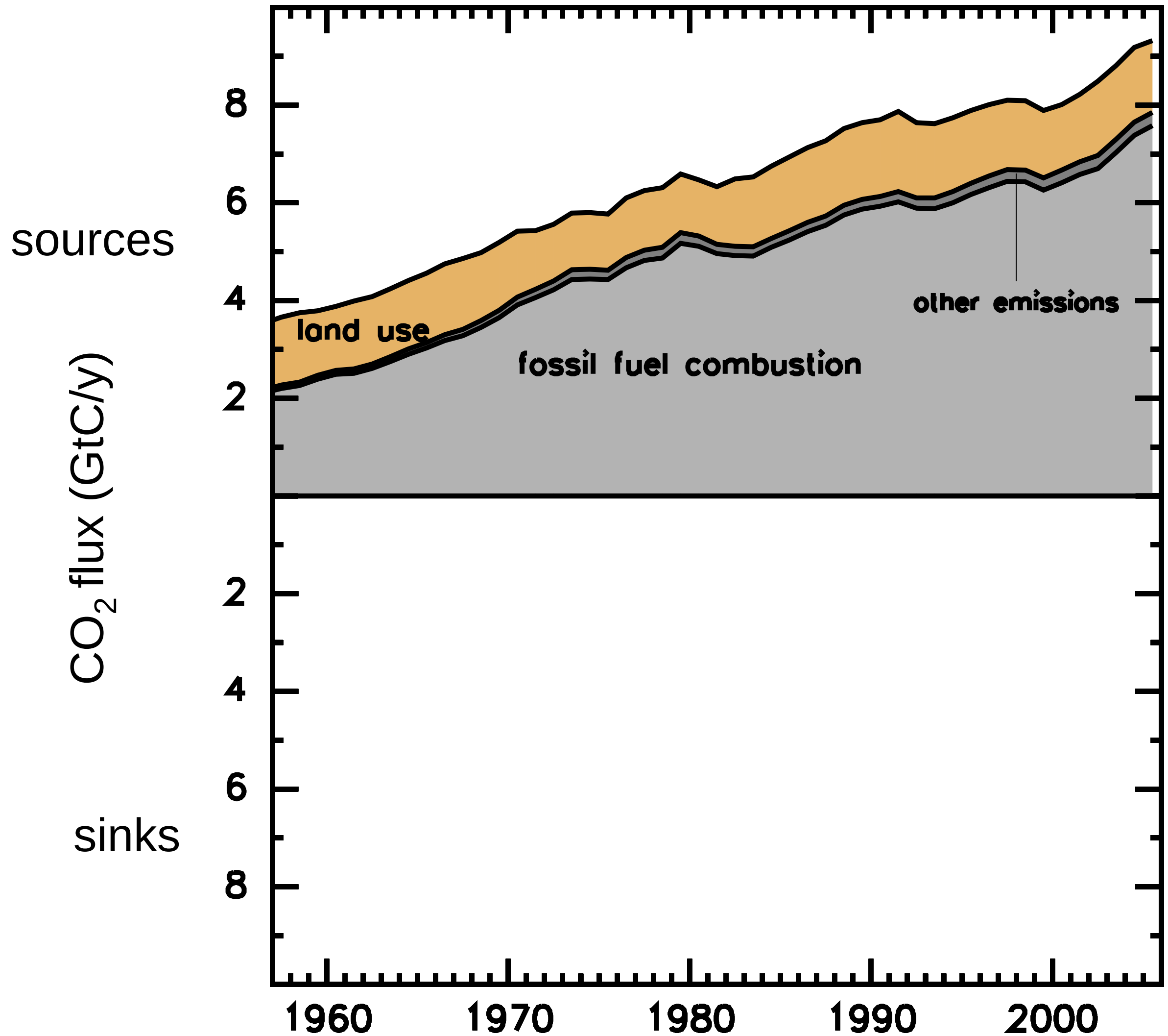
Climate-carbon feedbacks. Insights from coupled models.

Laurent Bopp (IPSL / LSCE)

Pierre Friedlingstein, Patricia Cadule,
Andrew Lenton, Corinne Le Quéré….

PATHWAYS FOR GREENHOUSE GAS EMISSIONS:
THE GAP BETWEEN ECONOMIC PRACTICALITY AND ENVIRONMENTAL NECESSITY
26 Septembre 2008 – Observatoire de Paris

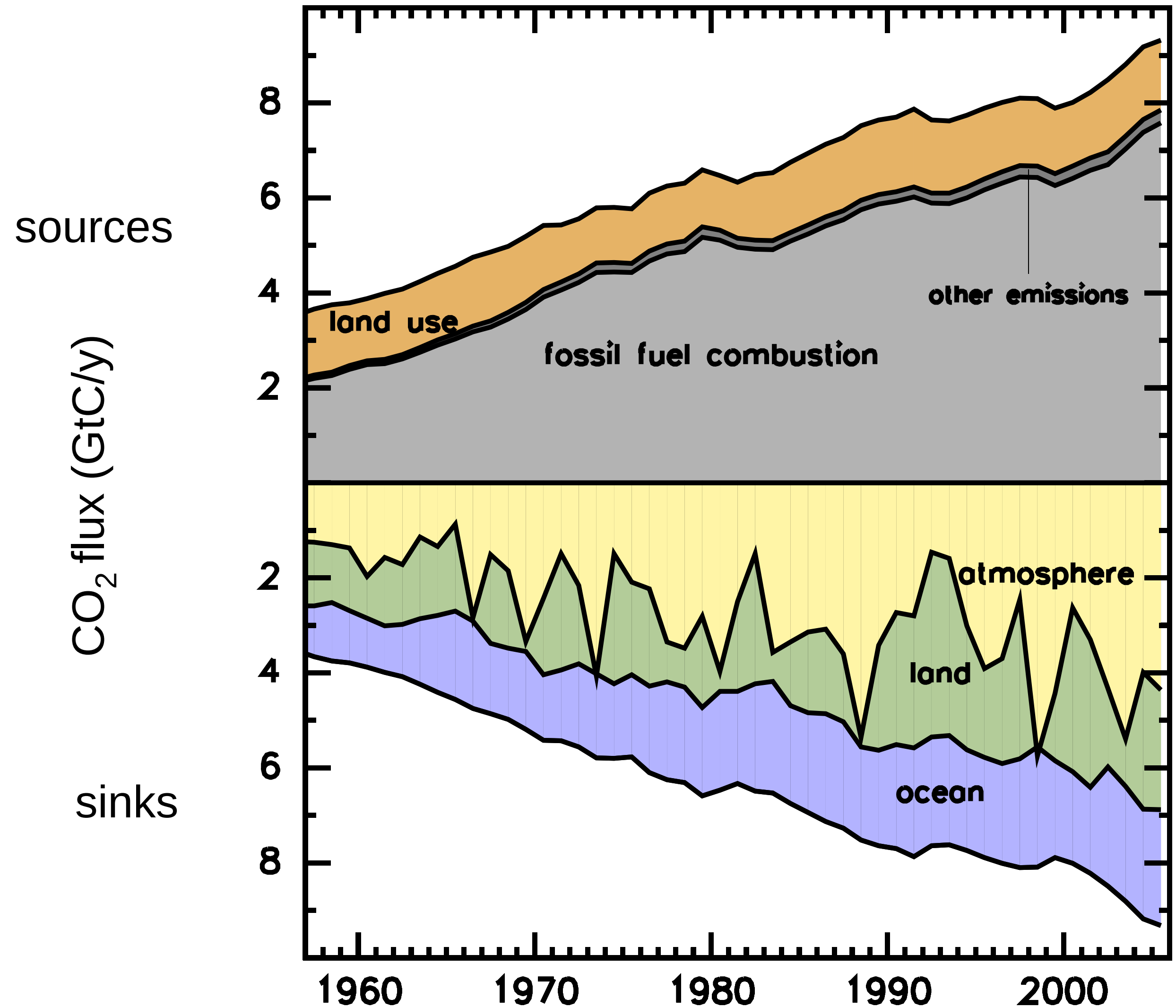
Carbon Budget (1958-2008)



Atm. CO_2 Concentration = Emissions – Ocean Sink – Land Sink

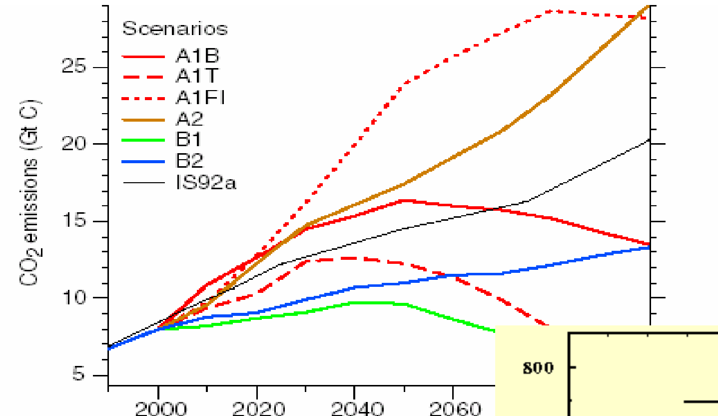
Carbon Budget (1958-2008)

Le Quéré and GCP



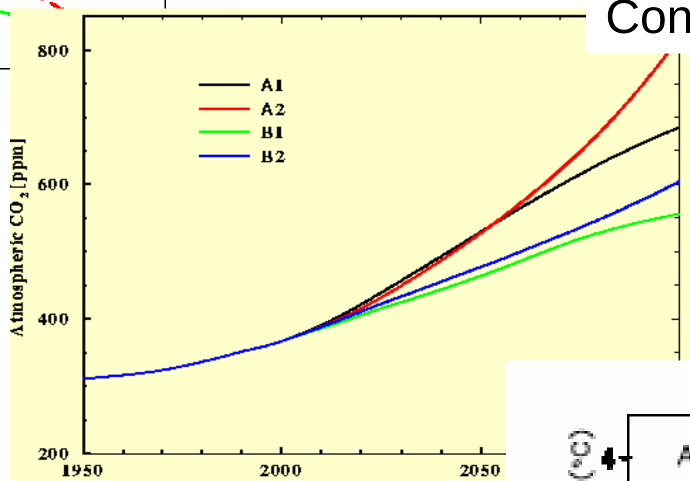
Atm. CO_2 Concentration = Emissions – Ocean Sink – Land Sink

Climate-Carbon Coupling (2000-2100)



Emissions

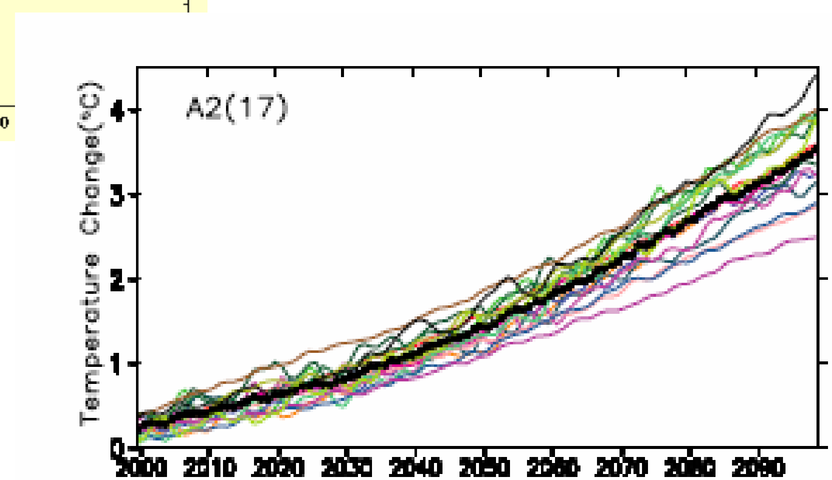
(Simple models)



Concentrations

(GCMs)

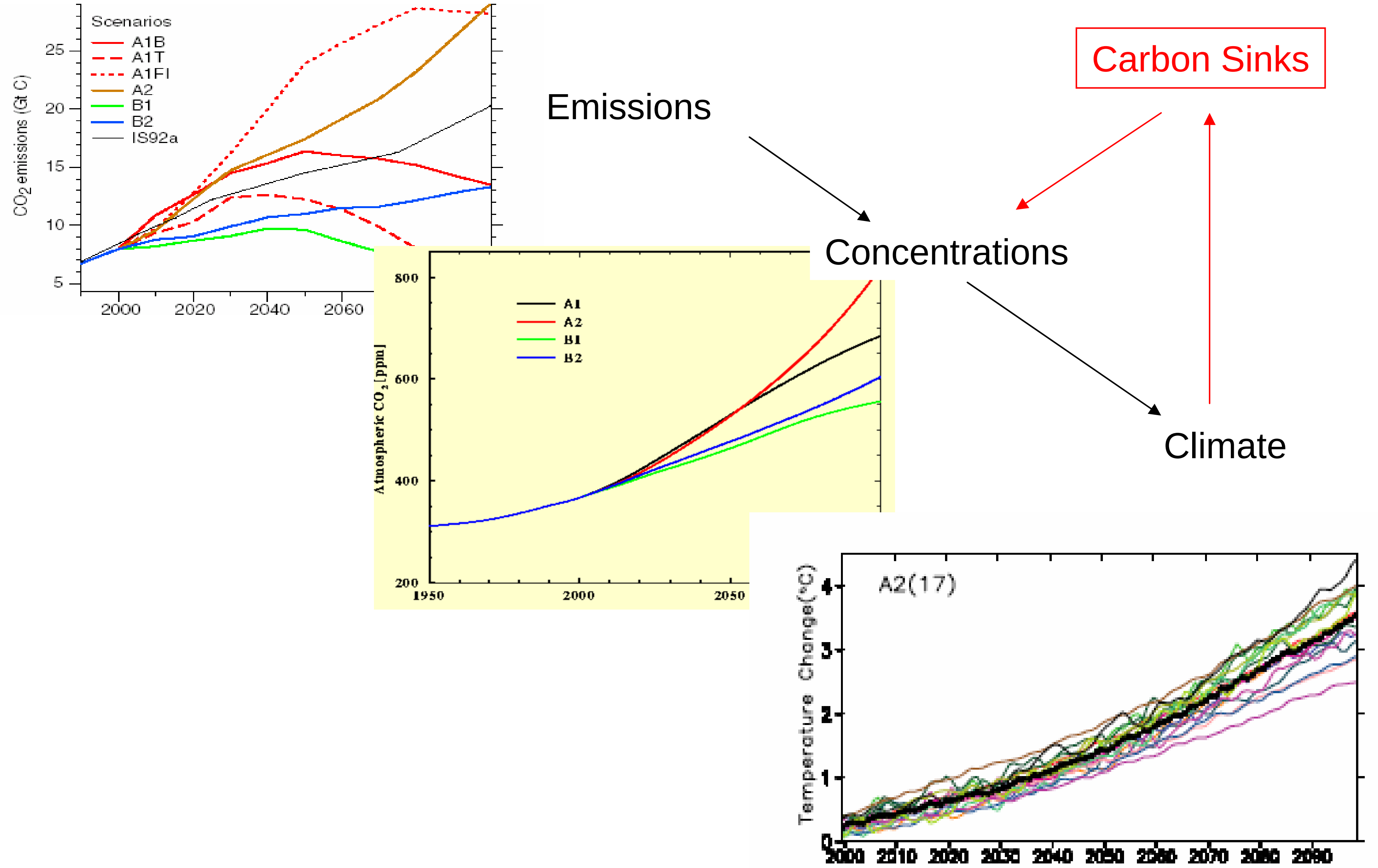
Climate



« Classical » climate simulations

(IPCC, 2007)

Climate-Carbon Coupling (2000-2100)



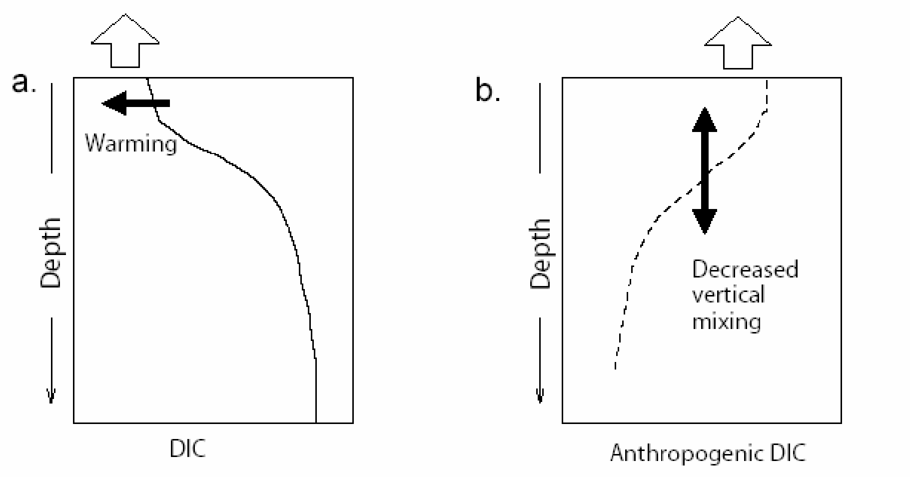
(IPCC, 2007)

Climate-Carbon Coupling (2000-2100)

- Response of the oceanic sink to climate change

    - Warming effect on gas solubility in seawater

    - Stratification impacts on anthropogenic carbon penetration



Maier-Reimer et al. 1996 (Max Planck)
Sarmiento et Le Quéré, 1996 (Princenton)

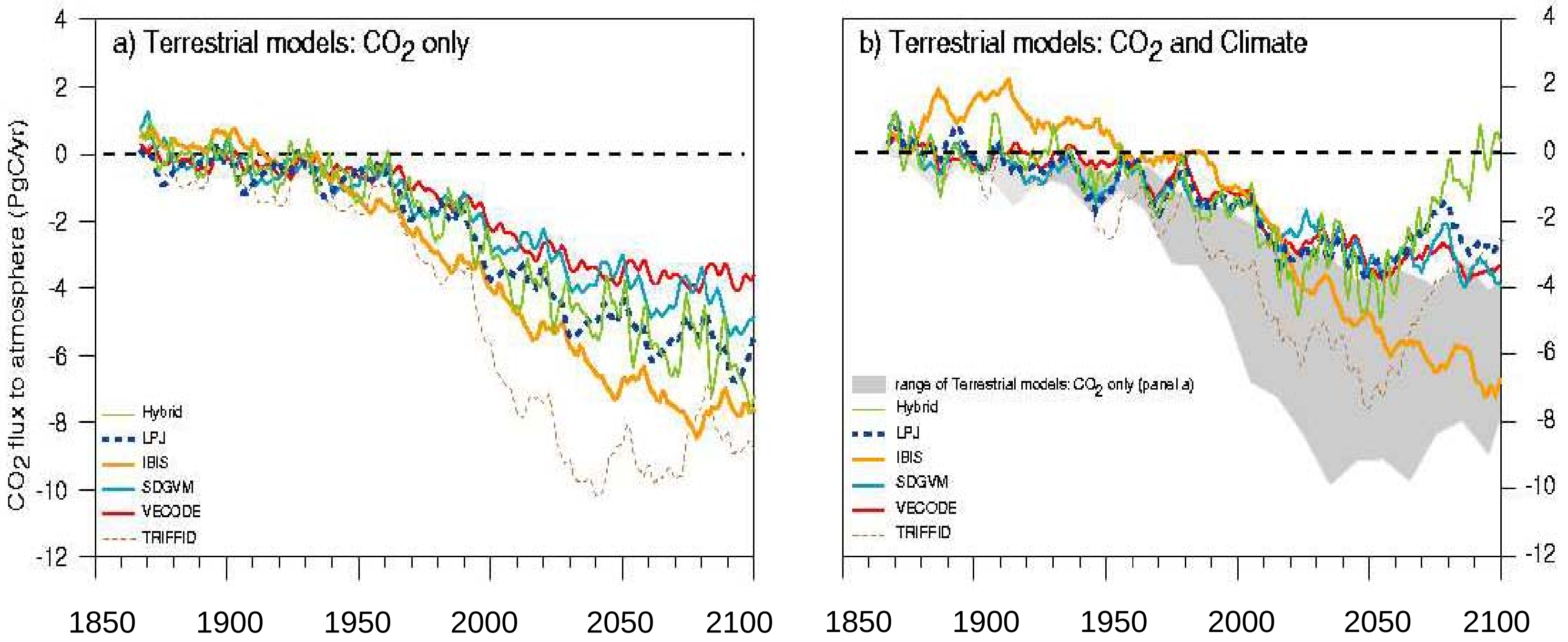
➡ Ocean carbon sink reduced by 6 to 25 % in 2100 !

Climate-Carbon Coupling (2000-2100)

- Response of the land sink to climate change

(Cao and Woodward, Nature, 1998
Cramer et al. 2000, IPCC, 2001)

Response more variable than for the ocean sink
Mechanisms : dynamical vegetation,
decreased precipitation / NPP,
increased temperature / soil respiration, … …



Climate-Carbon Coupling (2000-2100)

- First coupled climate carbon models….

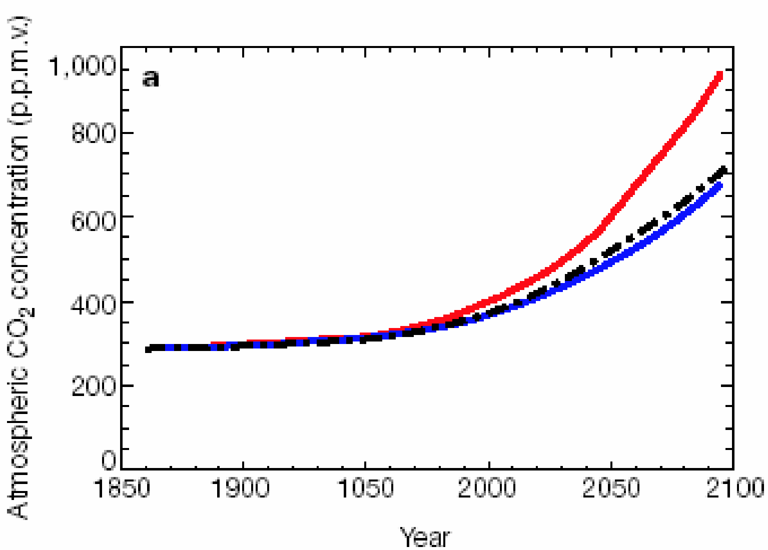
Climate-Carbon Coupling (2000-2100)

- First coupled climate carbon models….

Cox et al. Nature 2000

Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model

Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†



+ 225 ppm in 2100 !

Friedlingstein et al. GRL 2001

GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 8, PAGES 1543-1546, APRIL 15 , 2001

Positive feedback between future climate change and the carbon cycle

Pierre Friedlingstein, Laurent Bopp, Philippe Ciais,
IPSL/LSCE, CE-Saclay, 91191, Gif sur Yvette, France

Jean-Louis Dufresne, Laurent Fairhead, Hervé LeTreut,
IPSL/LMD, Université Paris 6, 75252, Paris, France

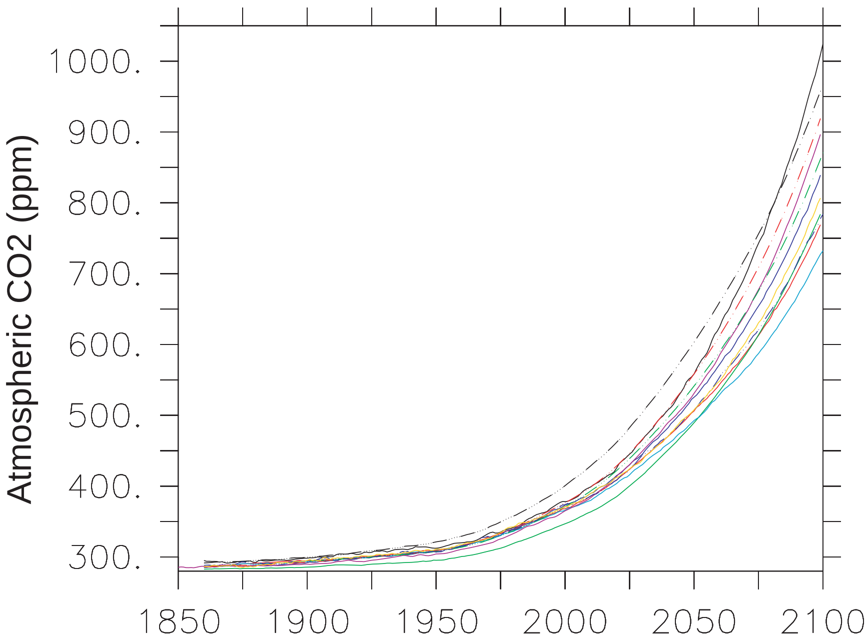
Patrick Monfray, and James Orr
IPSL/LSCE, CE-Saclay, 91191, Gif sur Yvette, France

+ 70 ppm in 2100 !

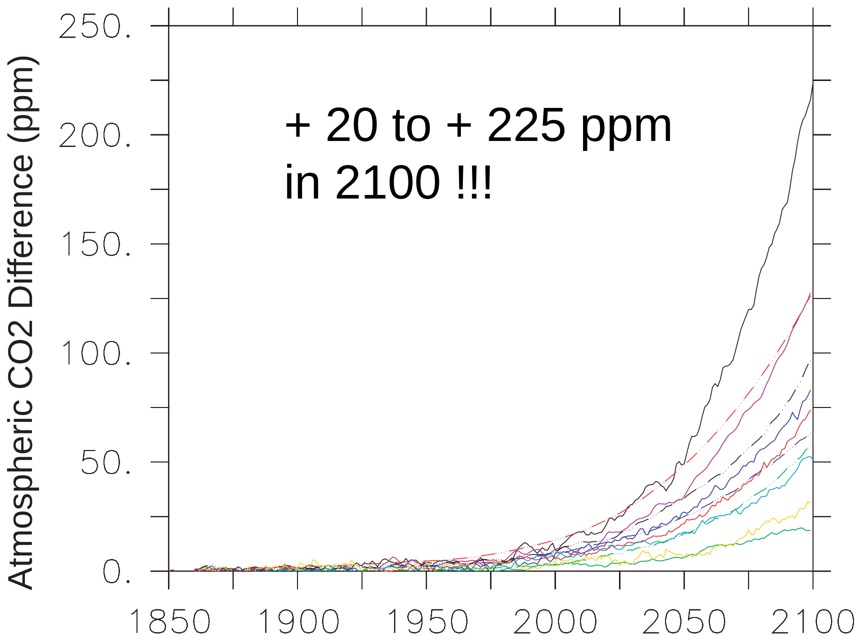
Climate-Carbon Coupling (2000-2100)

- C4MIP : Coupled Carbon Cycle – Climate Models InterComparison
  - 11 coupled climate-carbon models
    (7 GCMs + 4 EMICs)
  - One emission scenario (SRESA2) from 1860 to 2100.
  - 2 simulations : coupled and un-coupled

(a)



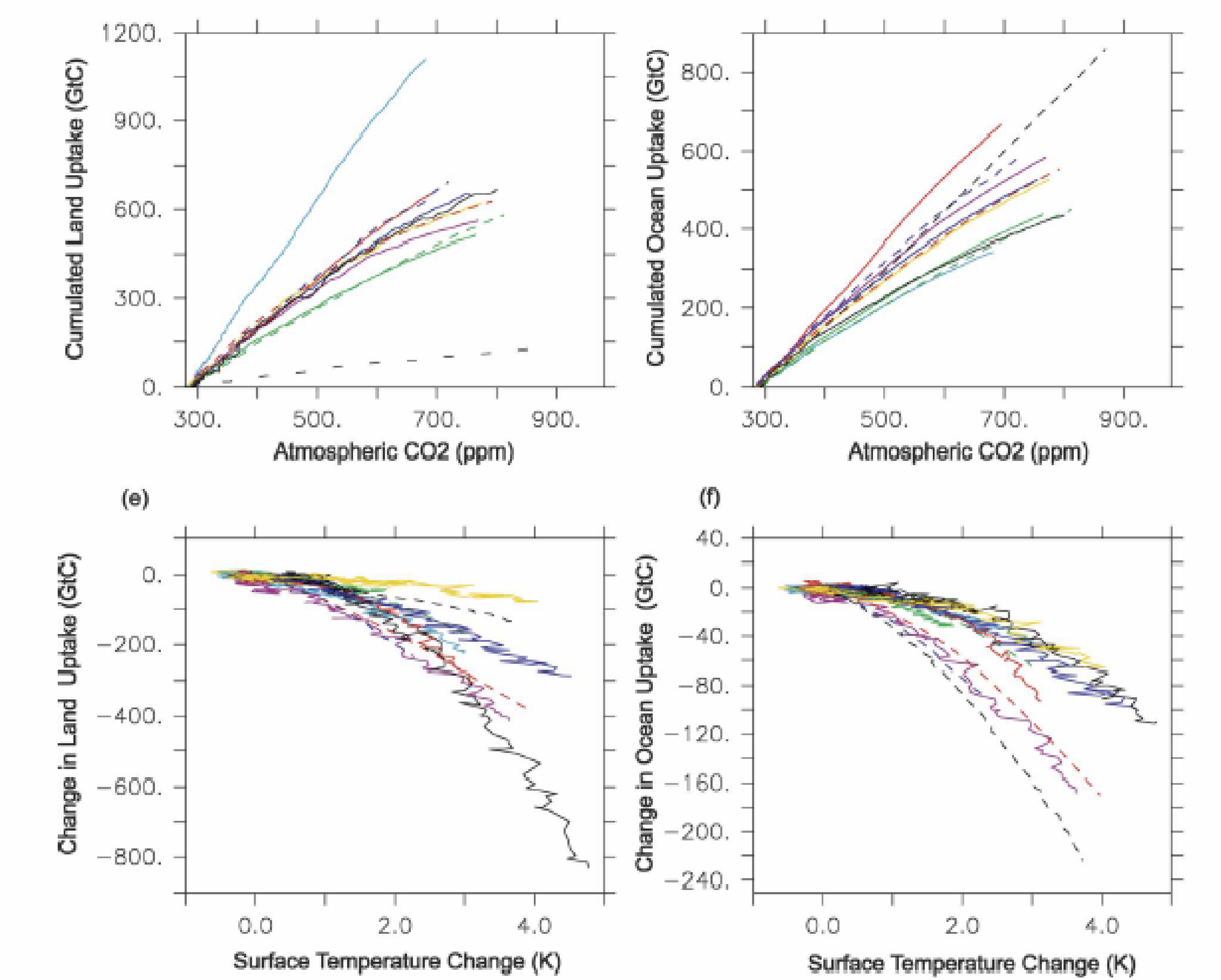
(b)



(Friedlingstein et al. 2006)

Climate-Carbon Coupling (2000-2100)

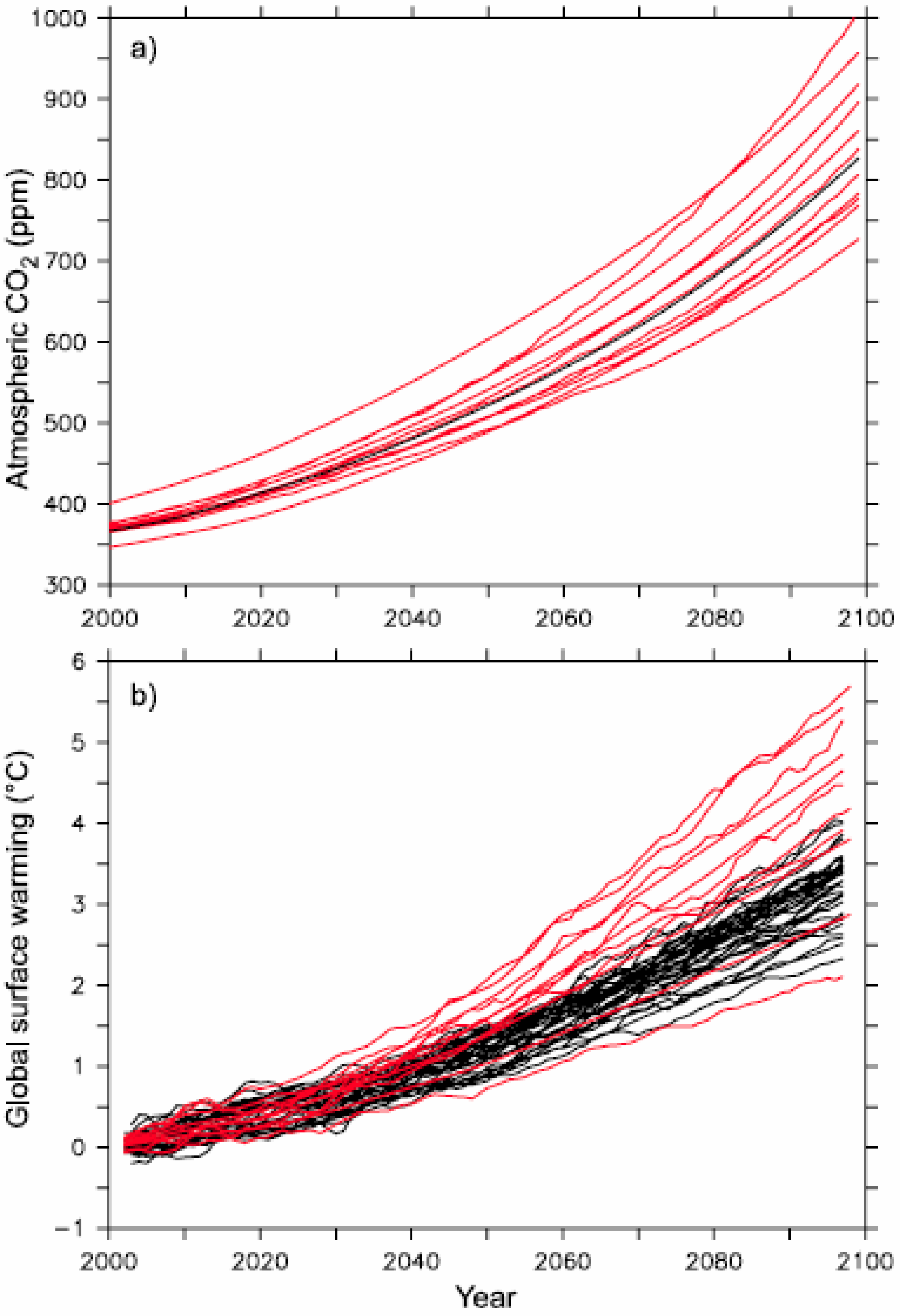
- C4MIP : Coupled Carbon Cycle – Climate Models InterComparison



Climate-Carbon Coupling (2000-2100)

- C4MIP :

Impact on temperatures



IPCC, 2007

Climate-Carbon Coupling: other GHGs

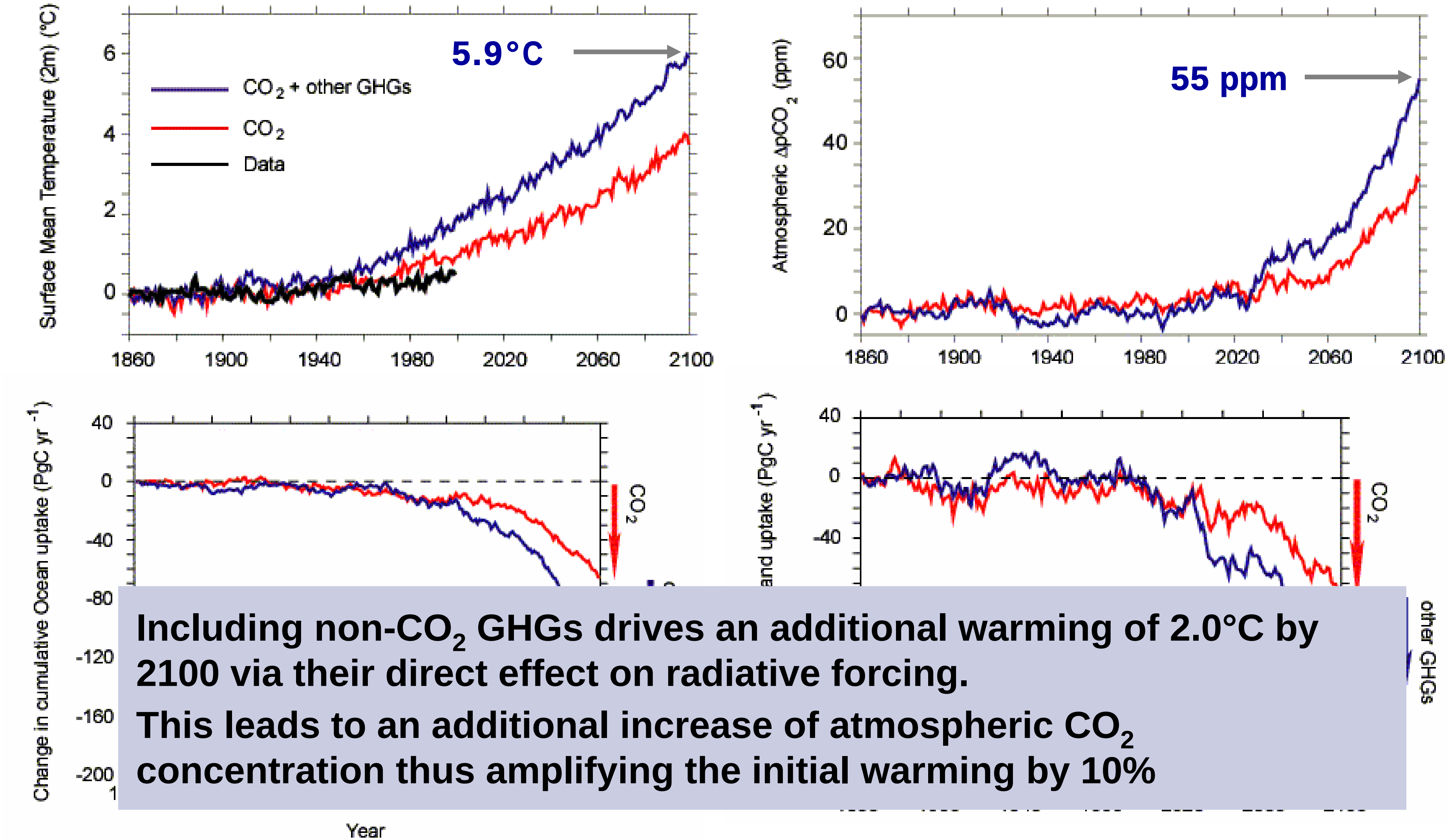
-C4MIP simulations : only forced by CO_2 emissions

An effect on the feedback from other GHGs or aerosols ?

Cadule et al., 2008

Climate-Carbon Coupling: other GHGs

- Inclusion of other GHGs



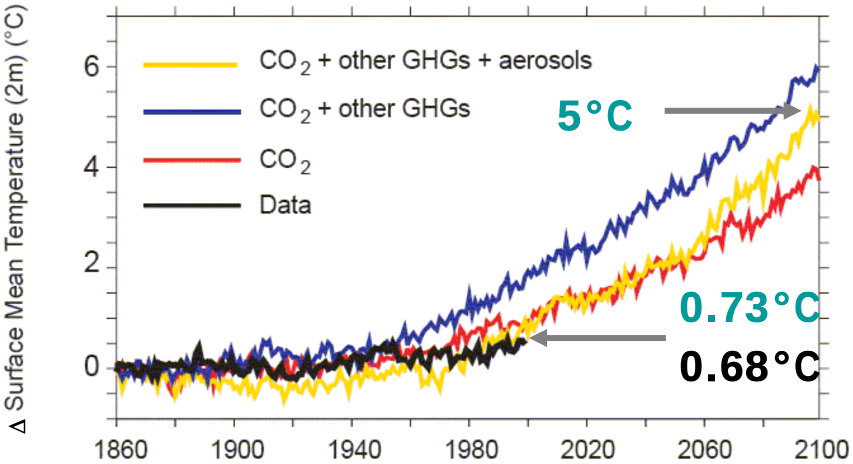
Including non-CO_2 GHGs drives an additional warming of 2.0°C by 2100 via their direct effect on radiative forcing.

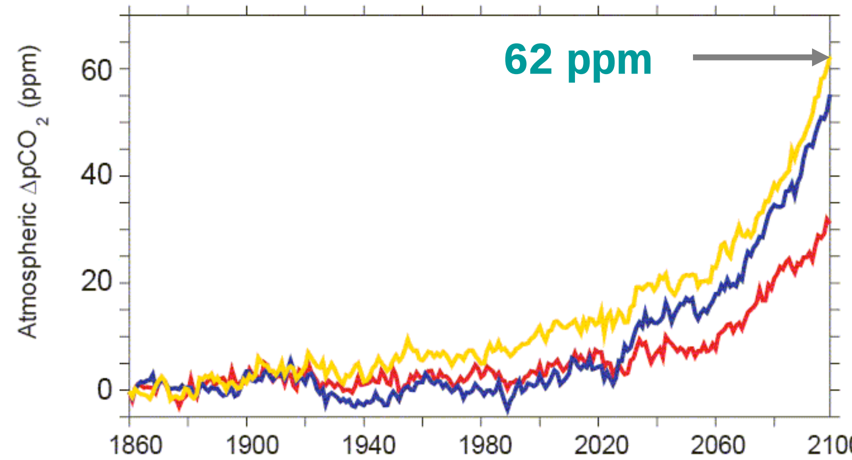
This leads to an additional increase of atmospheric CO_2 concentration thus amplifying the initial warming by 10%

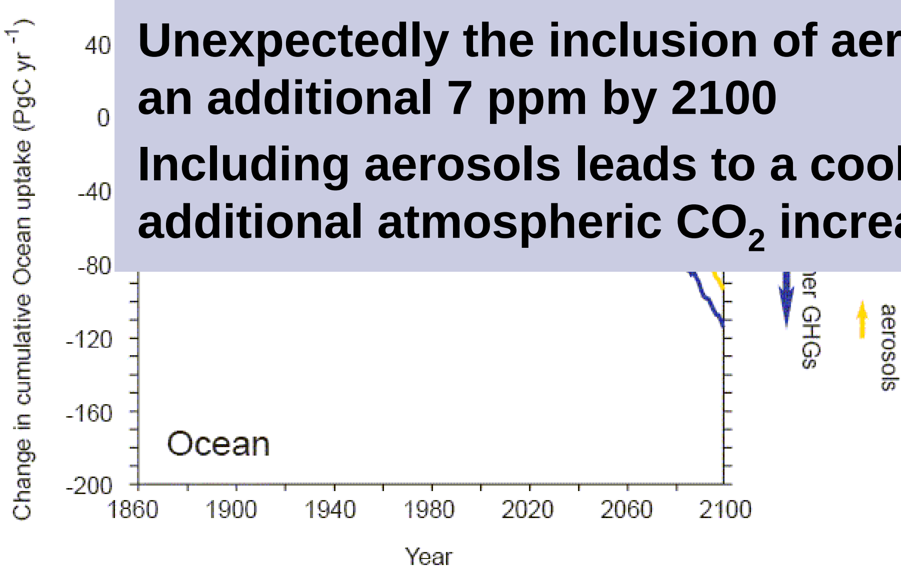
Cadule et al., 2008

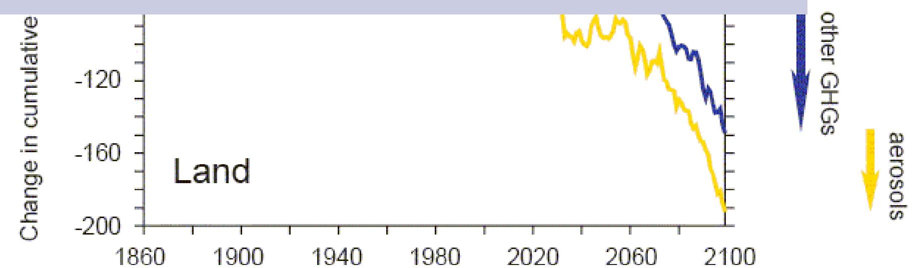
Climate-Carbon Coupling: GHG + aerosols

- Inclusion of other GHGs and 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

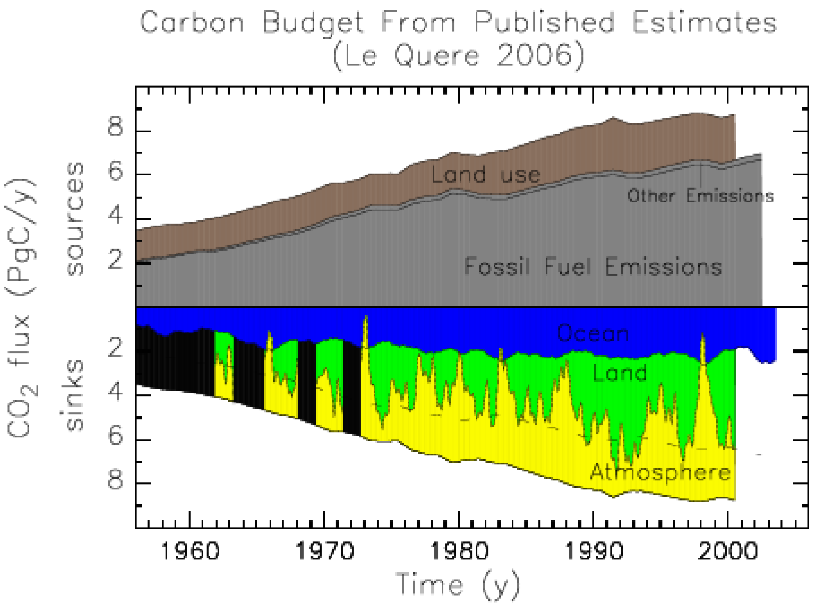
Cadule et al., 2008

Evaluation

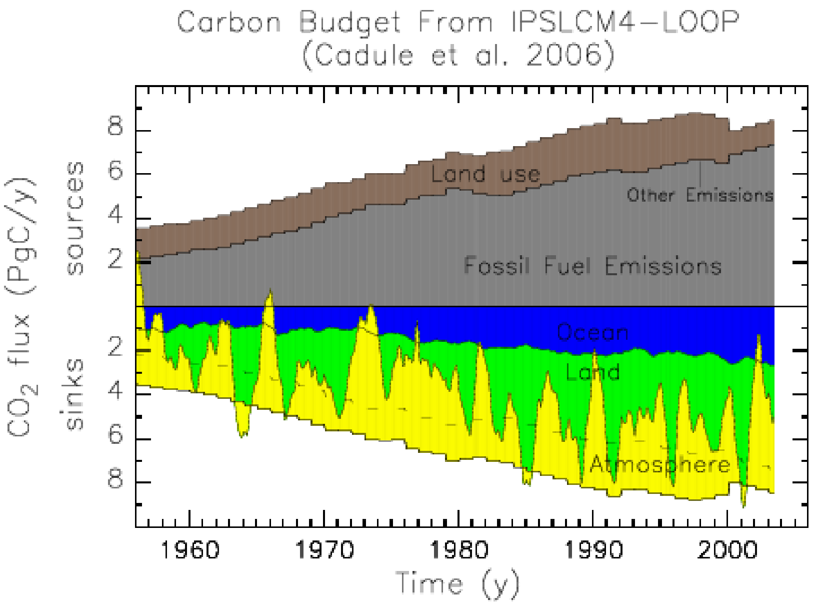
- Today : evaluation needed to reduce uncertainties…

  + Carbon Budgets

Data - based



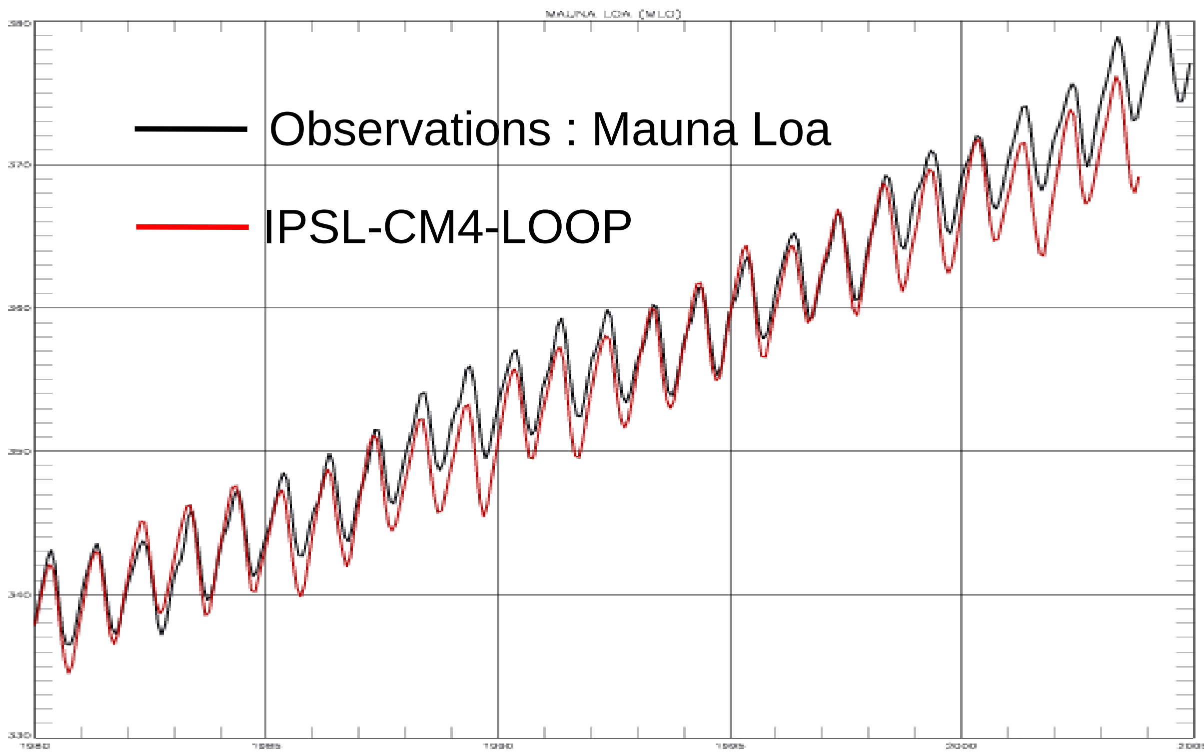
IPSLCM4-LOOP



Evaluation

- Today : evaluation needed to reduce uncertainties…

  + Atmospheric CO_2



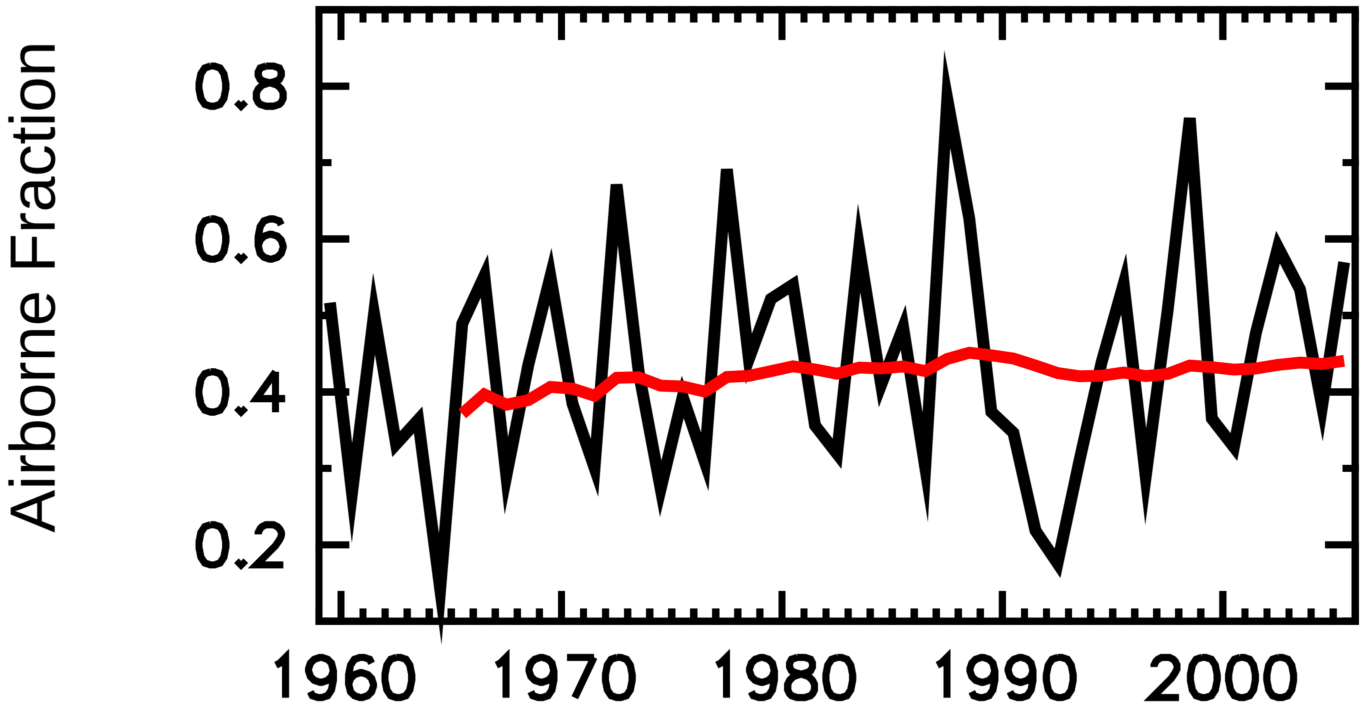
(Cadule et al.)

Evaluation

- Today : evaluation needed to reduce uncertainties…

+ Trends in airborne fraction

Canadell et al. 2008



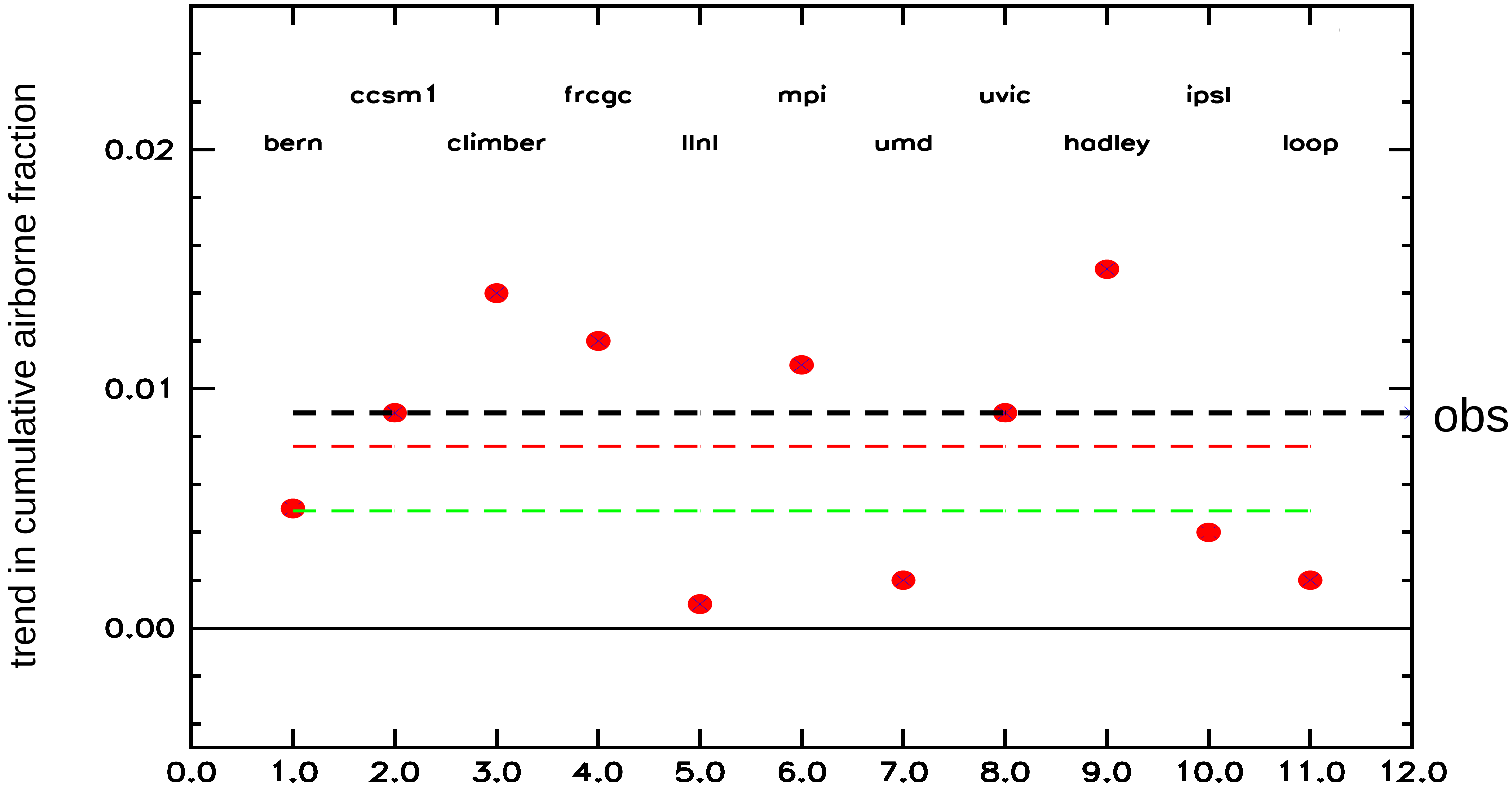
10% increase in cumulative airborne fraction between 1965 and 2005…

Airborne Fraction = Atm CO2 /(fossil fuel + cement + land use emissions)

Evaluation

- Today : evaluation needed to reduce uncertainties…

+ Trends in airborne fraction



the observed cumulative airborne fraction can provide constraints to C4MIP models

Courtesy of LeQuéré

Evaluation

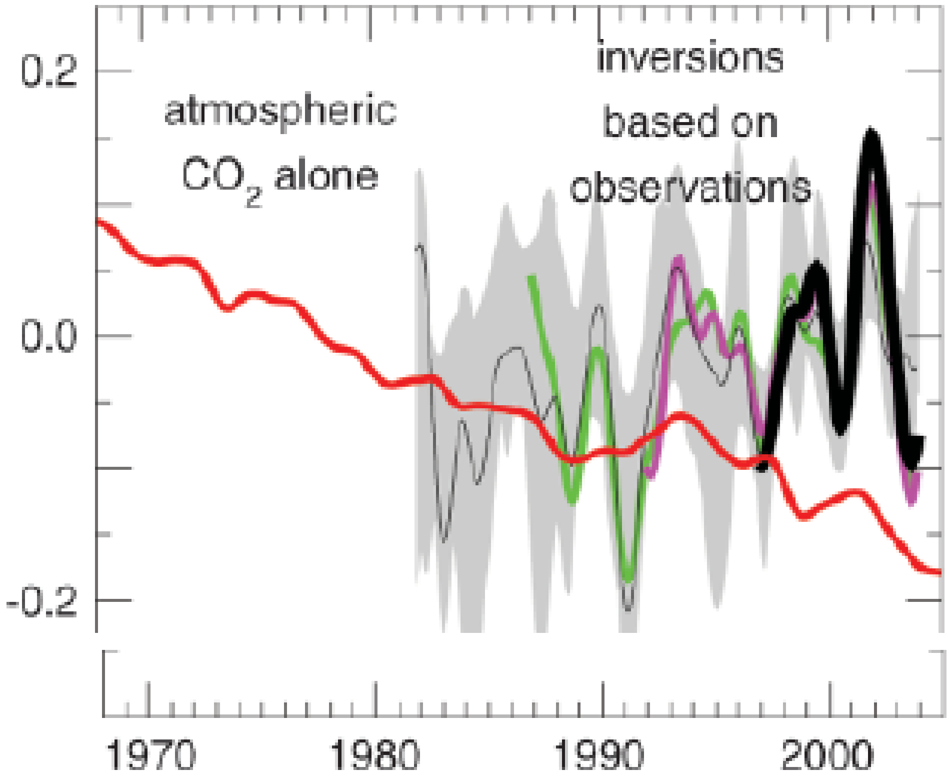
- Today : evaluation needed to reduce uncertainties…

  + Regional carbon fluxes

Saturation of the ocean carbon sink
In the Southern Ocean

CO2 Flux
(GtC/yr)

More
sink



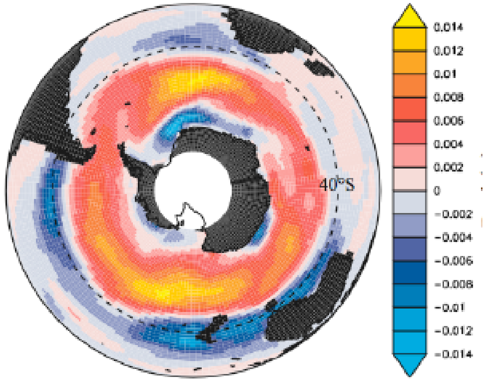
? Mismatch coupled models / obs. ?

(Le Quéré et al. Science 2007)

Evaluation

- Today : evaluation needed to reduce uncertainties…

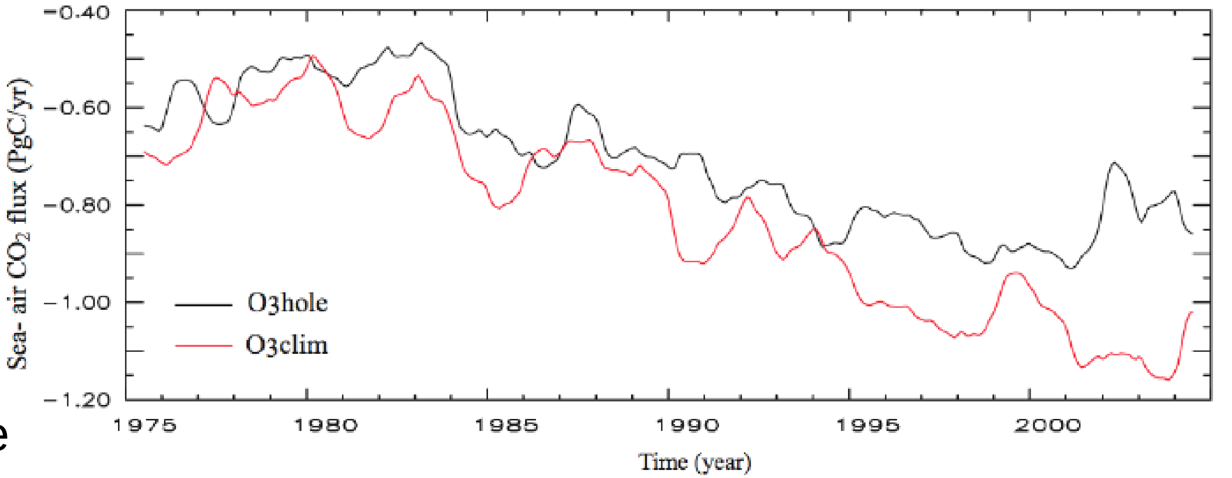
+ Regional carbon fluxes



↘ stratospheric O3

→ ↗ winds in the Southern Ocean

→ Saturation of the Carbon Sink



With O3 decrease

No O3 decrease

(Lenton et al. 2008 sub)

Conclusions

- Positive feedback between climate and carbon cycle
- Both land and ocean carbon cycle
- Large uncertainty in amplitude of this feedback

  (+ interactions with other cycles, land-use, …)
- More evaluation is needed to reduce uncertainties – work in progress