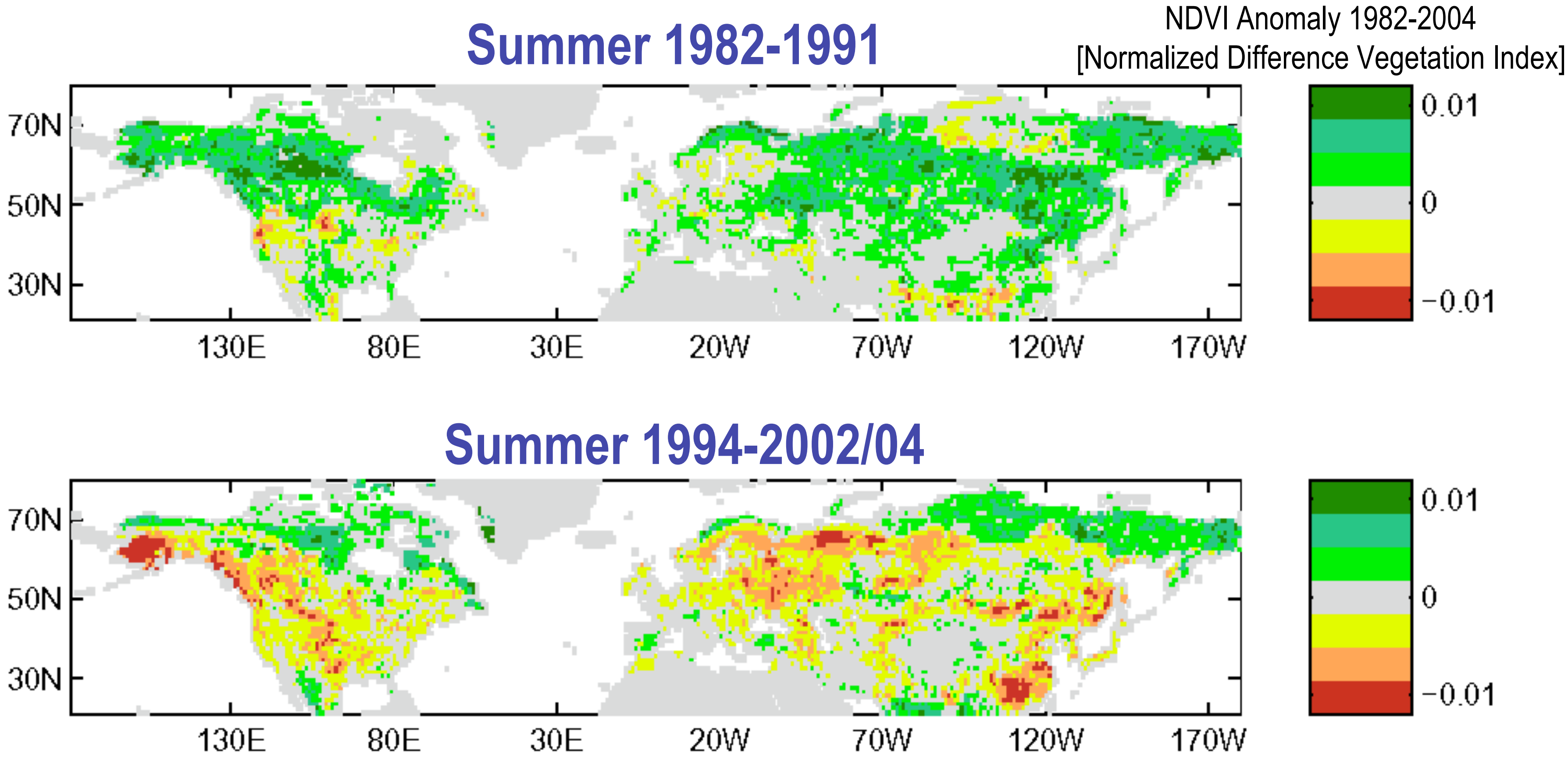
Causes of the Declined in the Efficiency of the Ocean Sink

- Part of the decline is attributed to up to 30% decrease in the efficiency of the Southern Ocean sink over the last 20 years.
- This sink removes annually 0.3±0.2 Pg of anthropogenic carbon.
- The decline is attributed to the strengthening of the winds around Antarctica which enhances ventilation of natural carbon-rich deep waters.
- The strengthening of the winds is attributed to global warming and the ozone hole

Le Quéré et al. 2007, Science

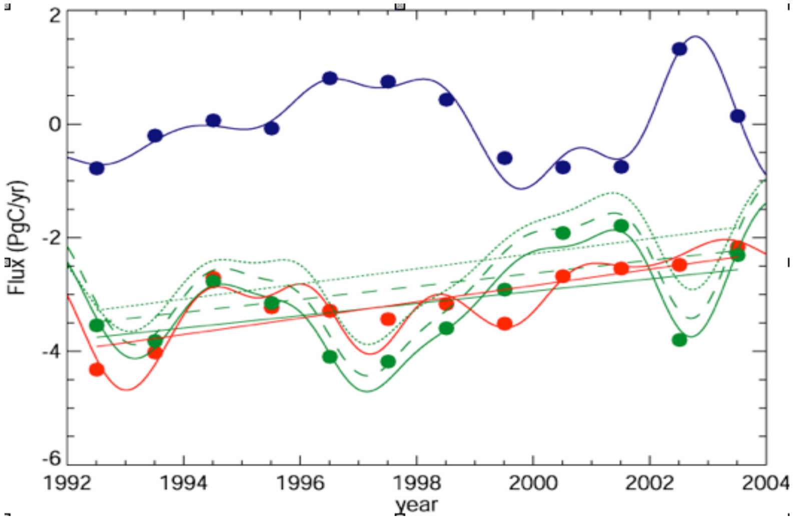
Drought Effects on the Mid-Latitude Carbon Sink

A number of major droughts in mid-latitudes have contributed to the weakening of the growth rate of terrestrial carbon sinks in these regions.



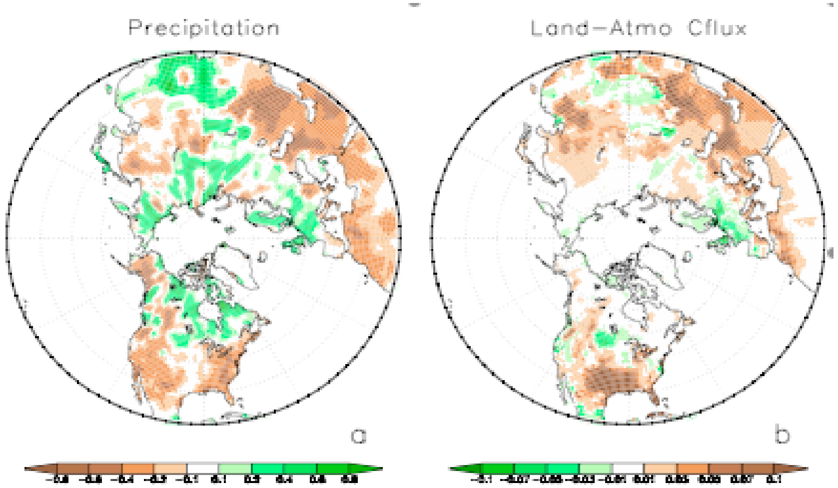
Angert et al. 2005, PNAS; Buermann et al. 2007, PNAS; Ciais et al. 2005, Nature

A northern Terrestrial sink decrease ?



^{13}C latitudinal gradients inverted in double deconvolution (Miller et al. pers. com.)

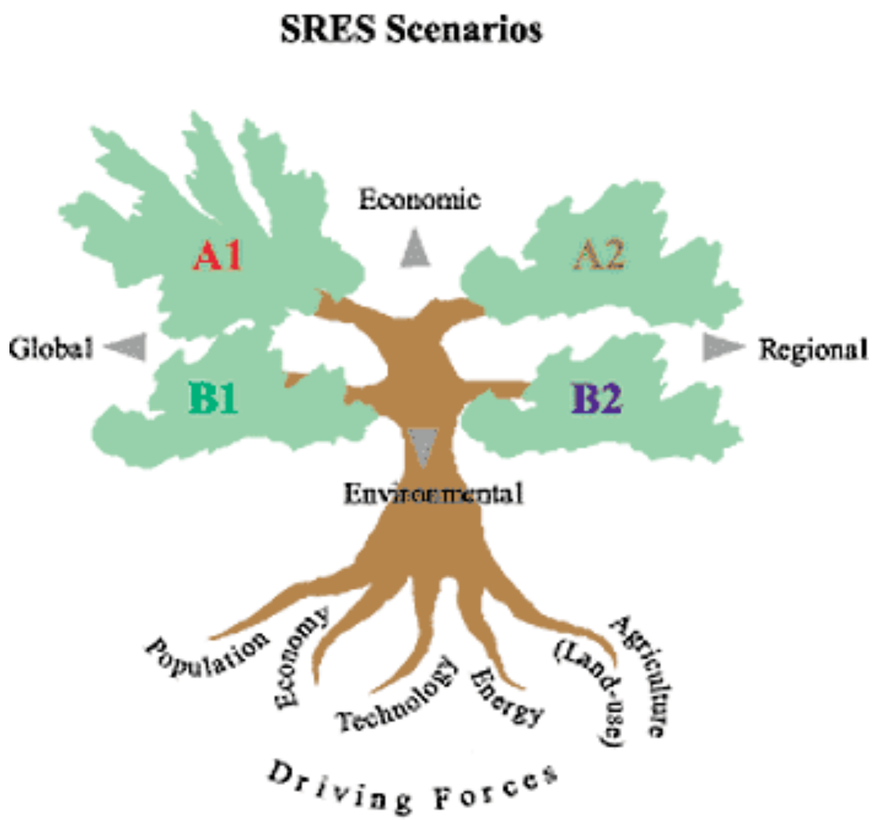
Anomalies for the period June 1998 to May 2002 relative to climatology (Zheng et al. 2004)



The constant global Land-absorbed fraction suggests ….

… An increasing tropical land sink ?

Back to the future
The IPCC approach :
Scenarized emission scenarios based on economic development pathways

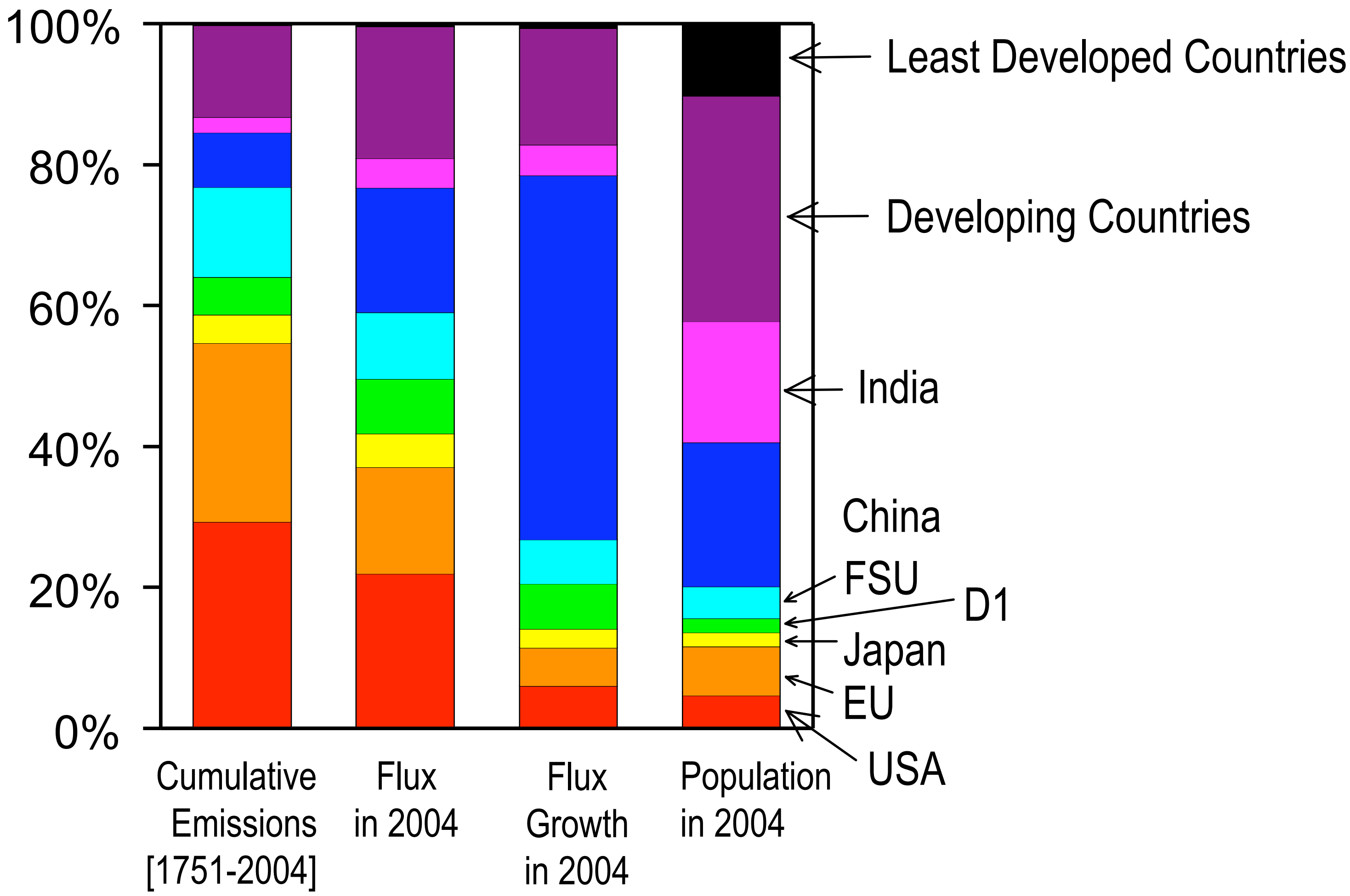


Are the emissions poised to increase ?

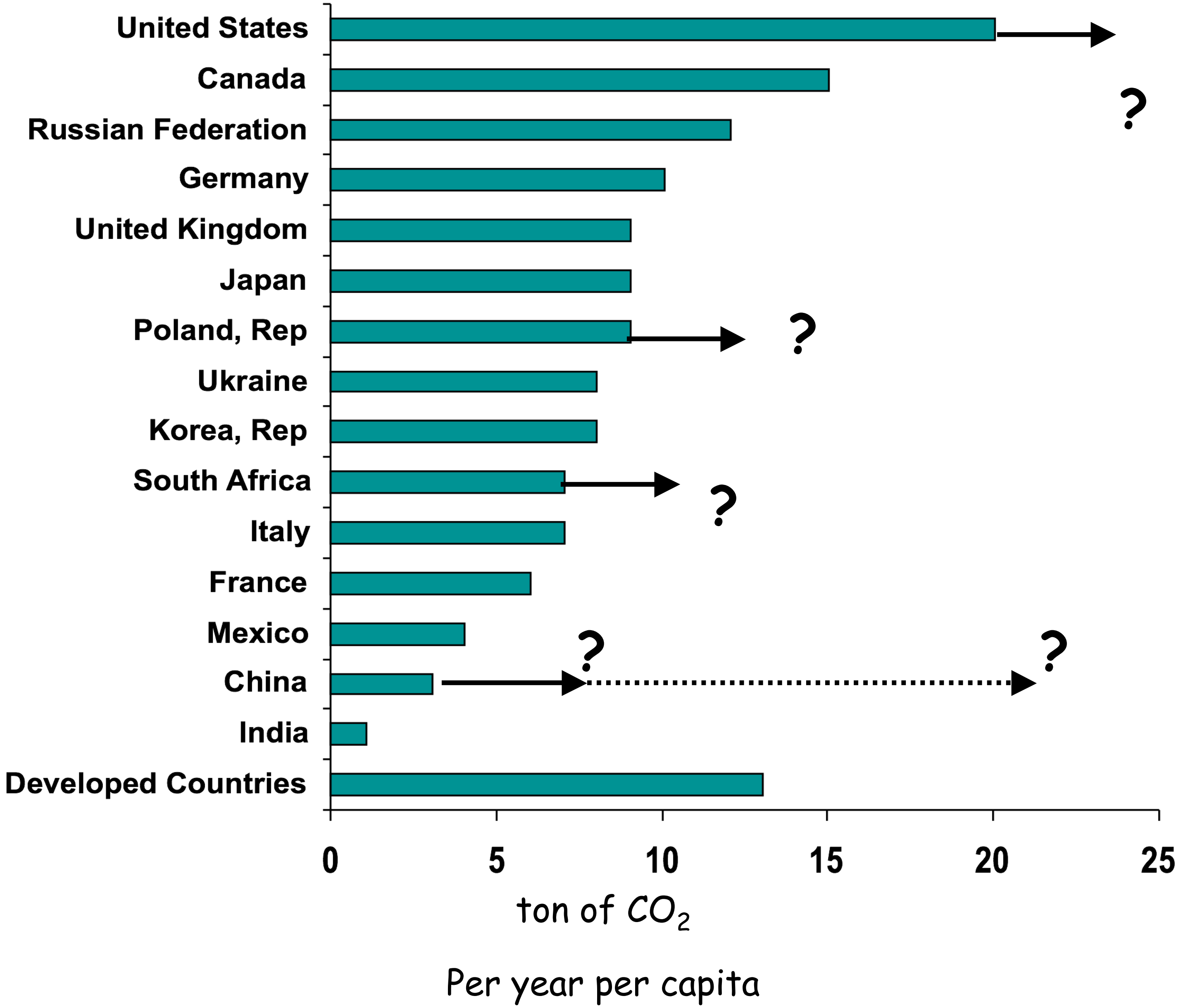
Is there enough fossil Carbon ?

How will the land and ocean sink change ?

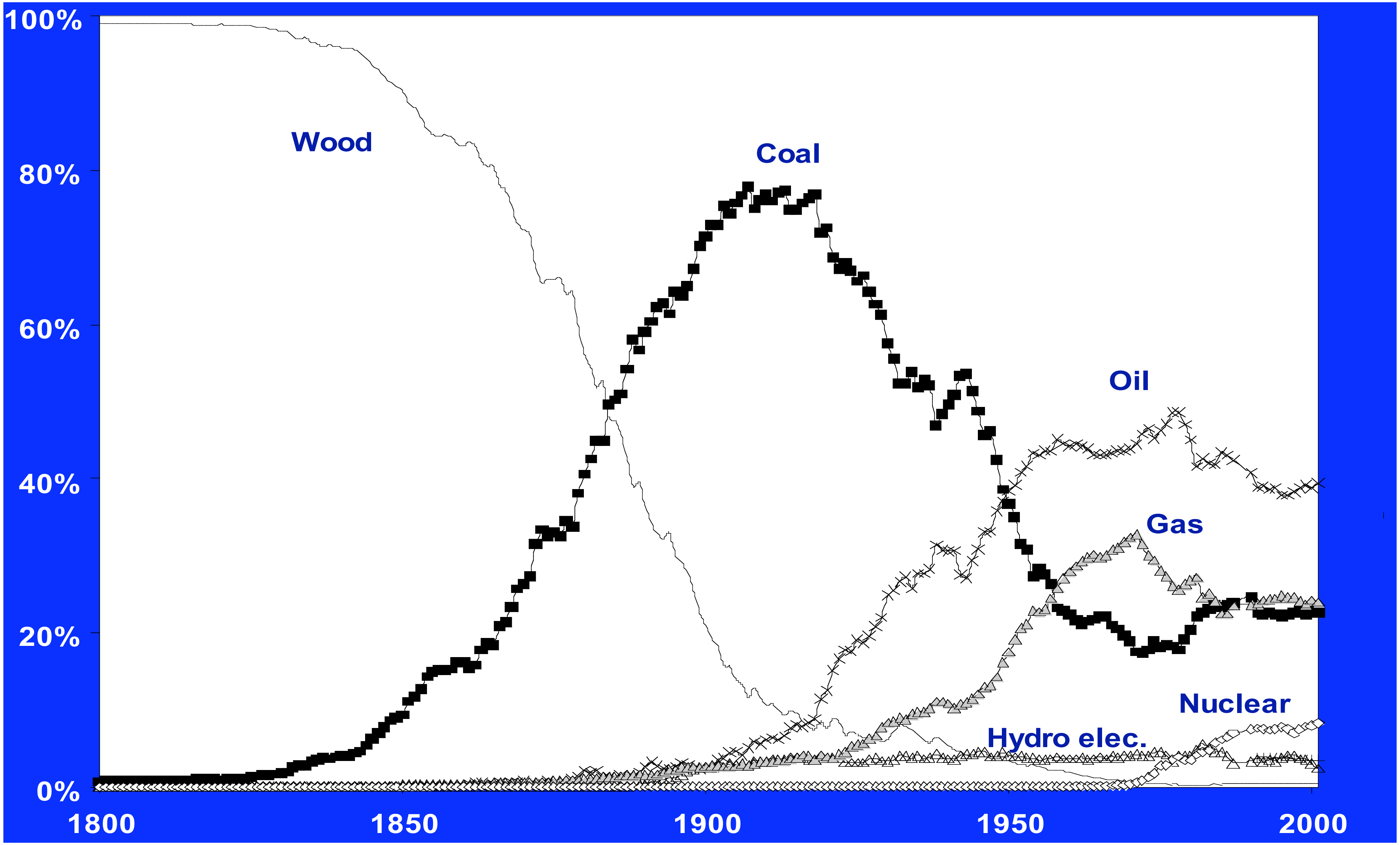
Back to the future :
Anthropogenic C Emissions trends



Per capita emissions, still a large potential to increase In the future, with increasing wealth

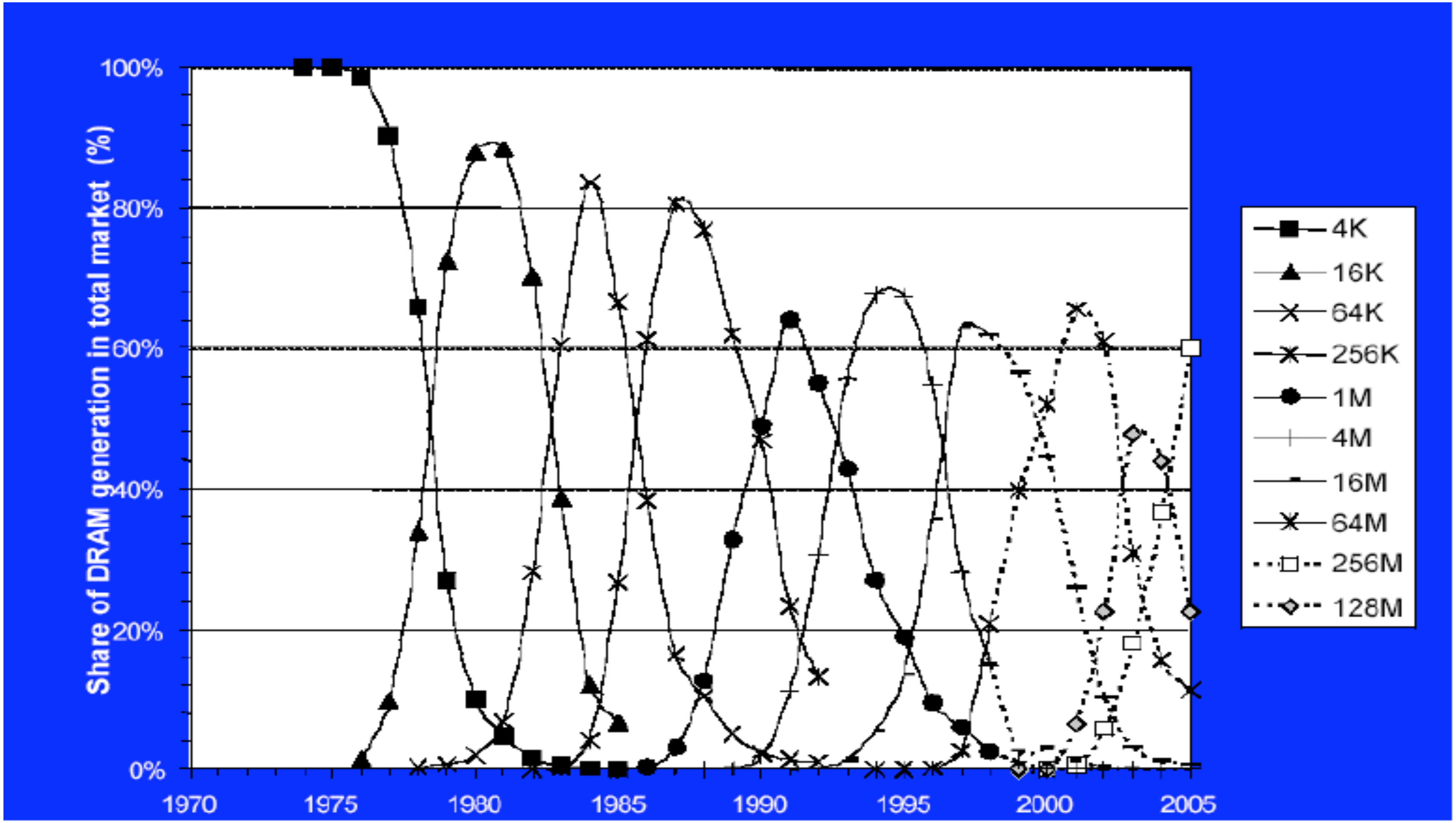


Slow changes in energy production technologies



Source: Nakicenovic and Grubler; IIASA

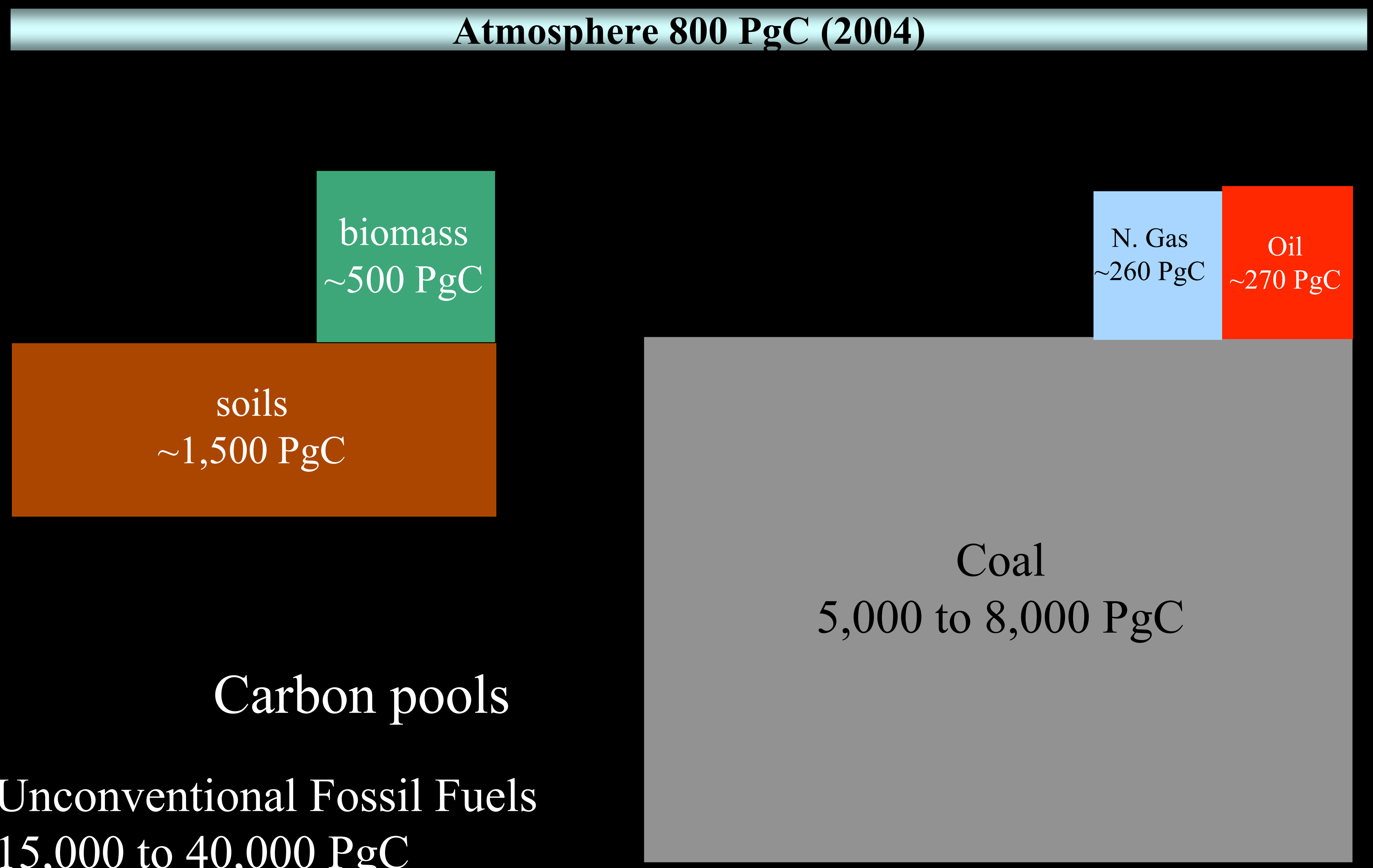
Unlike fast technological innovation in other sectors (here example of electronic industry)



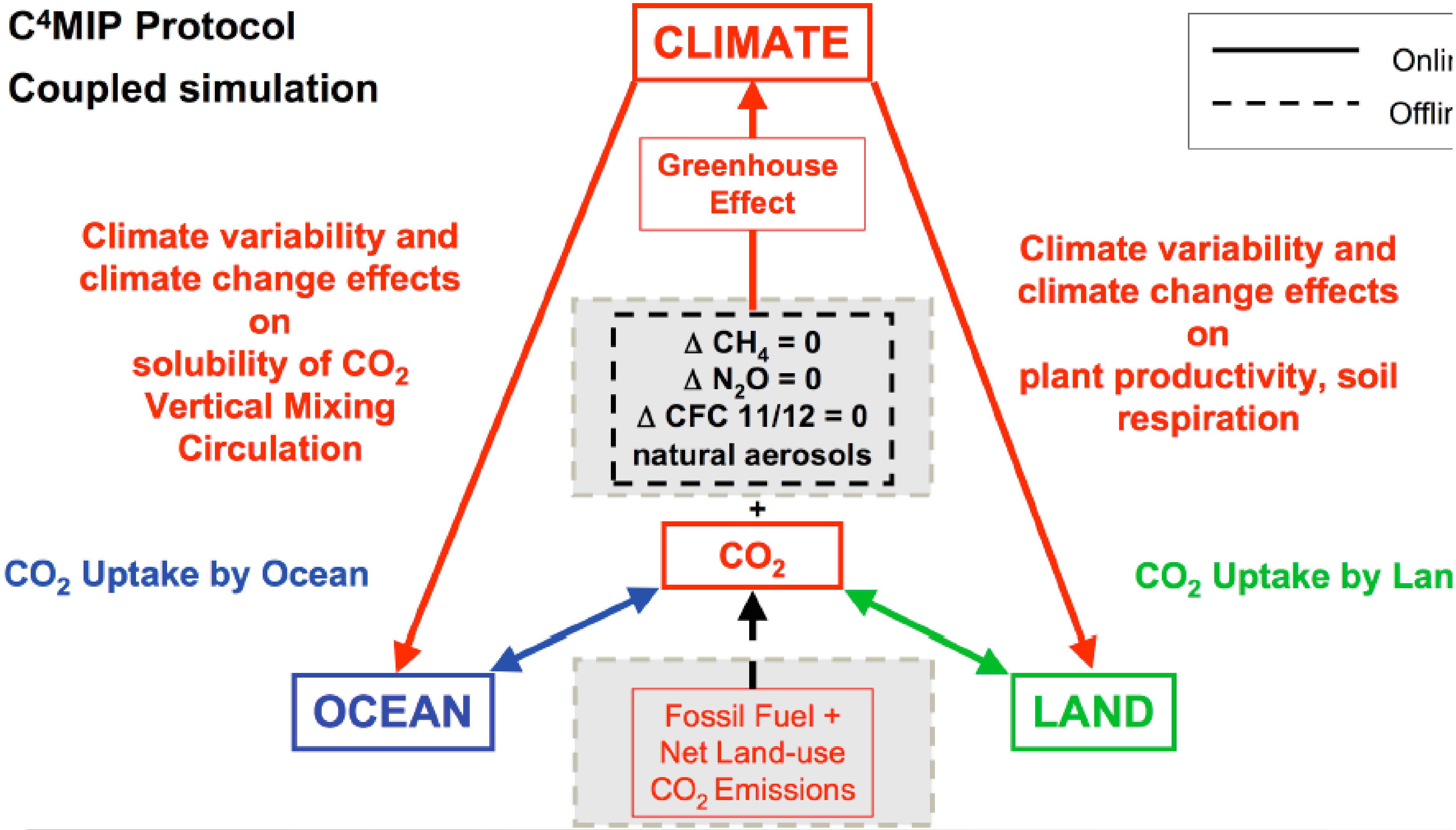
Source: Ausubel and N. V

Still huge amounts of fossil C available as energy sources

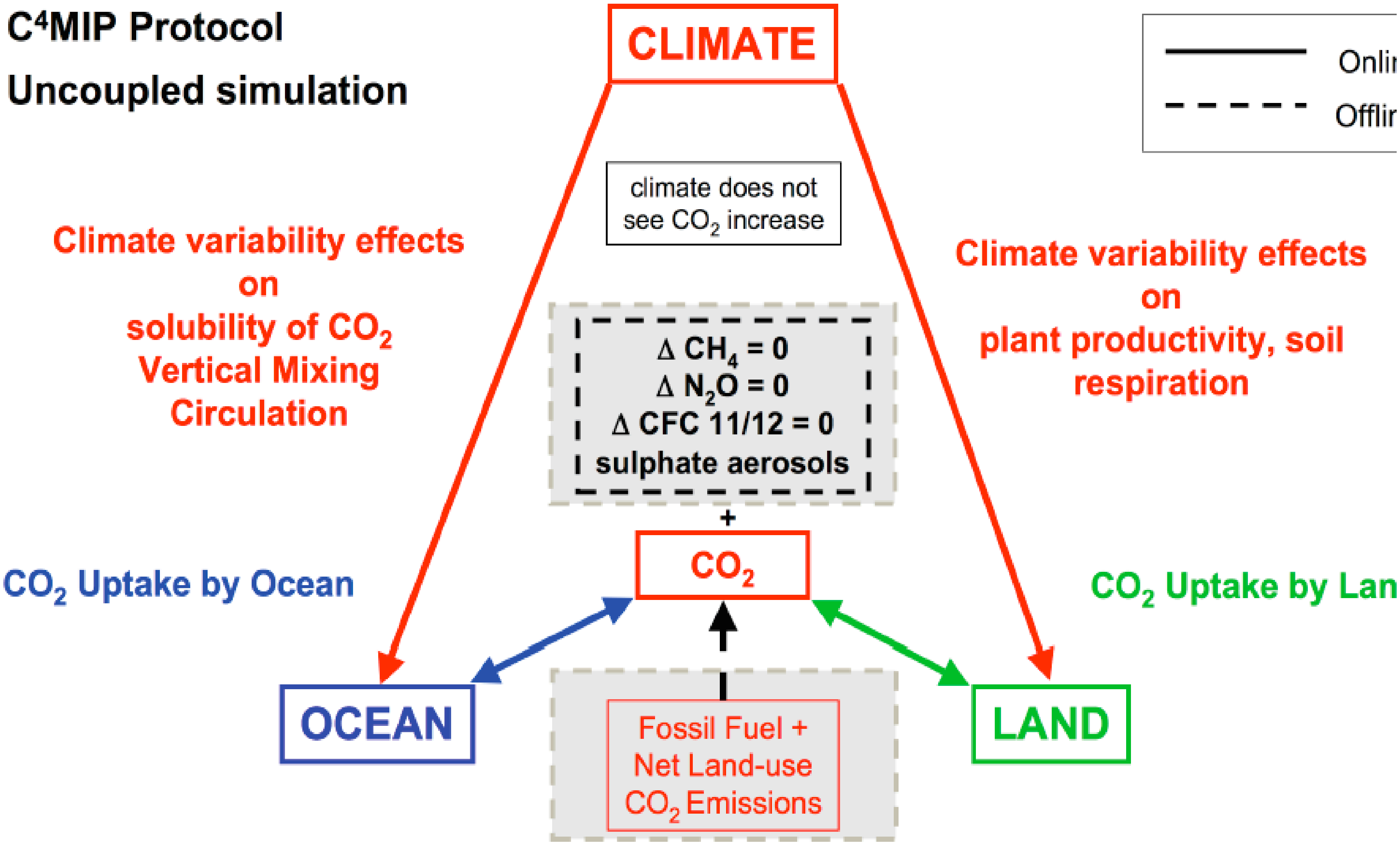
The adition of fossil C in the cycle is not reversible within 10^5 years



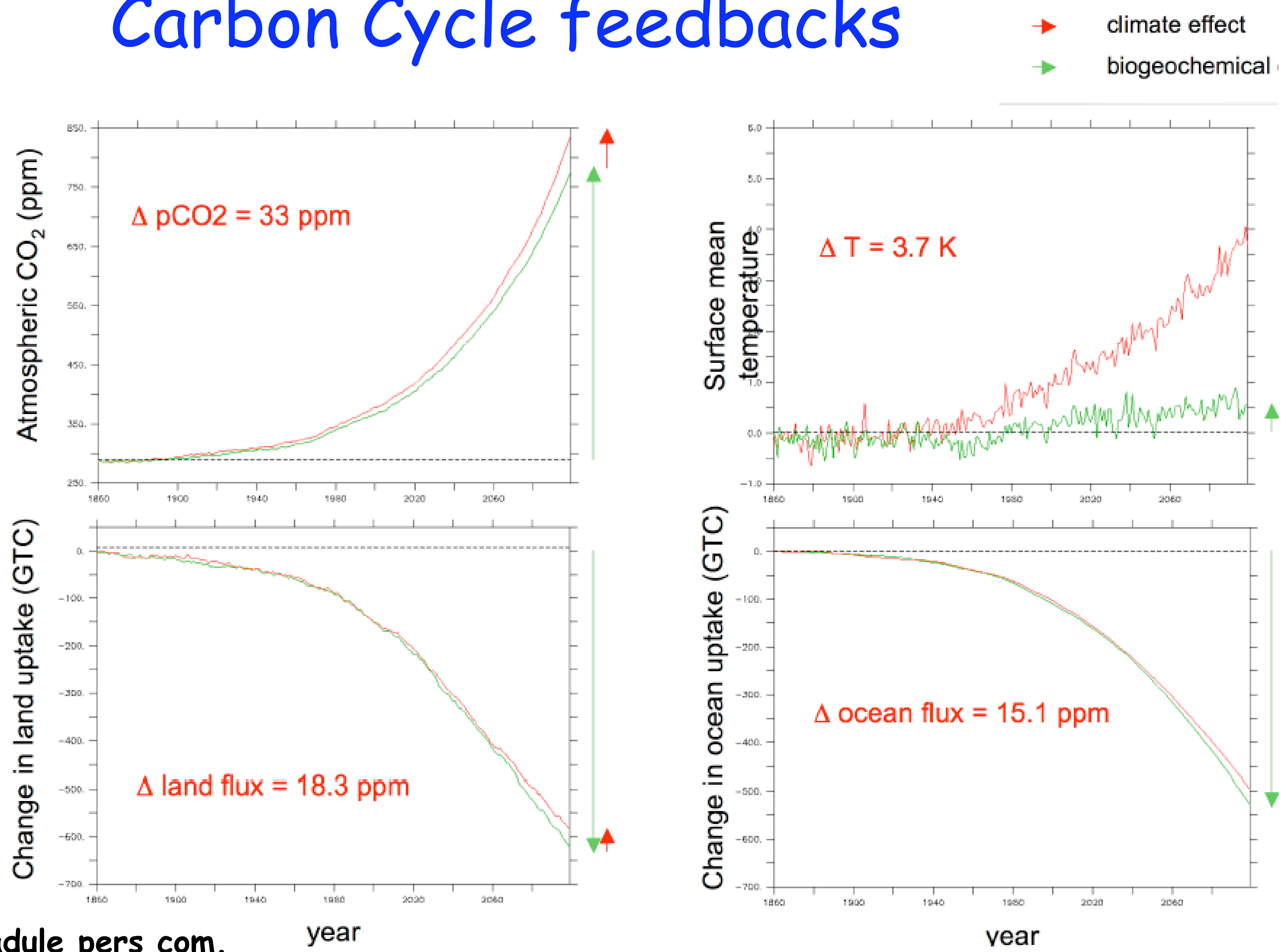
Predicting the future : the coupled carbon - climate system



Predicting the future : uncoupled sensitivity simulation



Carbon Cycle feedbacks

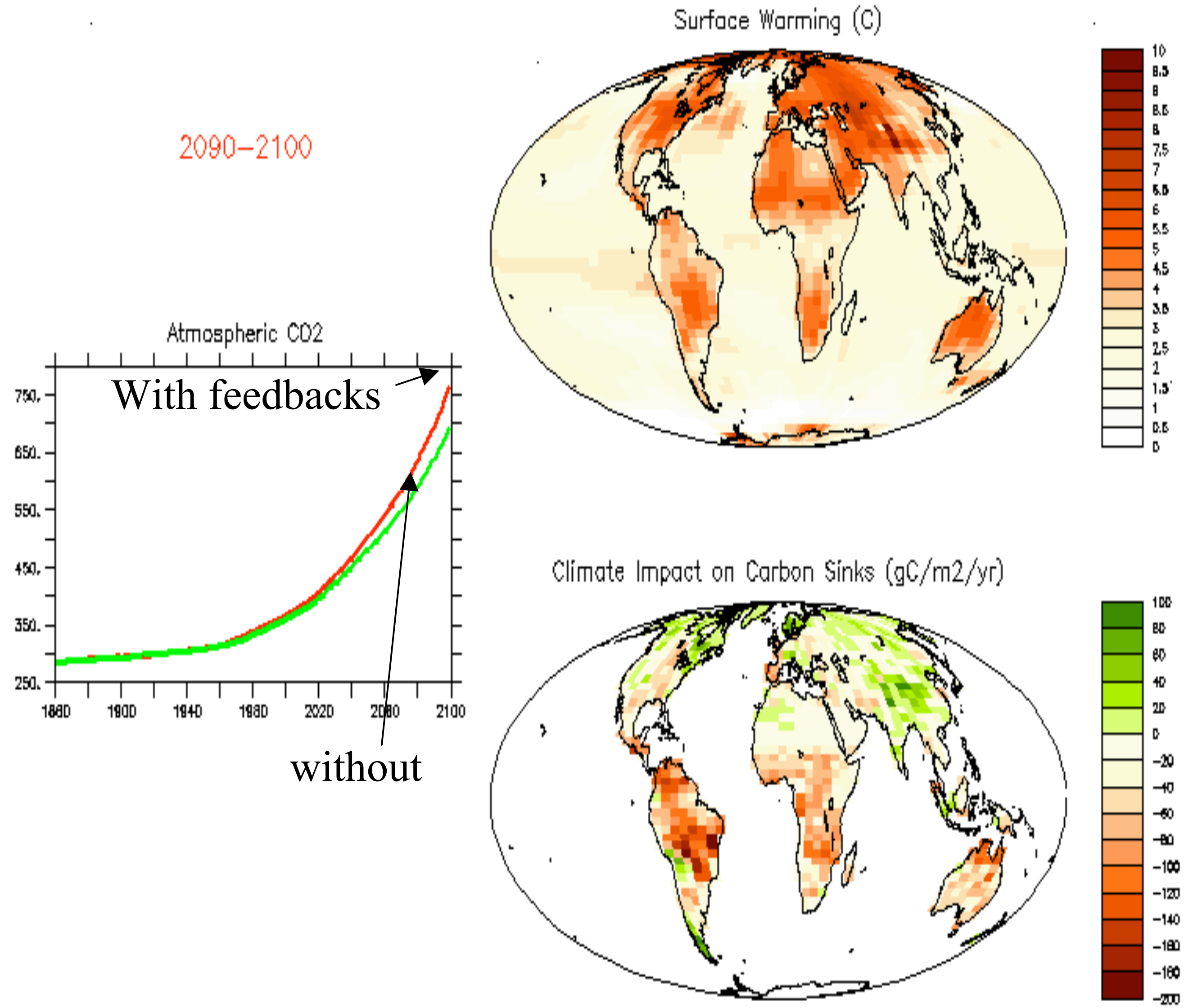


P. Cadule pers com.

All models indicate positive terrestrial carbon -cycle feedbacks models

- The Carbon cycle gives a positive feedback to climate change

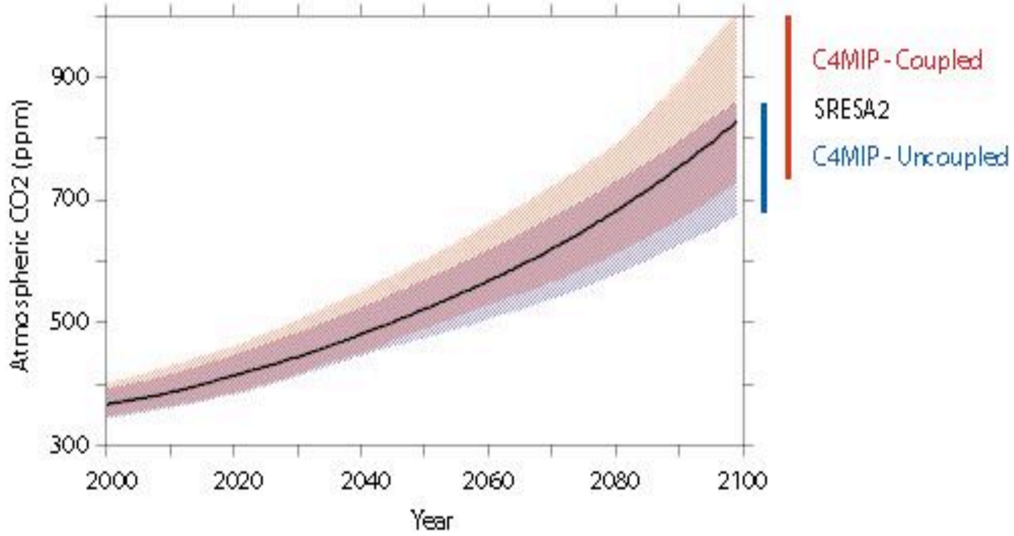
- Carbon cycle feedbacks increase the risks of meeting tipping points of the climate system

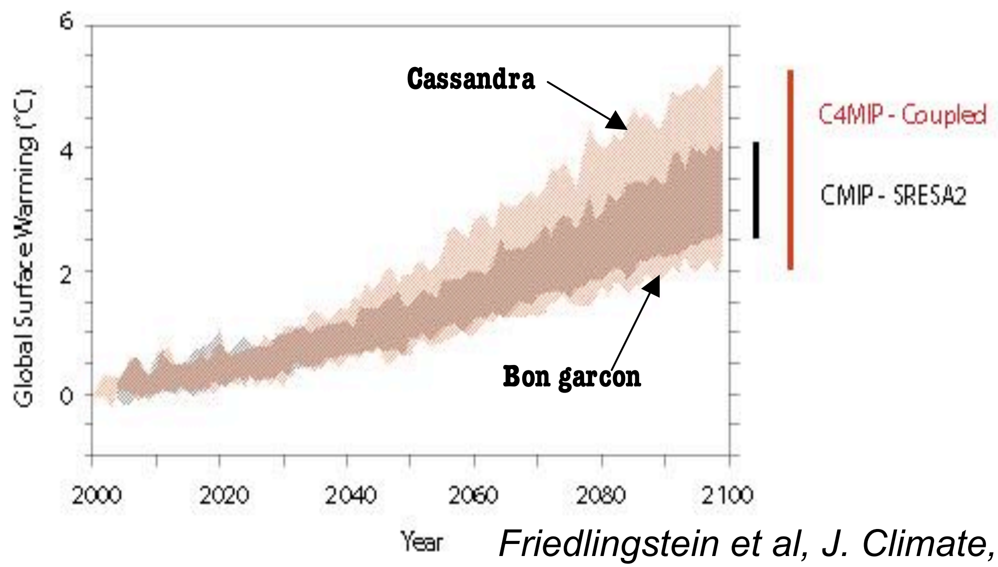


Coupling carbon cycle with climate increases the projected warming and its uncertainty

- There is a large ‘biogeochemical’ uncertainty on projected CO_2
- This uncertainty is comparable to economic scenario uncertainty
- CO_2 coupled > CO_2 uncoupled

Are models ‘bon garçons’ or ‘Cassandra’ ?



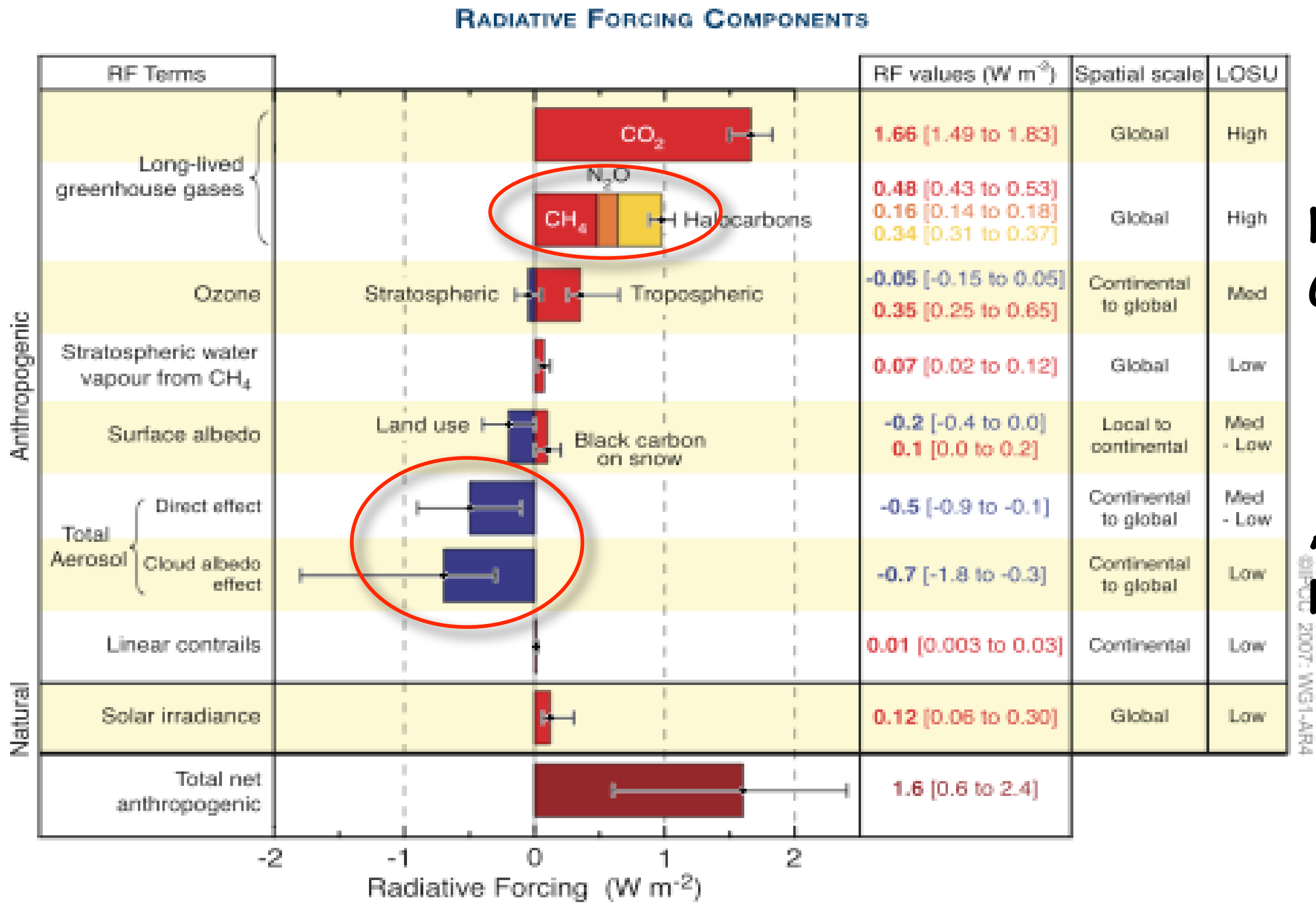


Friedlingstein et al, J. Climate, 2006

Is that all ?

No

The new frontier
carbon feedbacks caused by other radiative species

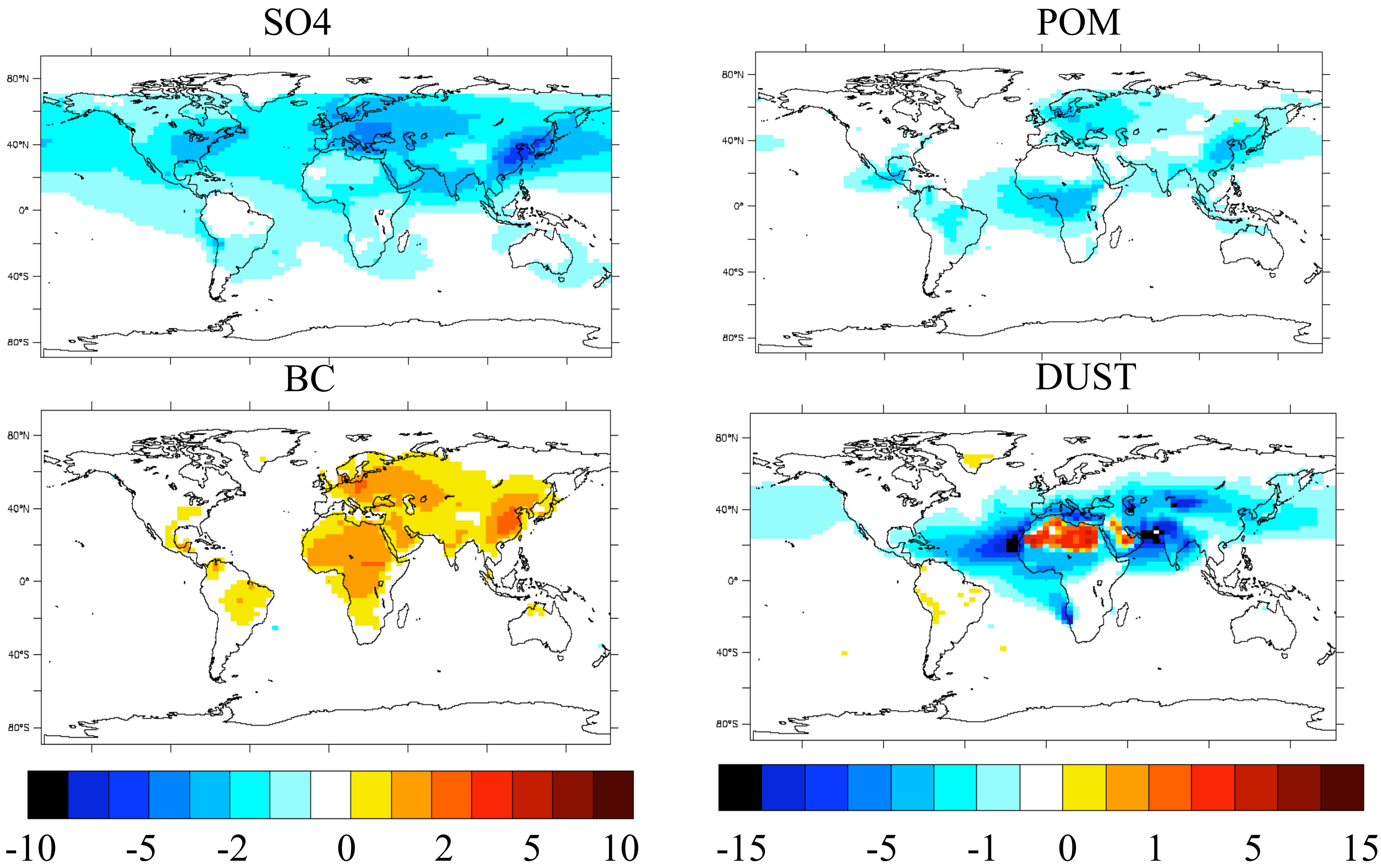


Non CO2 GHG
Global warming

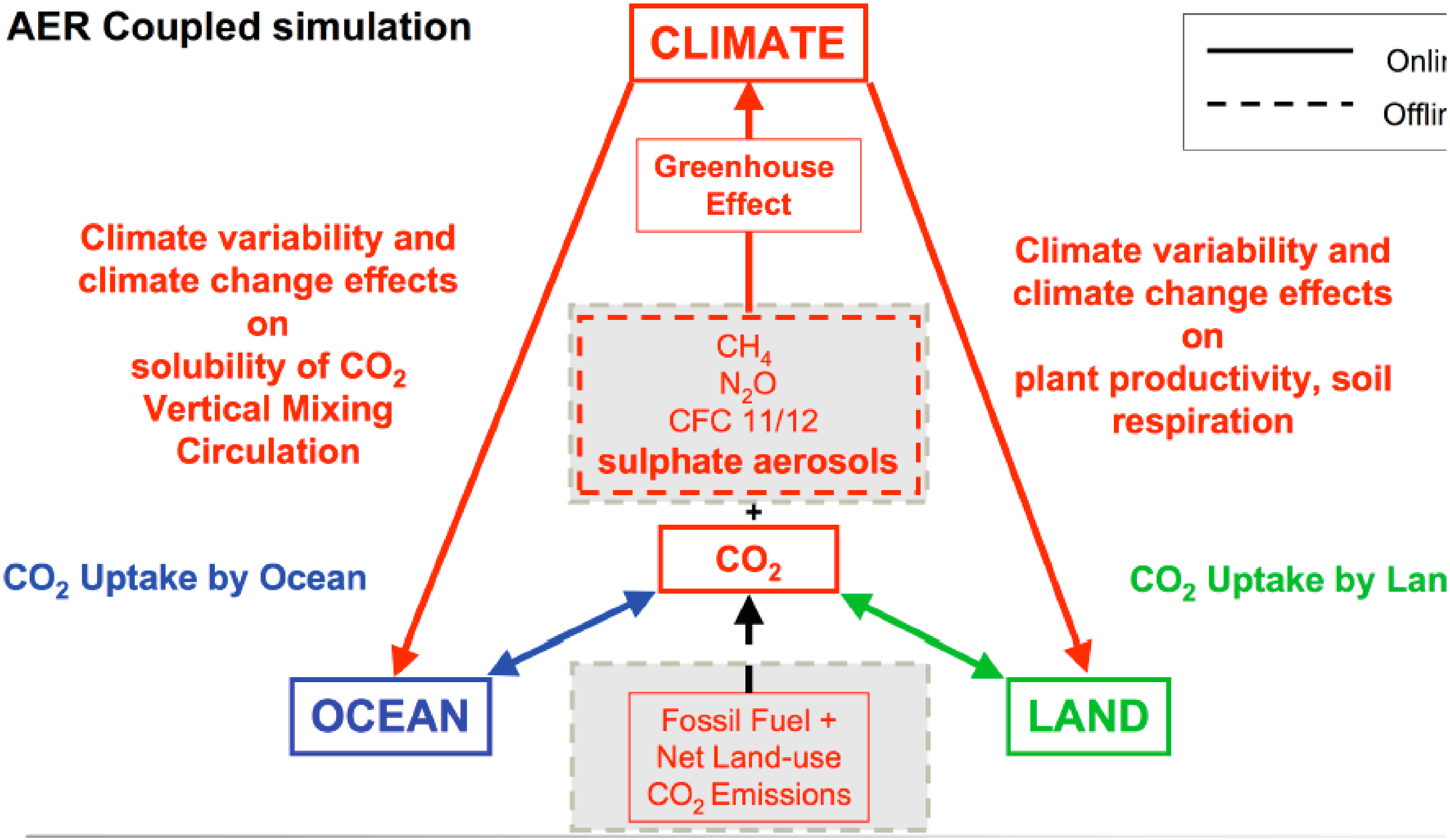
Aerosols
Regional cooling

Total : + 1.6 Wm^{-2} ; CO_2 : + 1.6 Wm^{-2}

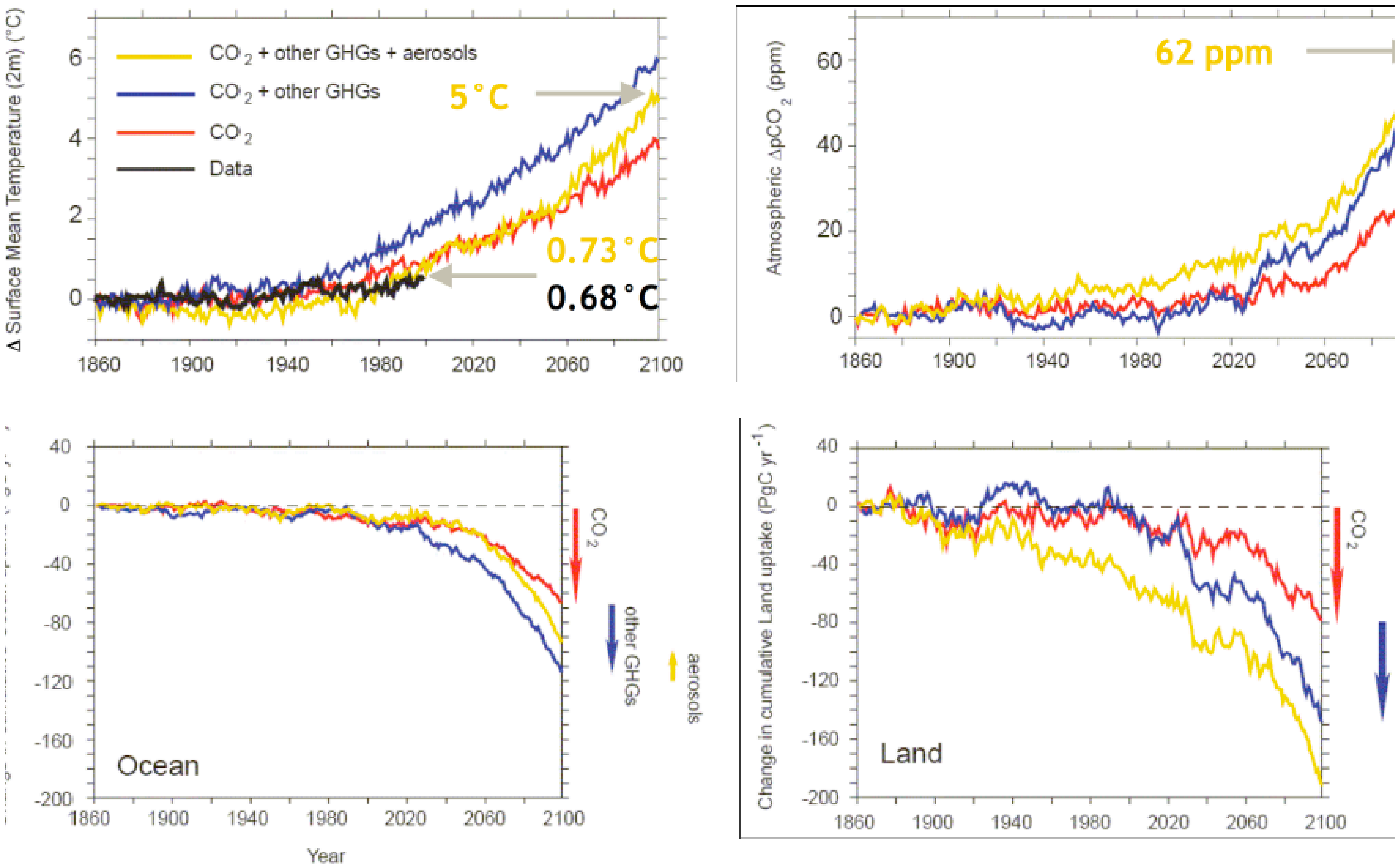
Direct radiative forcing of aerosols ($W.m^{-2}$)
Locally very high + high regional contrasts



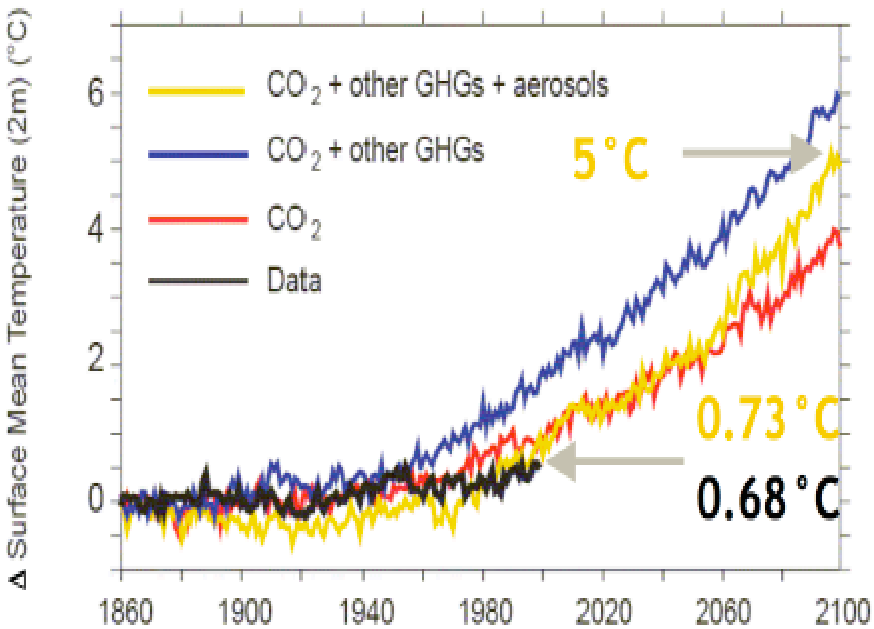
Adding other greenhouse gases and sulfate aerosols

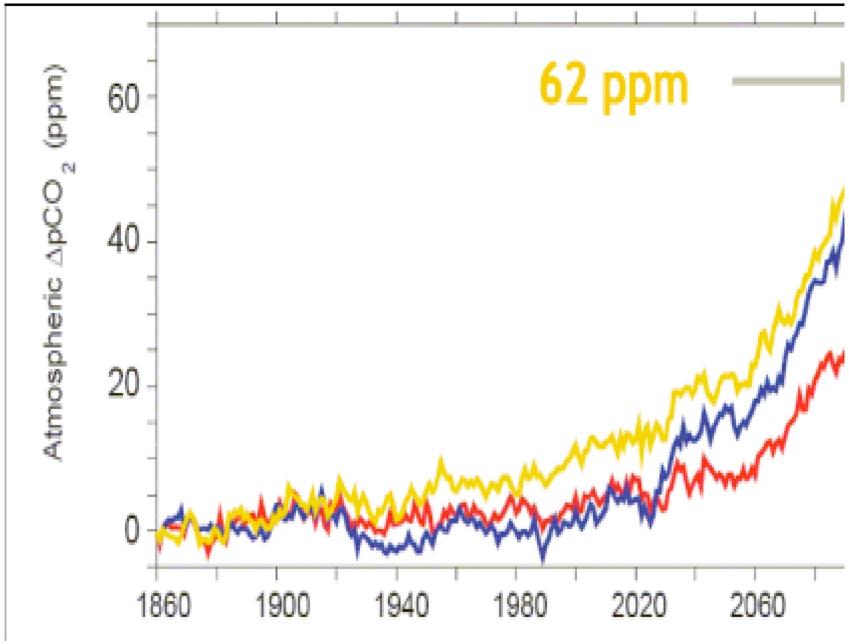


Role of sulfate aerosols



Role of sulfate aerosols





Unexpectedly the inclusion of aerosols increase atmospheric CO_2 by an additional 7 ppm by 2100

Including aerosols leads to a cooling of 0.51°C and causes an additional atmospheric CO_2 increase that reduces the initial cooling

Due to a reduction of NPP in northern forests by SO4 cooling

Conclusions

- Good news = Formidable resilience of carbon sinks to increased emissions
- Bad news = We begin to see a small weakening of the carbon cycle efficiency to clean up emissions
  - Northern terrestrial sink likely smaller
  - Possible that the tropical sink is intensifying (or the deforestation is deccelerating)
  - We do not have the observations to verify this
- It will take a major effort in the next century to reduce fossil fuel emissions
- Bad news = Natural carbon sinks are going to attenuate in response to global warming and to aerosols effects
- Regional trends in carbon sinks, through long data series of different nature
- Uncertainties are LARGE, we need new cohorts of carbon cycle researchers - please HELP US to train them !