European Geosciences Union

GIFT – Geosciences Information For Teachers

The global carbon cycle and climate-carbon coupling

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IPSL/LSCE, Paris, France

Vienna, 29th of April 2014, EGU General Assembly, GIFT Workshop

My sources

One of the 14 chapters of the last WG1 IPCC report

Ciais, P., et al., 2013 (15 authors): **Carbon and Other Biogeochemical Cycles**. In: *Climate Change 2013: The Physical Science Basis. Contribution of WG I to IPCC AR5* [Stocker, T.F., etal. (eds.)]

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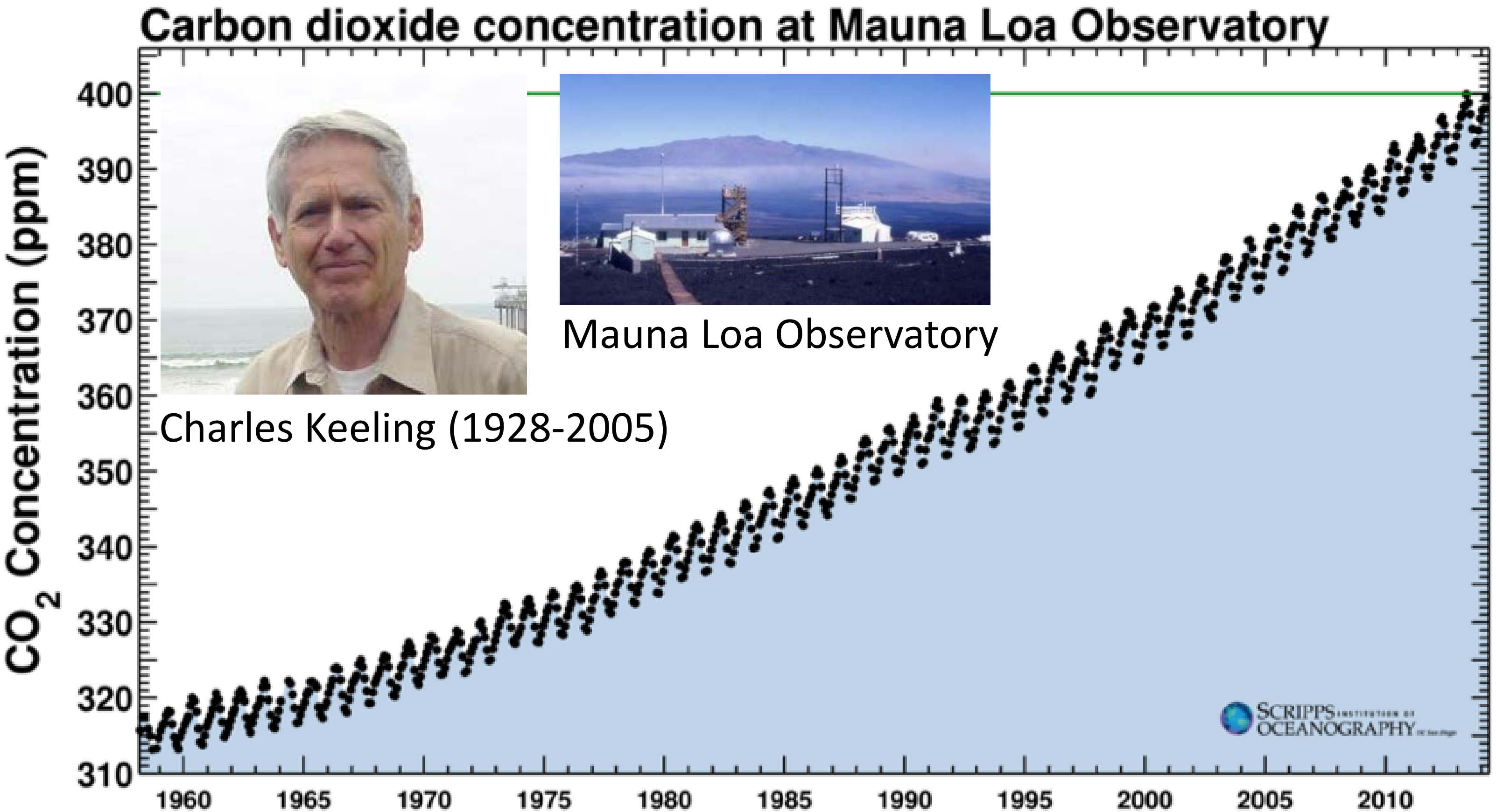
The annual report of the Global Carbon Project

Le Quéré, C., et al. (49 authors) : **Global carbon budget 2013**, Earth Syst. Sci. Data Discuss., 6, 689-760, doi:10.5194/essdd-6-689-2013, 2013.

Introduction: The Keeling curve



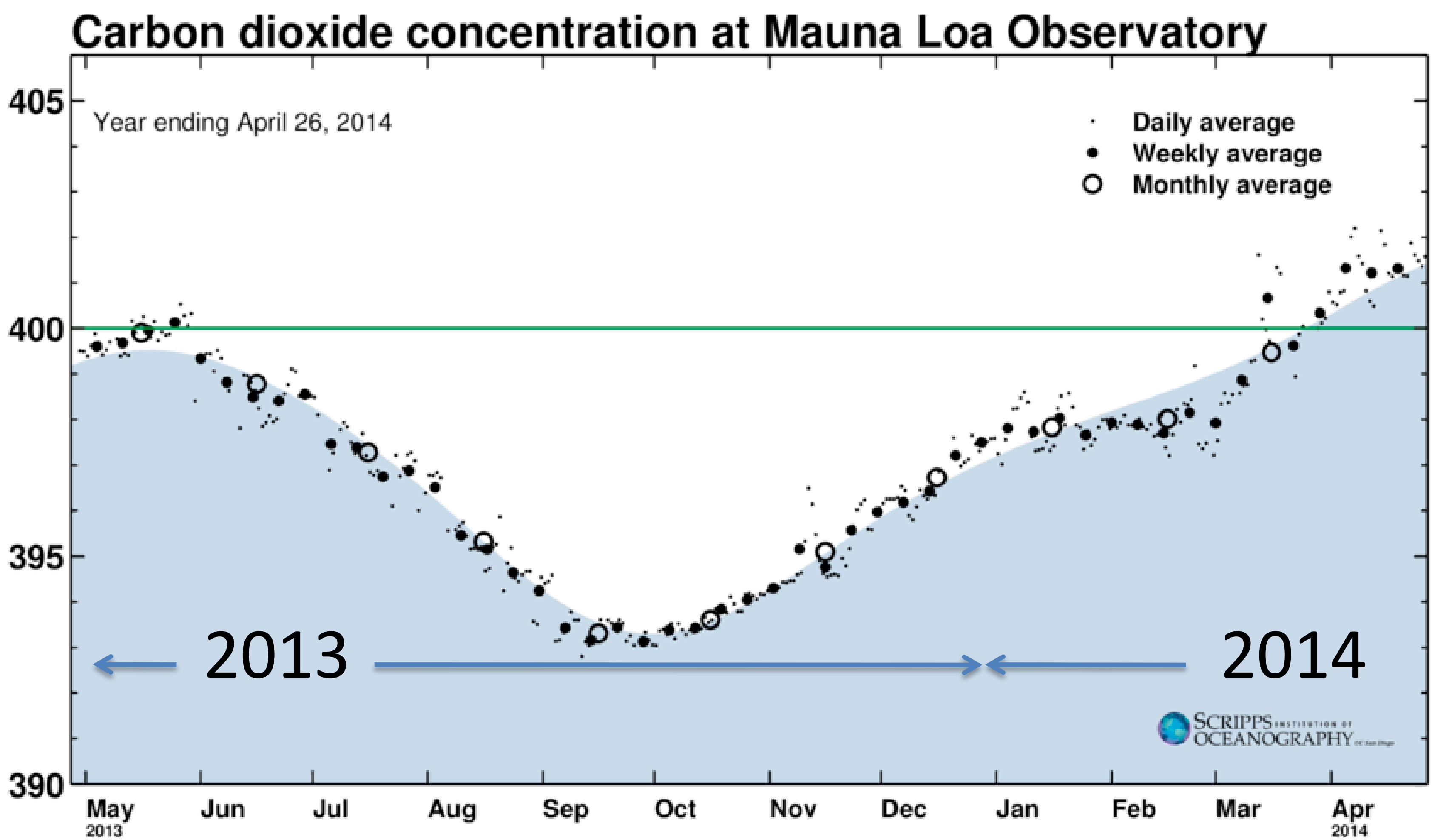
Atmospheric CO_2 has increased from 315 ppm in 1959 to 396.5 ppm in 2013

(+ 26 % in ~50 years)

http://keelingcurve.ucsd.edu

Introduction: The Keeling curve

Atmospheric CO_2 above 400 ppmv for the first time over 4 consecutive weeks



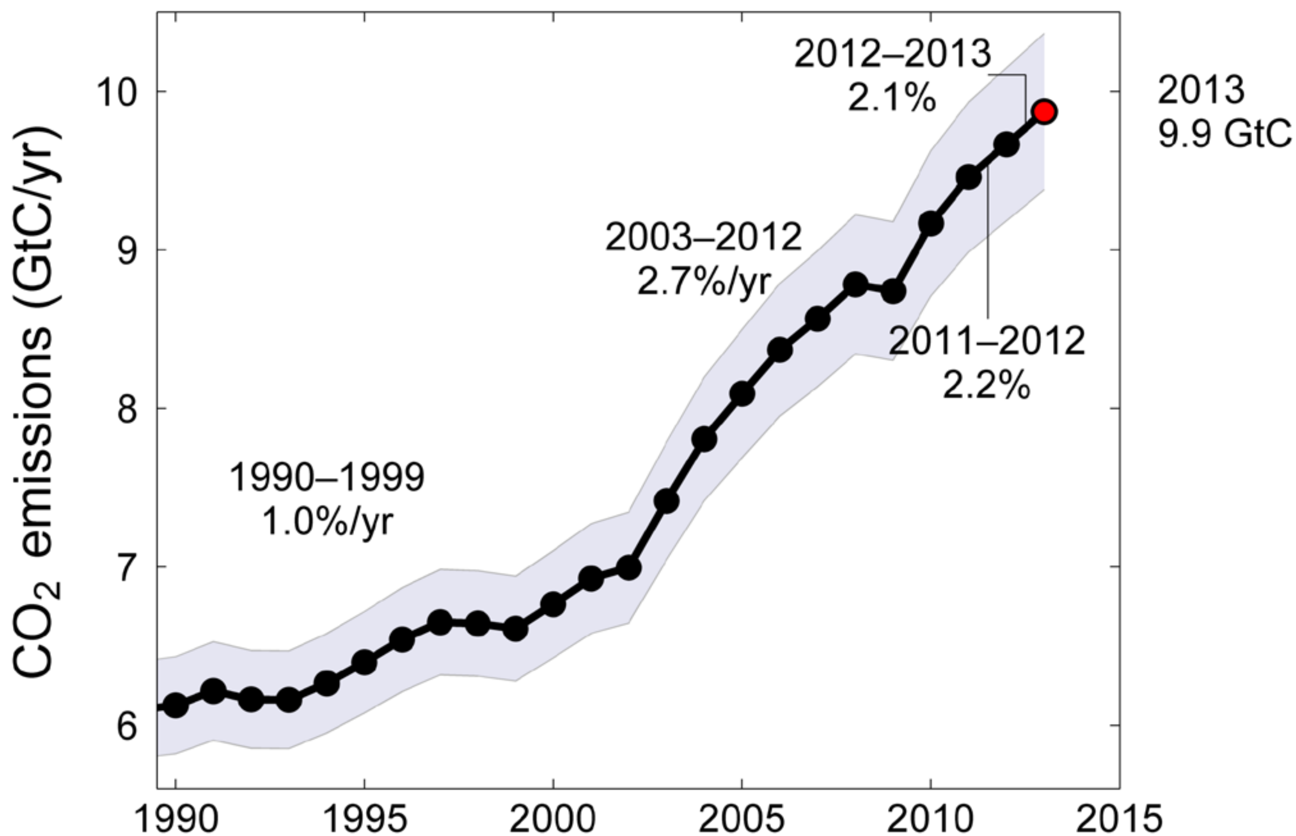
Introduction / Outline

- The Global Carbon Budget – ΔCO_2 = Emissions - F_{ocean} - F_{land}
- Natural Carbon Sinks - F_{ocean} and F_{land}
- Climate-Carbon coupling - F_{ocean} and F_{land} influenced by climate

The Global Carbon Budget : Emissions

Billions tonnes of Carbon

Global fossil fuel and cement emissions: 9.9 ± 0.5 GtC in 2013, 61% over 1990

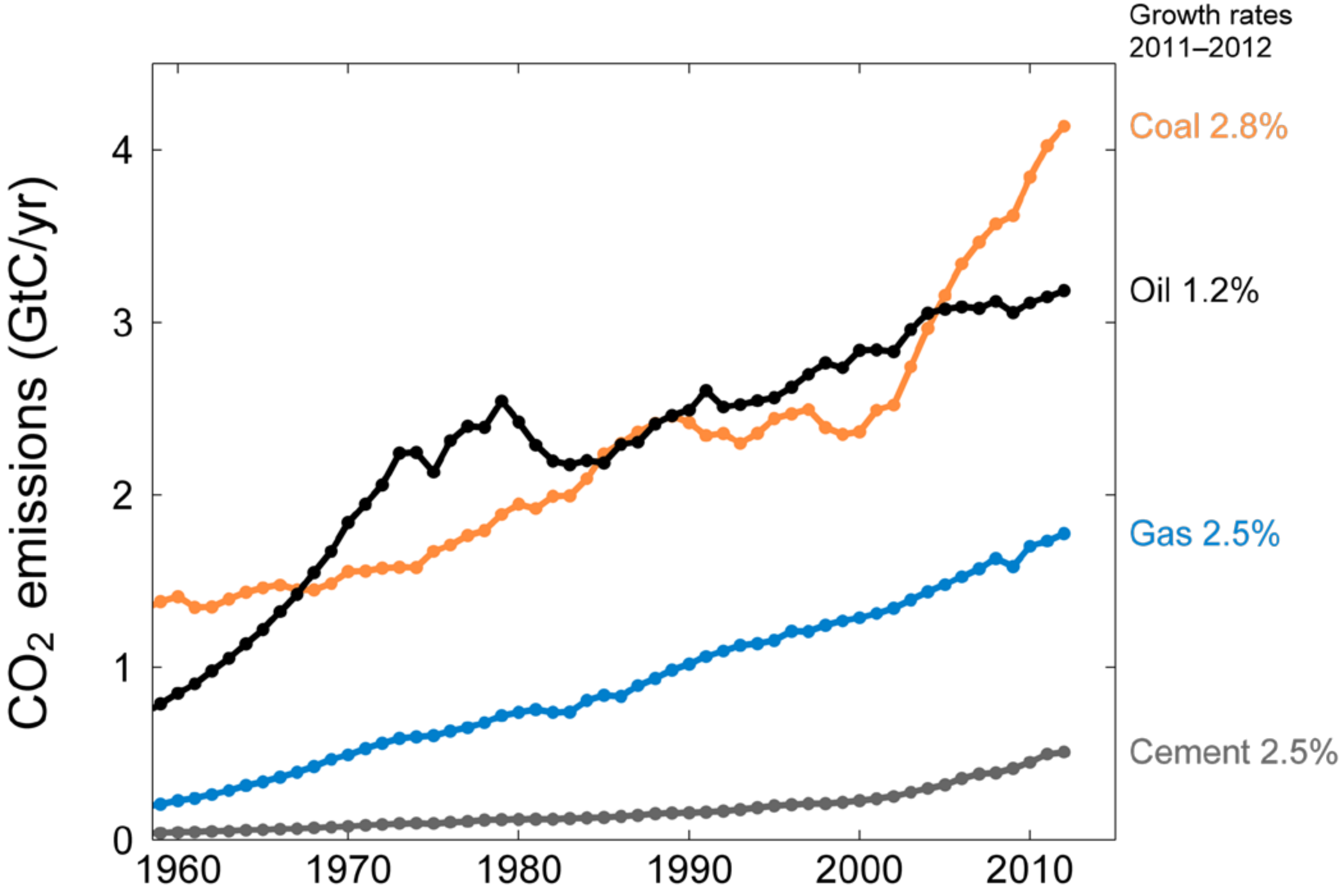


GCP, 2013

The Global Carbon Budget : Emissions

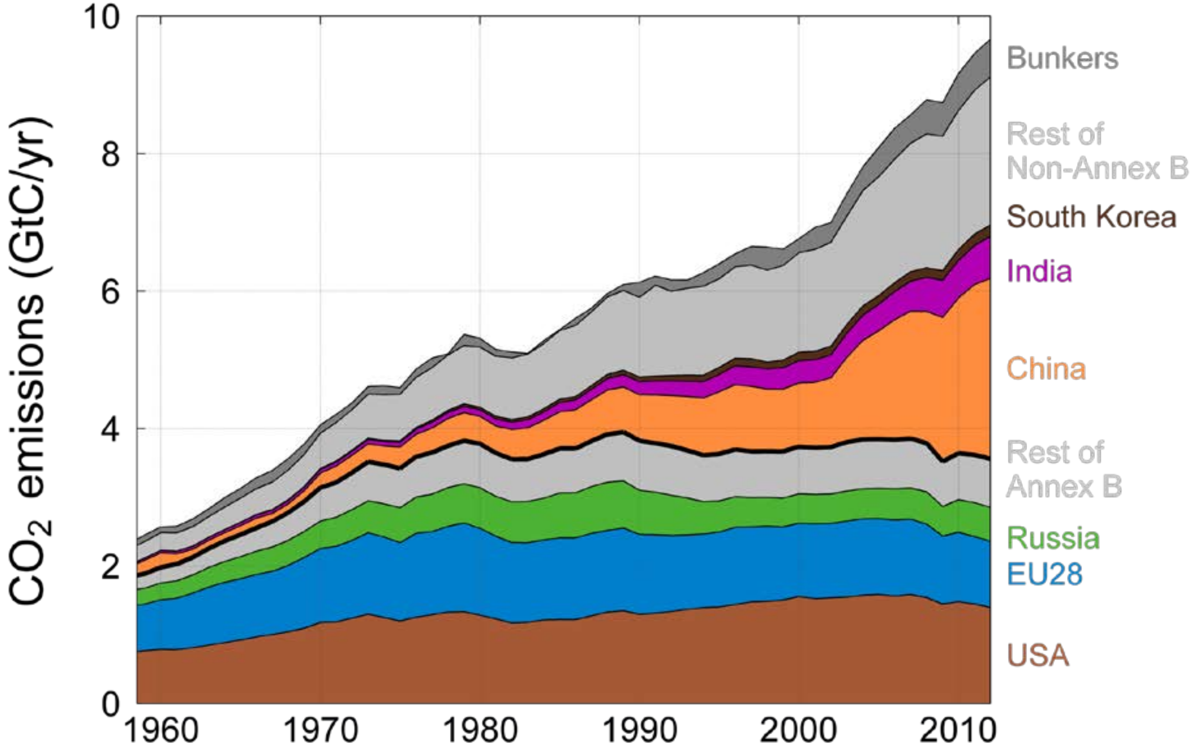
Share of global emissions in 2012:

coal (43%), oil (33%), gas (18%), cement (5%), flaring (1%, not shown)



GCP, 2013

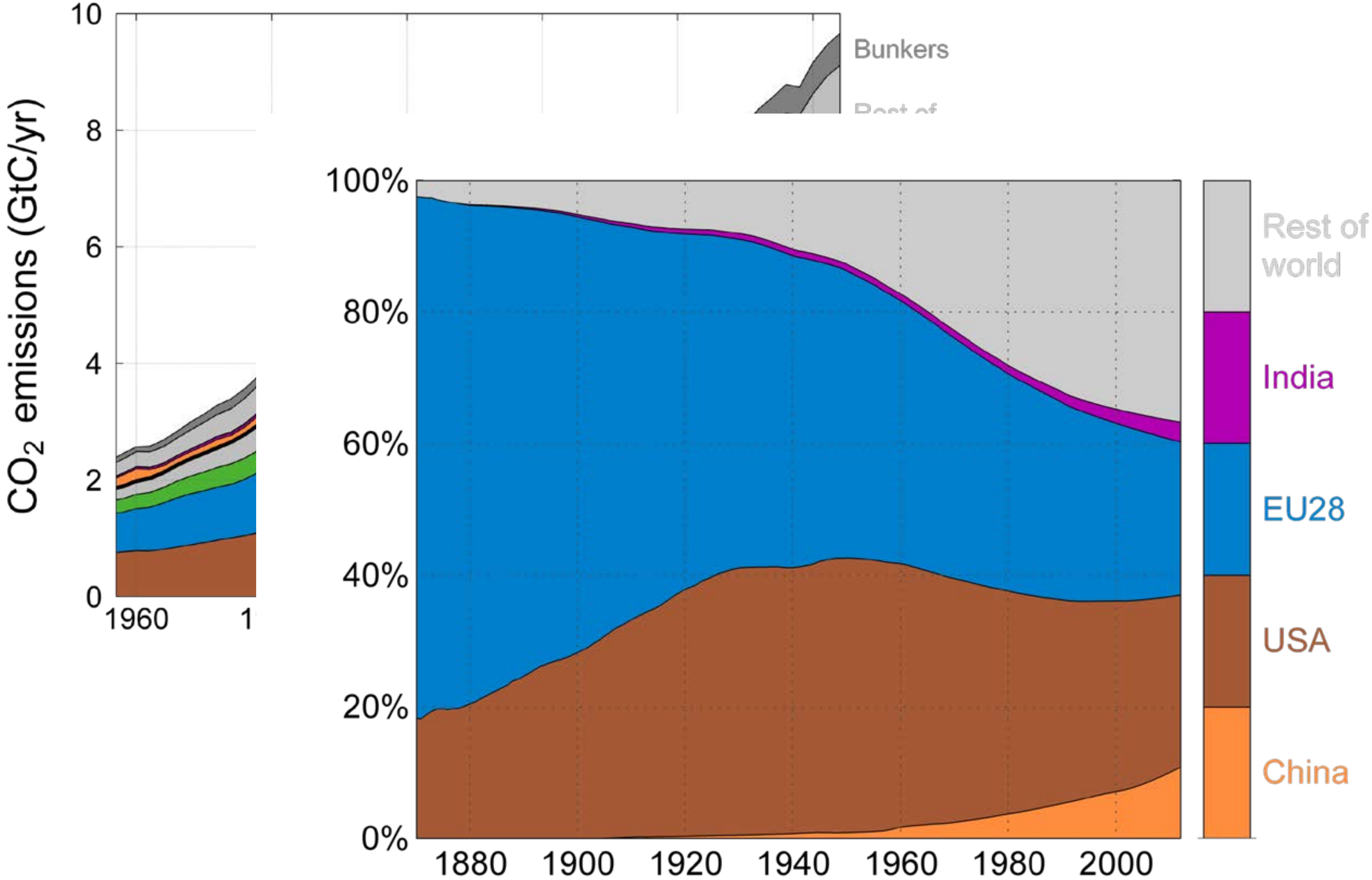
The Global Carbon Budget : Emissions per country / regions



Break-Down by Country

GCP, 2013

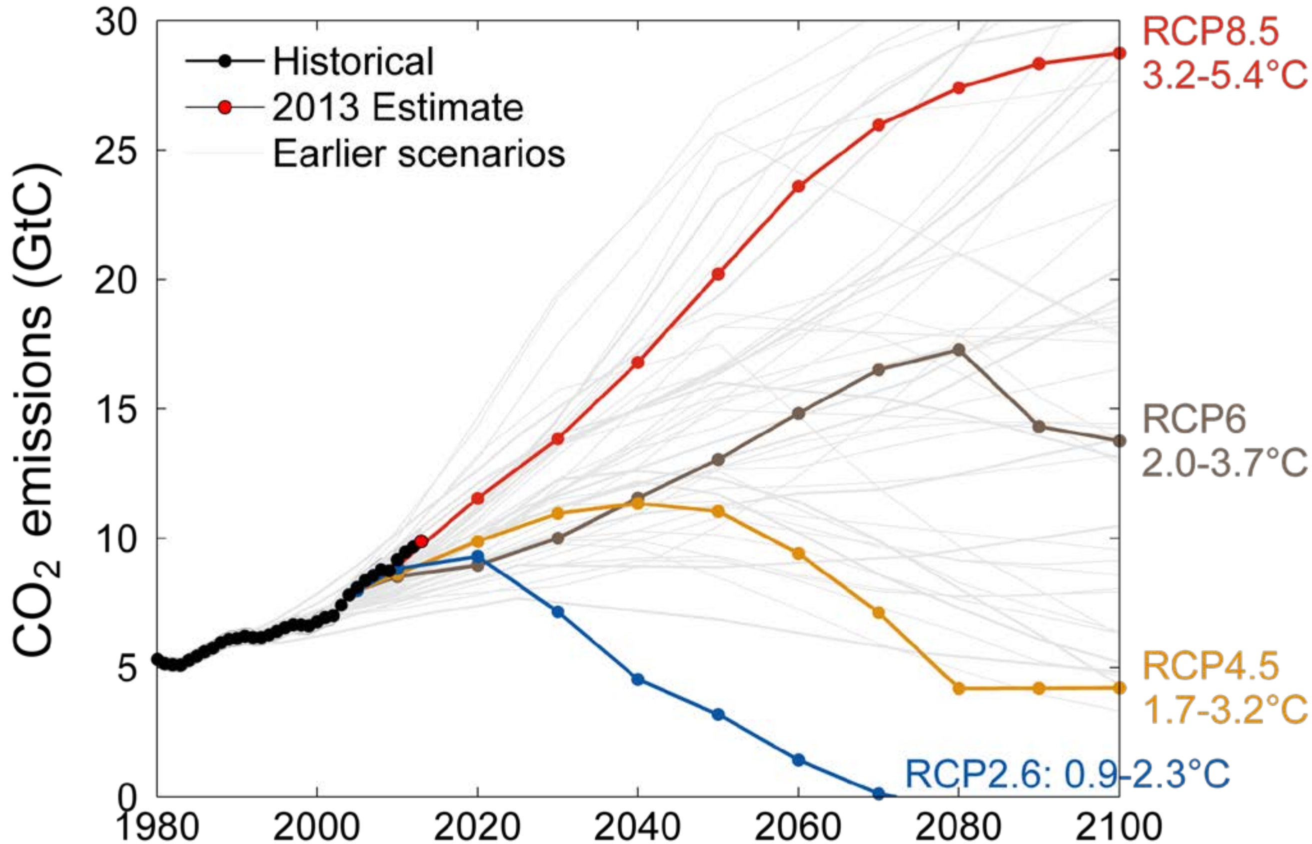
The Global Carbon Budget : Emissions per country / regions



Break-Down by Country for Historical Cumulative Emissions

GCP, 2013

The Global Carbon Budget : Emissions vs Scenarios

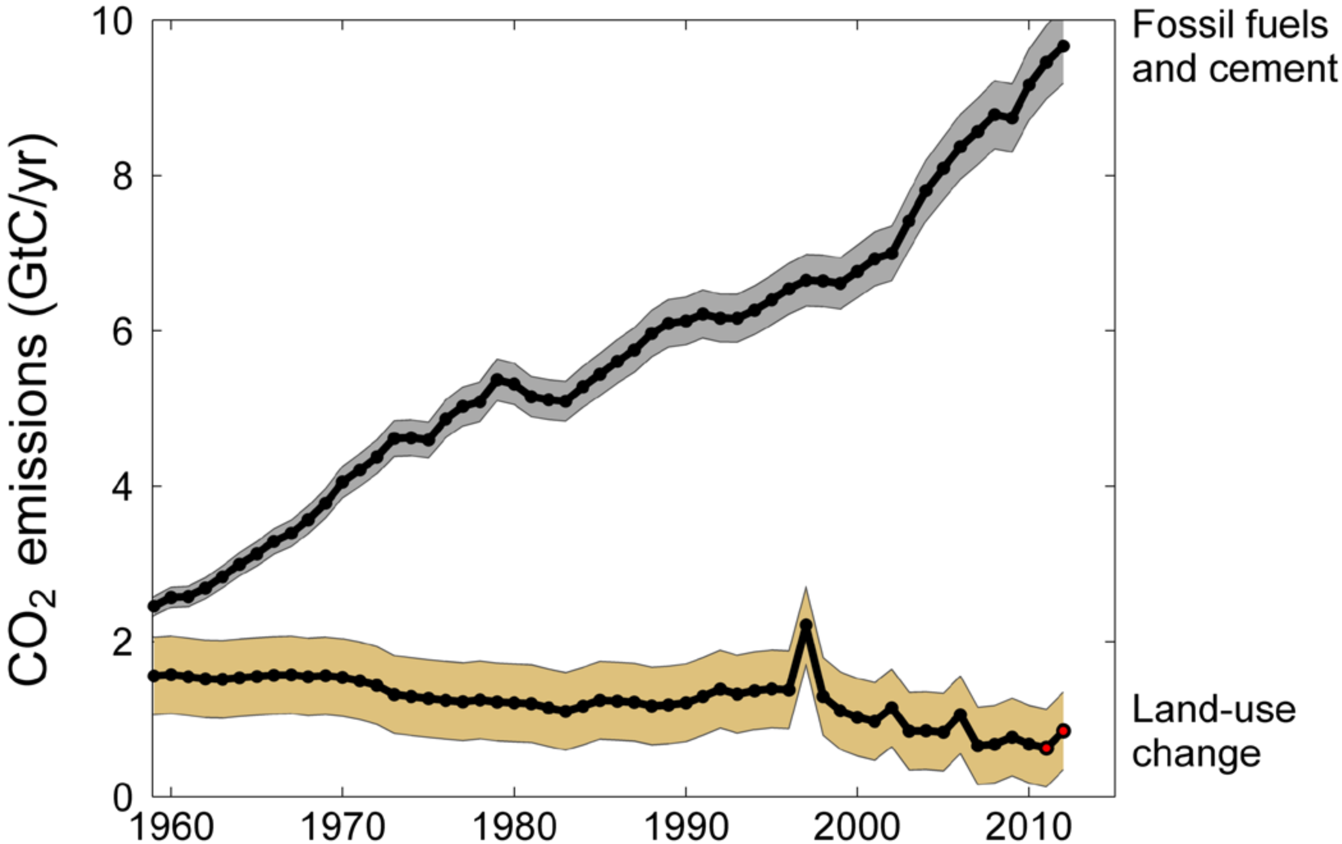


GCP, 2013

The Global Carbon Budget : Emissions incl. deforestation

Total global emissions: 10.5 ± 0.7 GtC in 2012, 43% over 1990

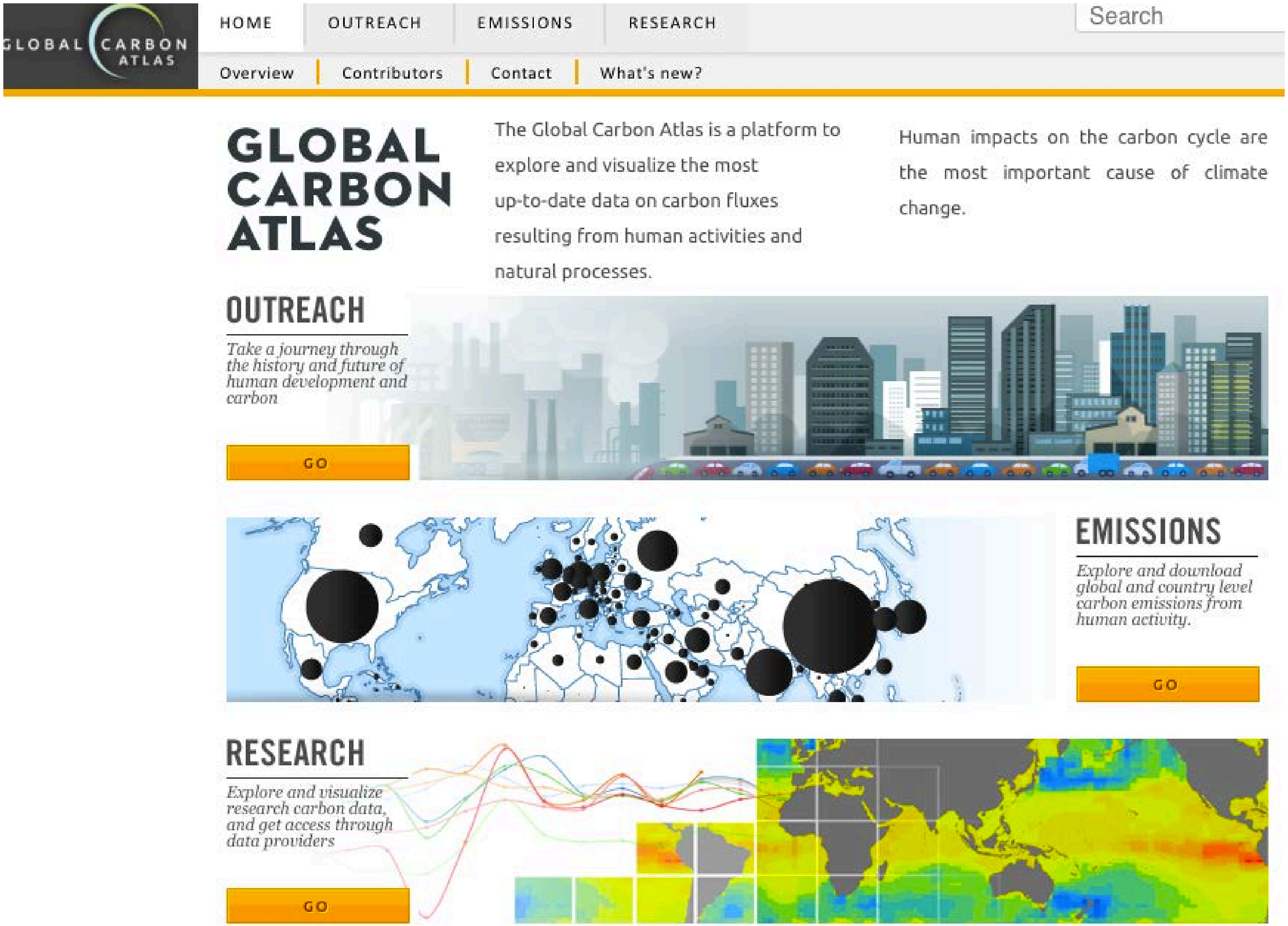
Percentage land-use change: 38% in 1960, 17% in 1990, 8% in 2012



GCP, 2013

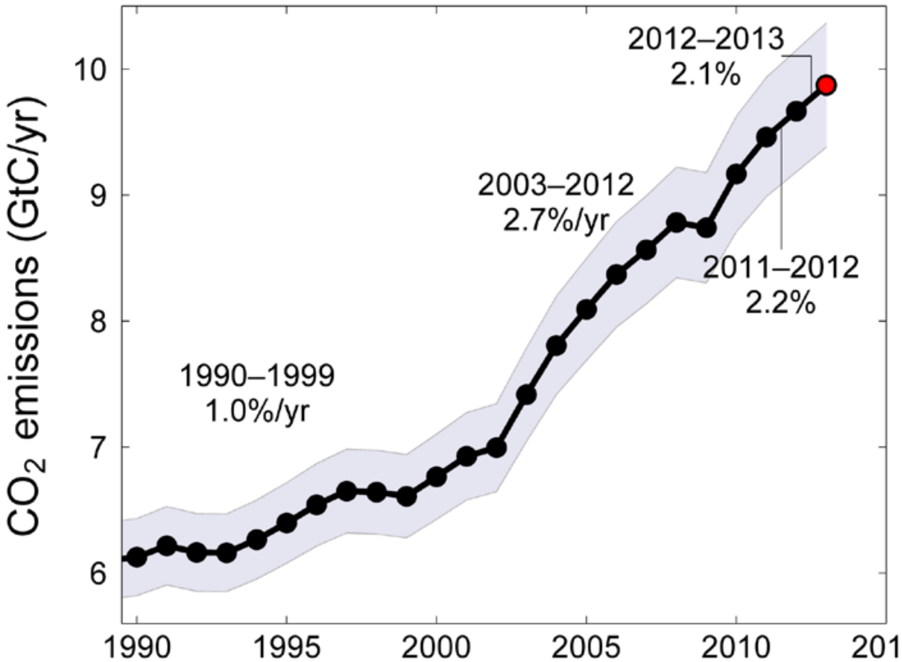
The Global Carbon Budget : see the Global Carbon Atlas

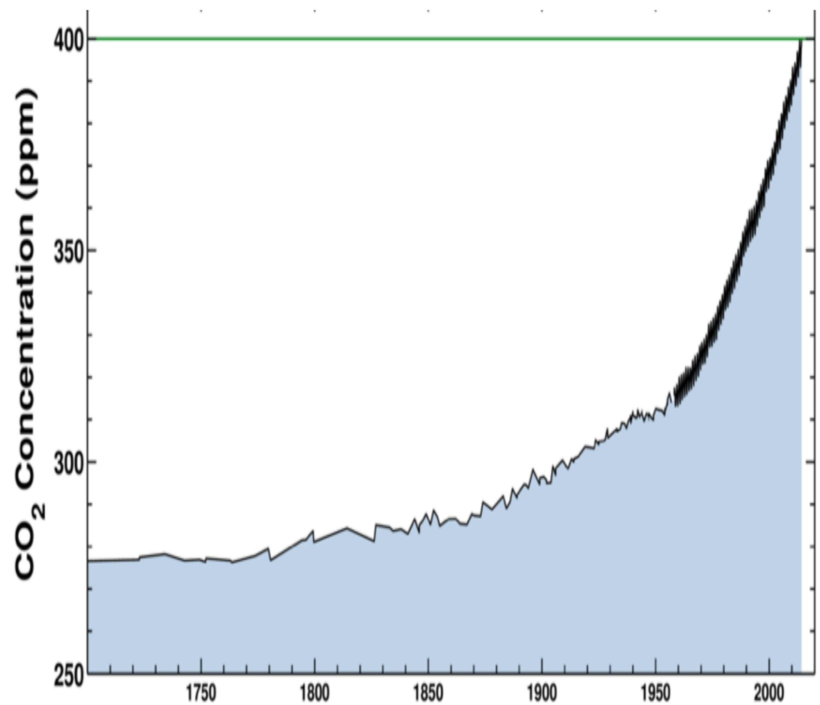
http://www.globalcarbonatlas.org



GCP, 2013

The Global Carbon Budget : emissions vs concentrations

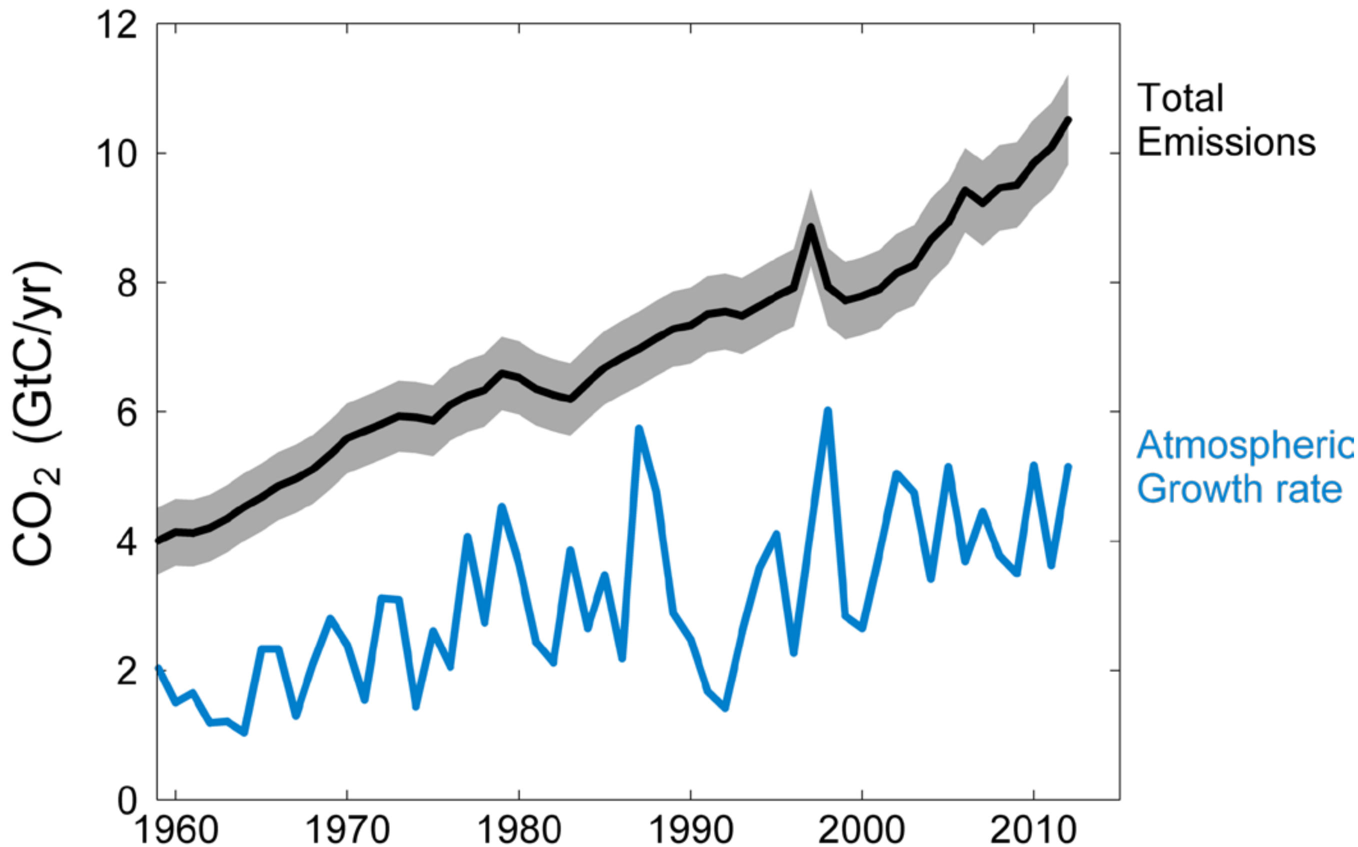




+1 ppm of CO_2 in the atmosphere equivalent to **+ 2.12 Gt of C**

= 2.12 billion tonnes of Carbon
= 2.12 10^{15} g of Carbon
= 2.12 PgC of Carbon
= 2.12 x 3.664 Gt of CO_2

The Global Carbon Budget : emissions vs concentrations



→ Atmospheric growth rate is less than 50% of total emissions : natural sinks !

$$\Delta CO_2 = \text{Emissions} - F_{ocean} - F_{land}$$

→ Atmospheric growth much more variable than the total emissions

The Global Carbon Budget : separating the sinks ?

ΔCO_2 = Emissions - F_{ocean} - F_{land} ….. 1 equation and 2 unknows

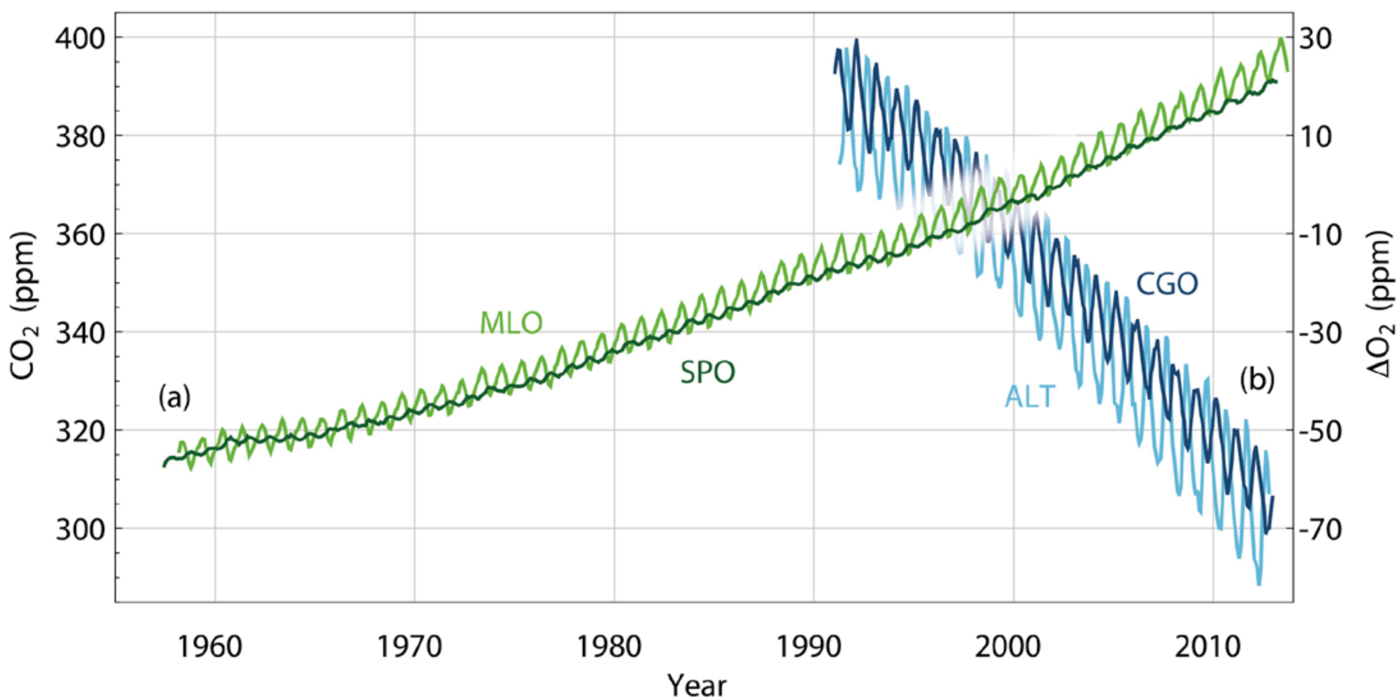
The Global Carbon Budget : separating the sinks – CO_2/O_2 method

$$\Delta CO_2 = \text{Emissions} - F_{ocean} - F_{land}$$

$$\Delta O_2 = -\alpha . \text{Emissions} + \beta . F_{land}$$ with $\alpha = 1.4$, $\beta = 1.1$

α → Combustion of FF (coal, oil, ..)

β → Photosynthesis, Respiration



IPCC, 2013

The Global Carbon Budget : for 2003-2012

8.6 ± 0.4 GtC/yr 92%

0.8 ± 0.5 GtC/yr 8%

\+

4.3±0.1 GtC/yr
45%

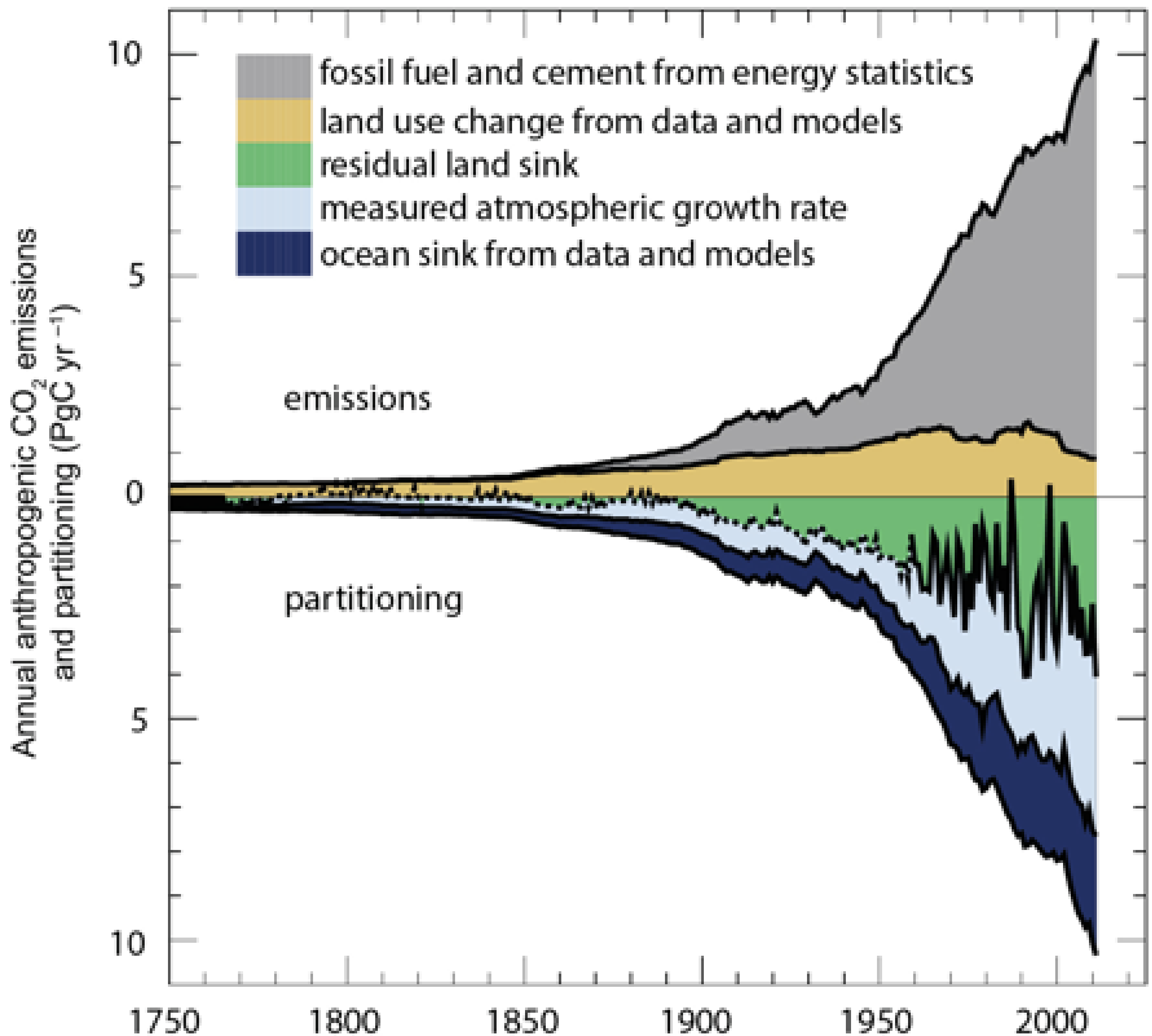
2.6 ± 0.5 GtC/yr
27%

2.6 ± 0.8 GtC/yr
27%

Calculated as the residual of all other flux components

GCP, 2013

The Global Carbon Budget : over 1750 - 2012



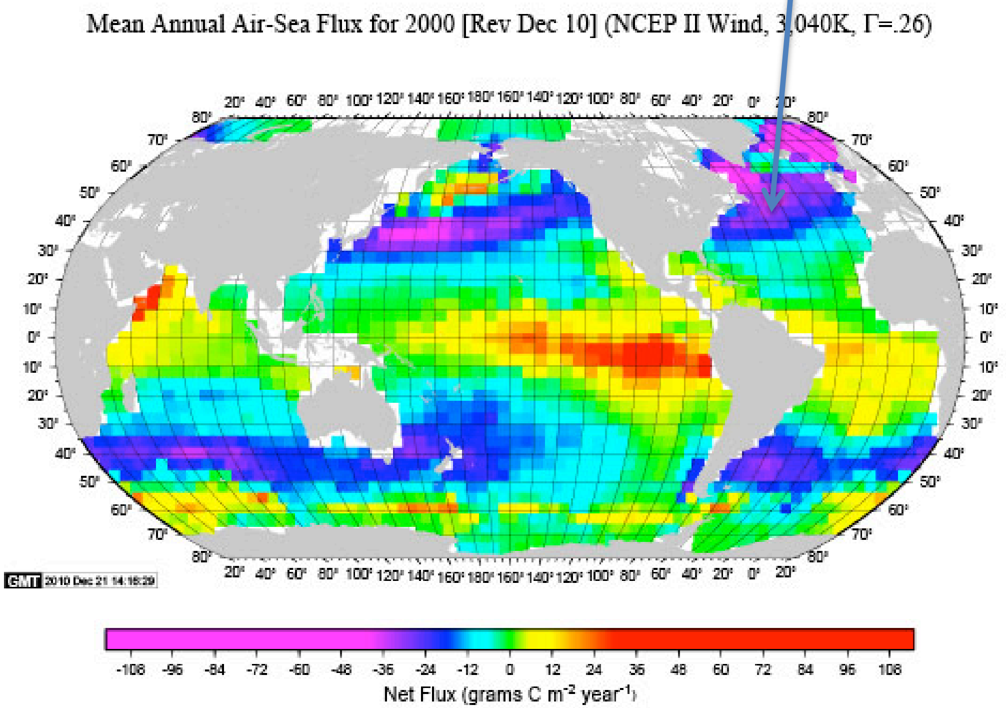
Natural Carbon Sinks : going regional

Sink regions

1. Direct measurements / observations

→ e.g., for the Ocean

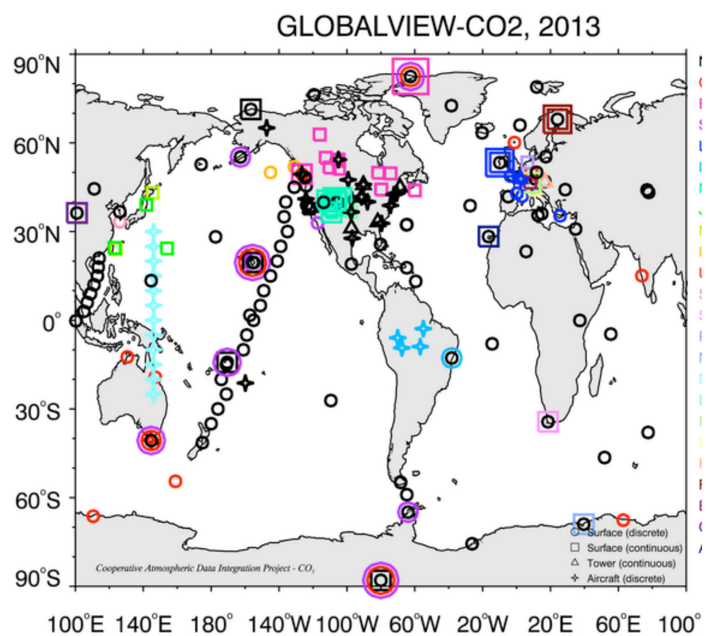
$F = kw\,(pCO_2\ \text{sea} - pCO_2\ \text{air})$

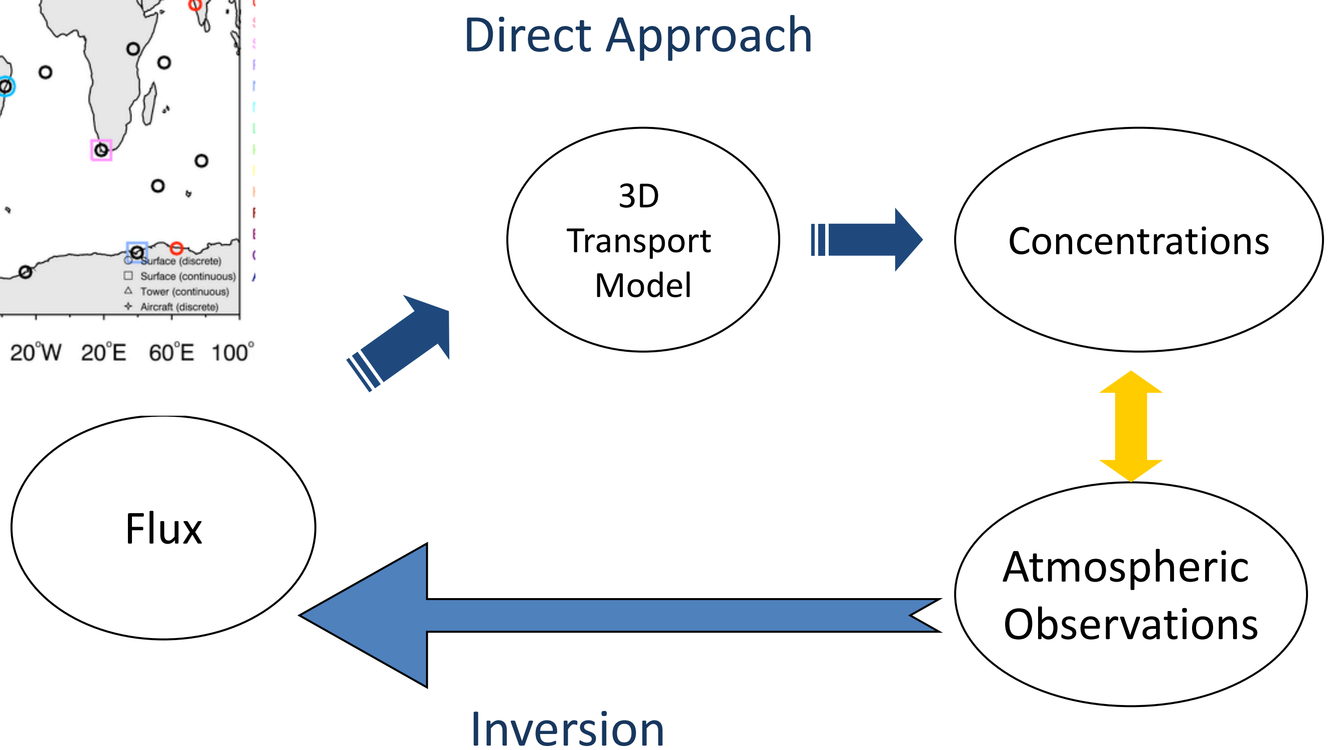


Takahashi et al. 2009

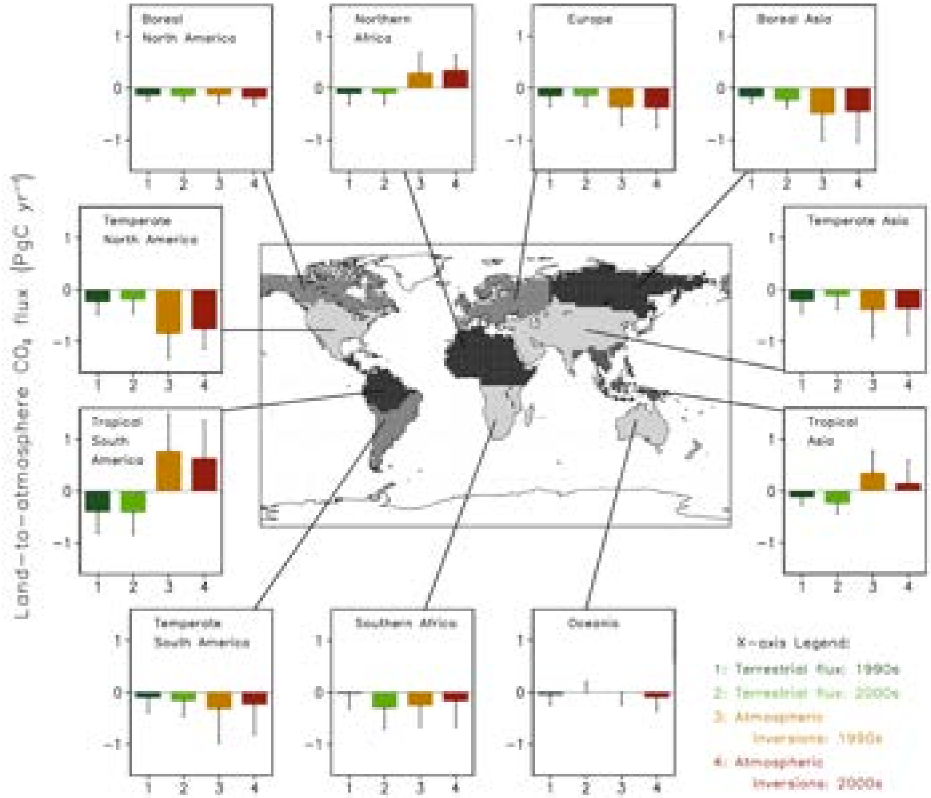
Natural Carbon Sinks : going regional

2 . Atmospheric Inversions to estimate regional fluxes

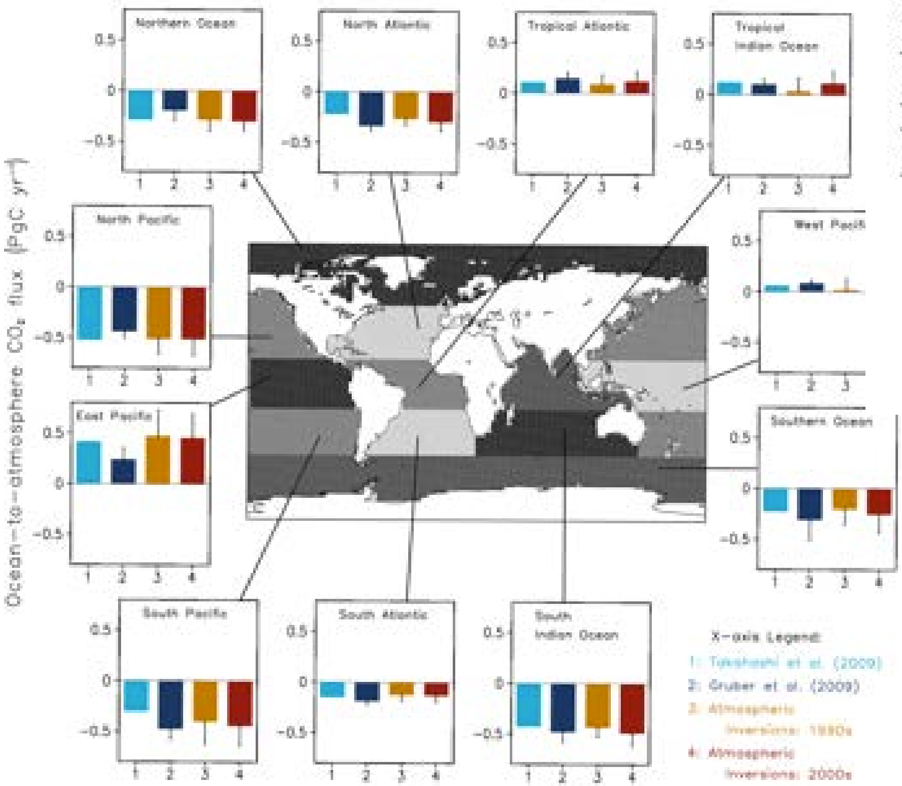




Natural Carbon Sinks : going regional



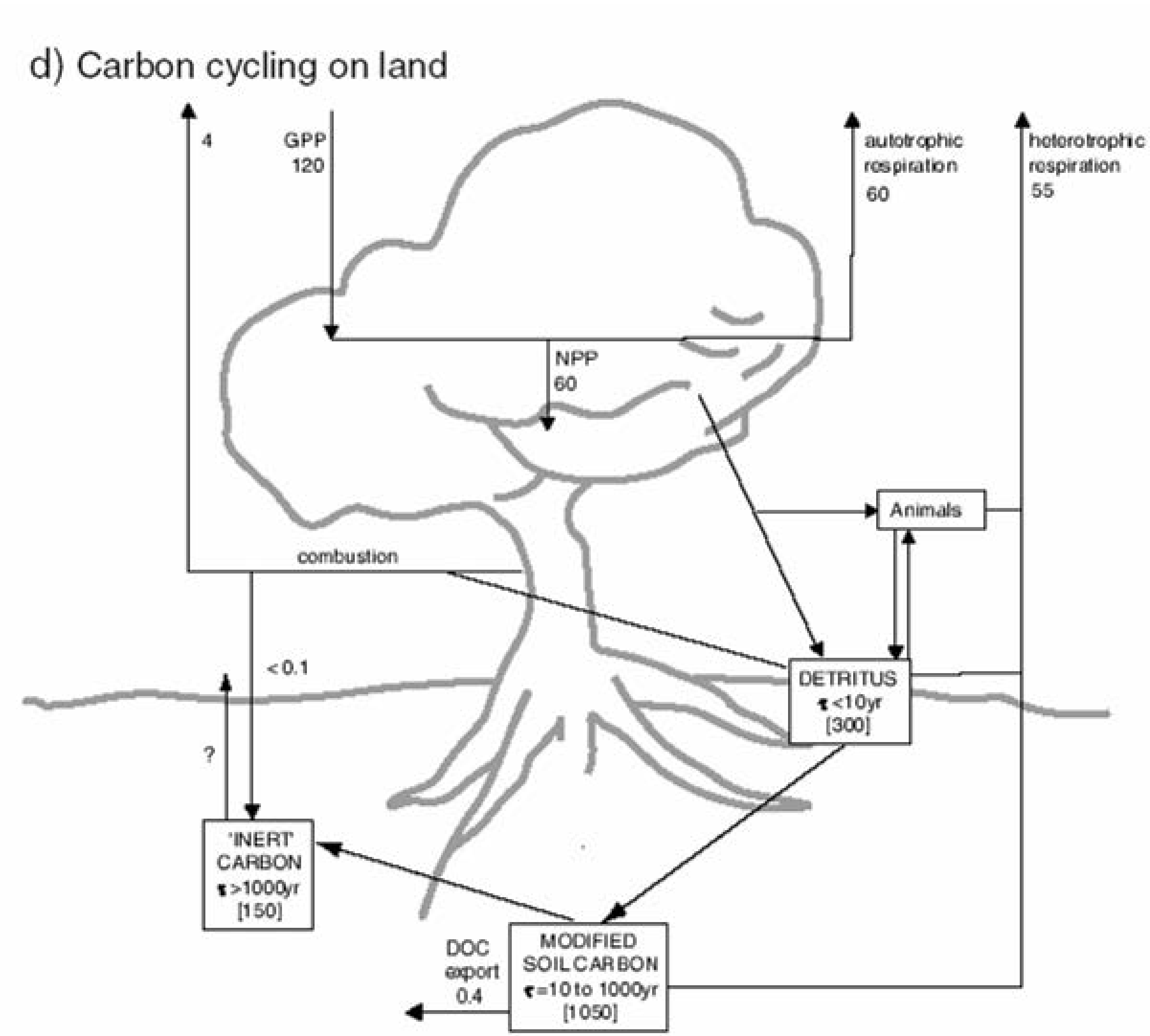
Estimated Ocean Sink



Estimated Land Sink

IPCC, 2013

Natural Carbon Sinks : Processes for the Land Sink



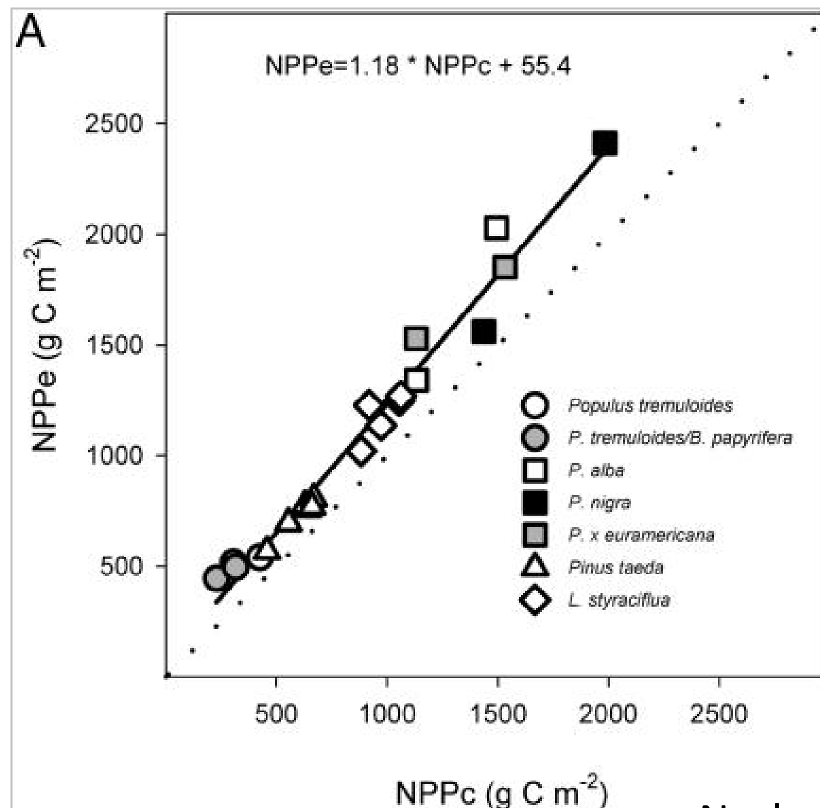
IPCC, TAR, 2001

Natural Carbon Sinks : Processes for the Land Sink

Which processes are responsible for the terrestrial sink ?

- CO_2 fertilization

FACE Experiments



Norby et al; 2005

Natural Carbon Sinks : Processes for the Land Sink

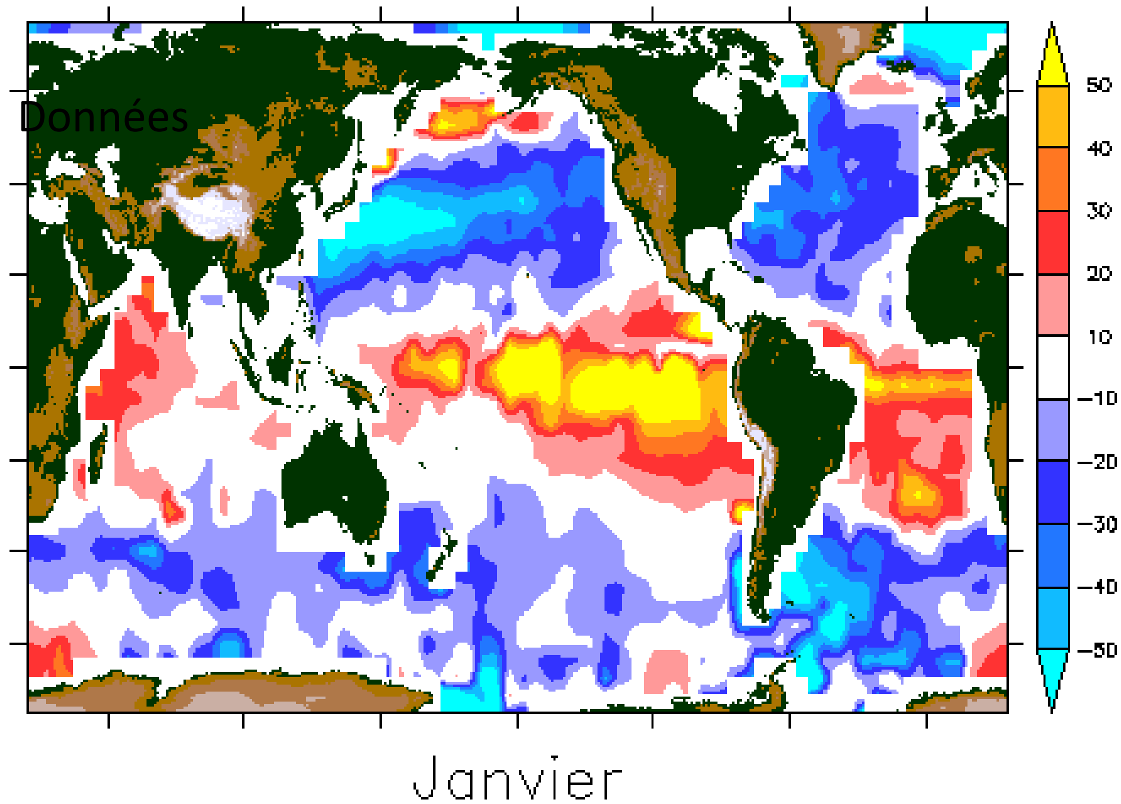
Which processes are responsible for the terrestrial sink ?

- CO_2 fertilization
- Anthropogenic nitrogen deposition
- Climatic Variability
- Land-use changes

Natural Carbon Sinks : Processes for the Ocean Sink

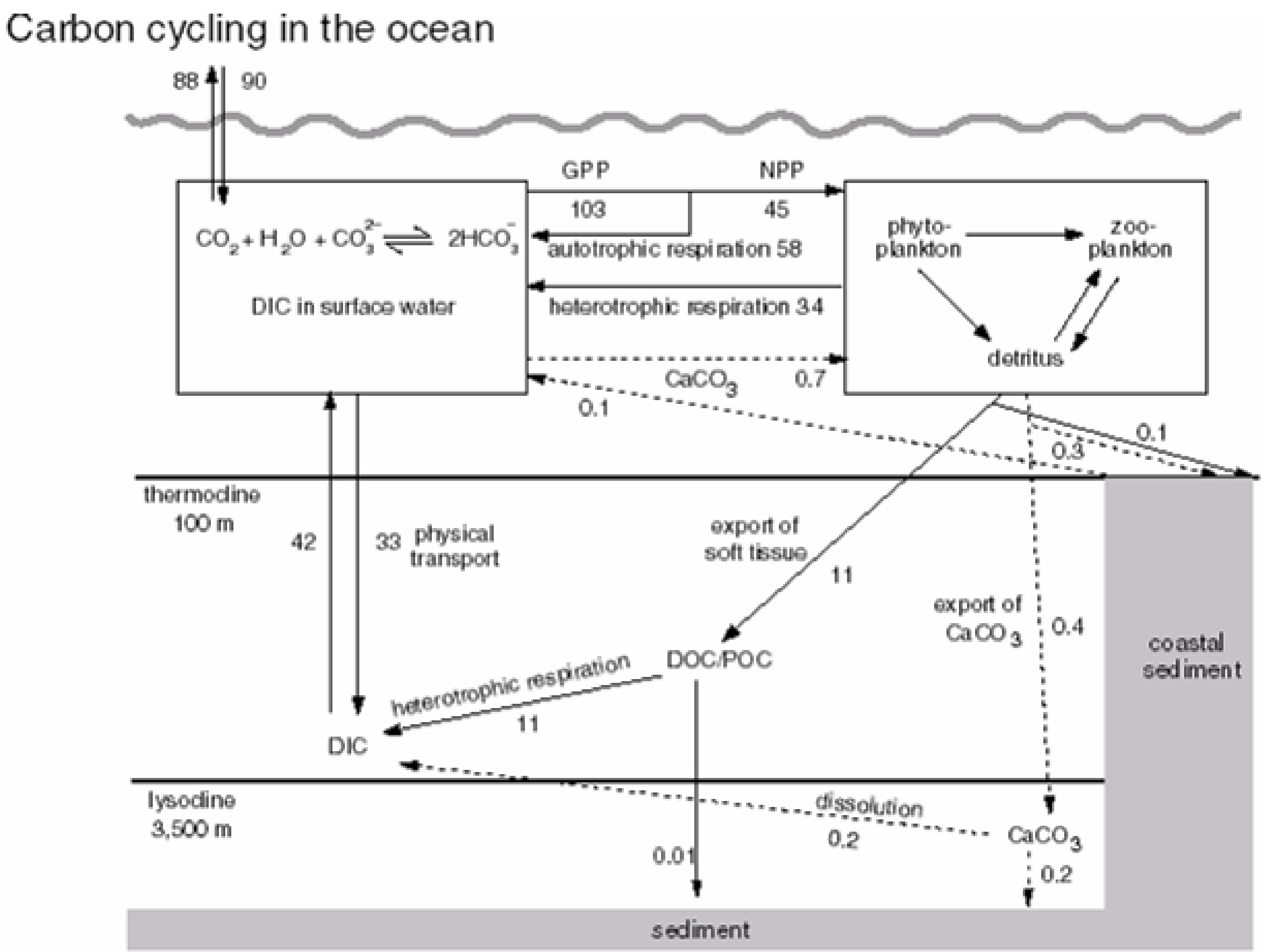
Carbon Sink

Carbon Source



(Takahashi et al. 2009)

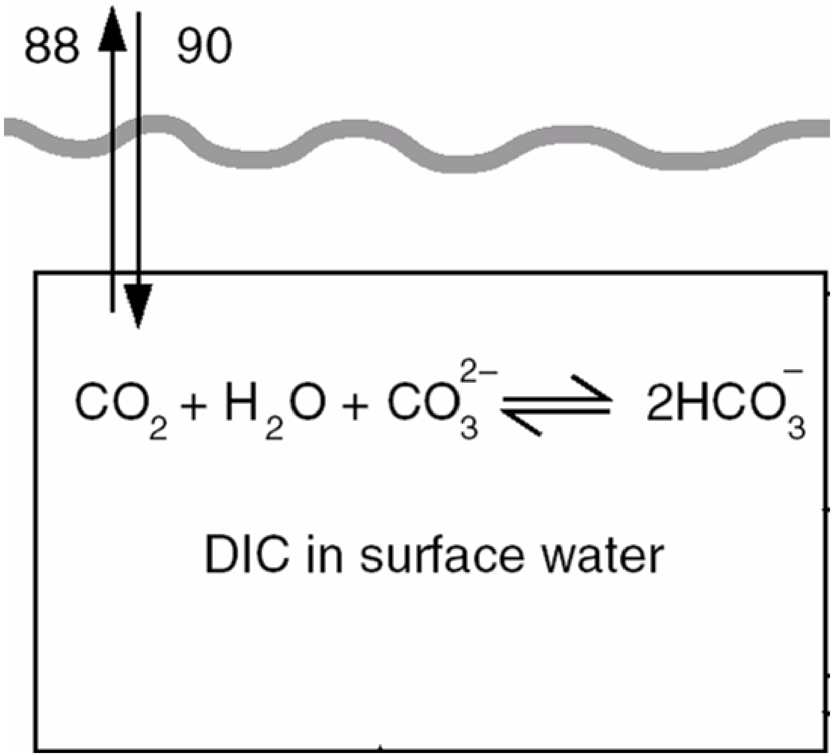
Natural Carbon Sinks : Processes for the Ocean Sink

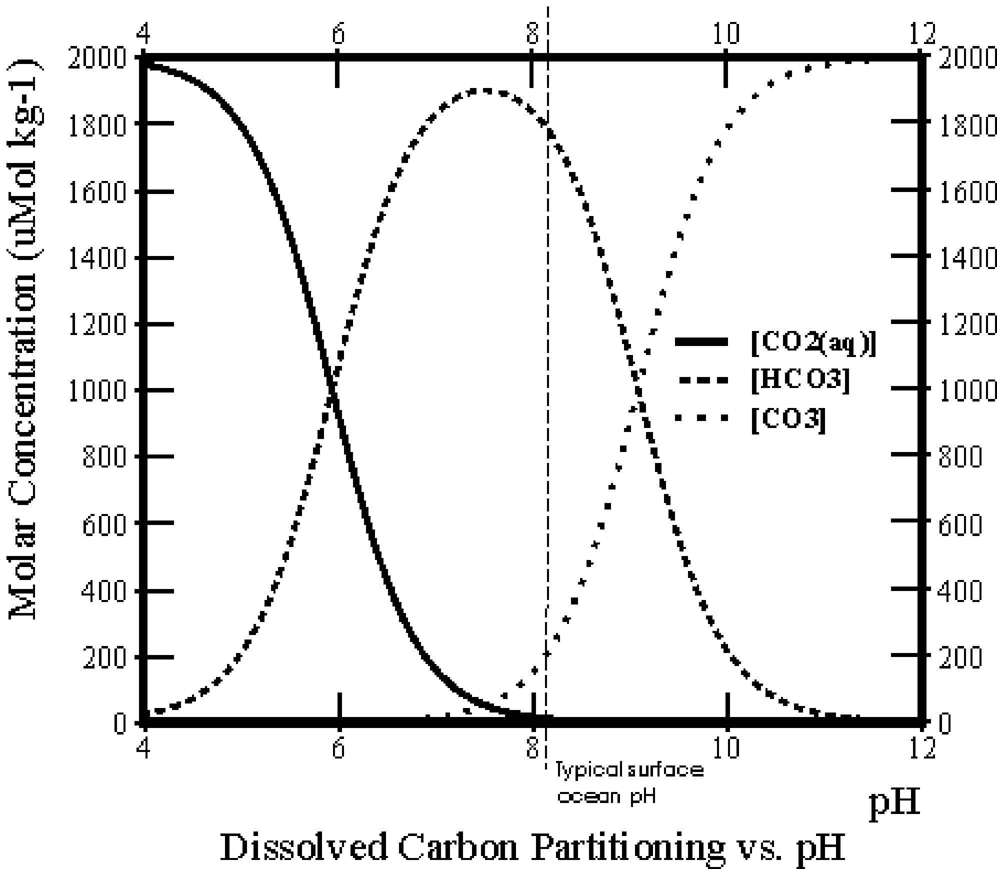


Marine Carbon Cycle : Physics / Chemistry / Biology

Natural Carbon Sinks : Processes for the Ocean Sink

Chemistry

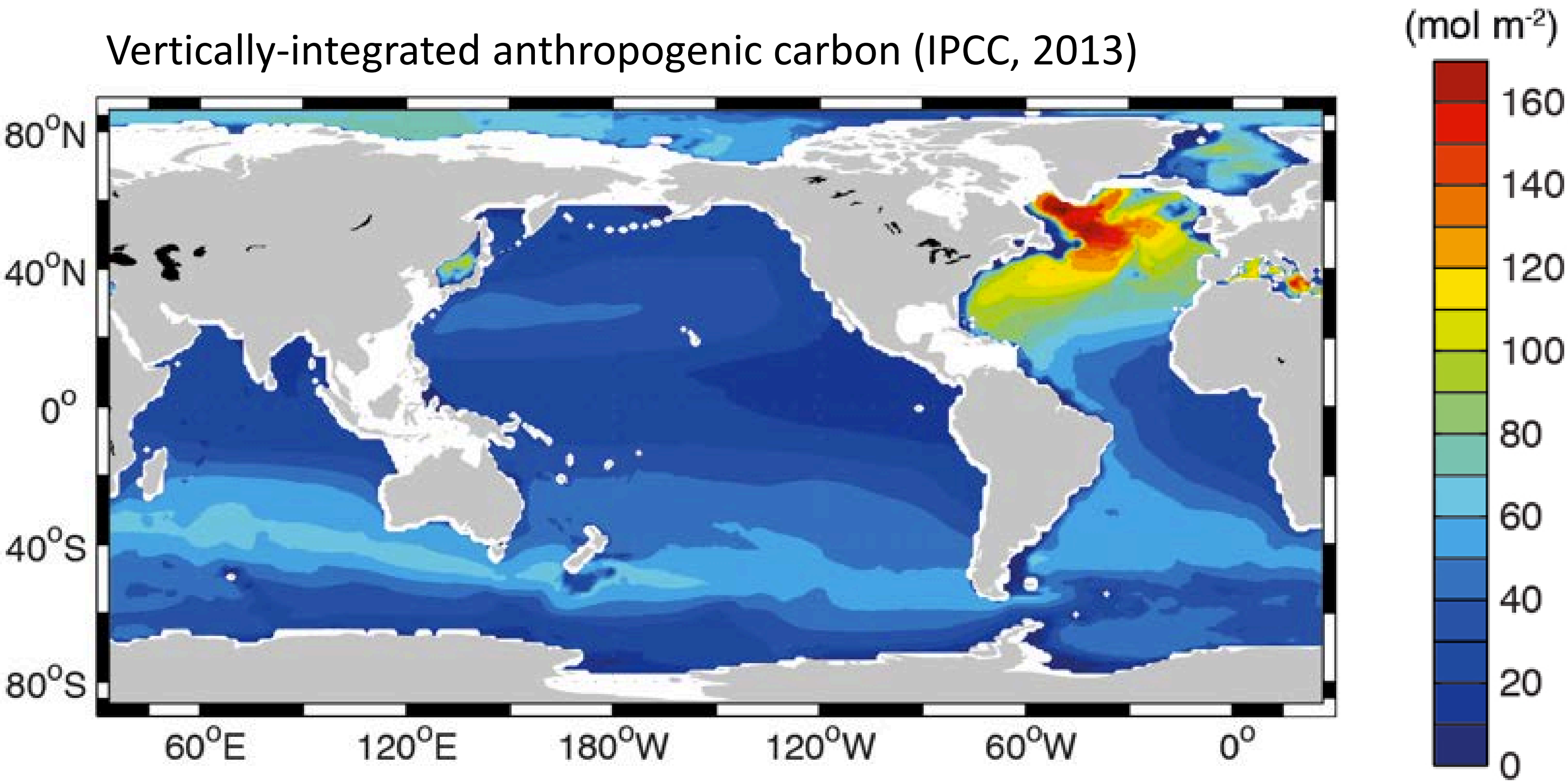




Natural Carbon Sinks : Processes for the Ocean Sink

Which processes are responsible for today's marine sink ?

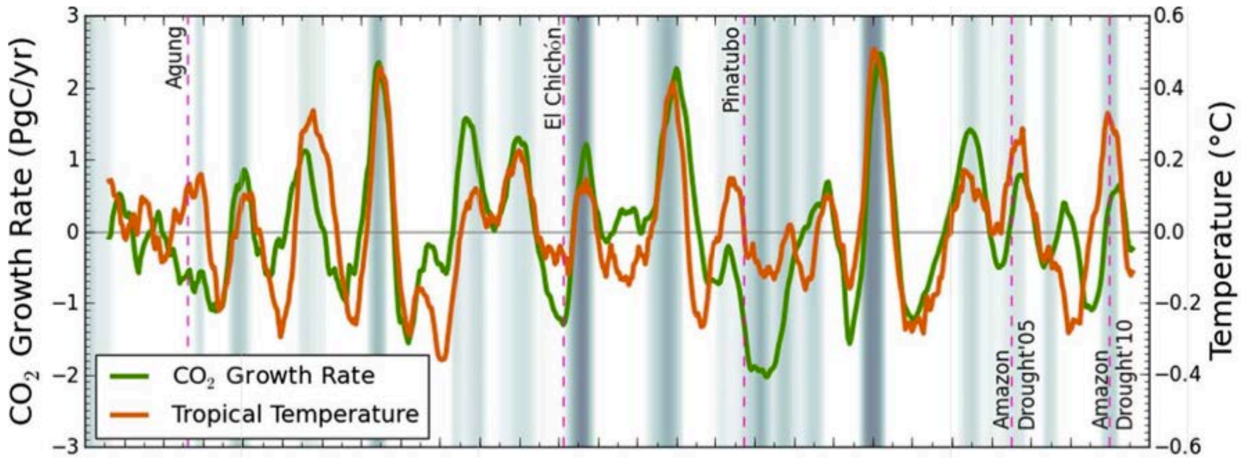
Vertically-integrated anthropogenic carbon (IPCC, 2013)



"Despite the importance of biological processes for the ocean's natural cycle, current thinking maintains that the oceanic uptake of anthropogenic CO2 is primarily a physically and chemically controlled process surimposed on a biogically driven carbon cycle that is close to steady state" (IPCC, 2001)

Climate-Carbon coupling – evidence on very different time-scales

Atmospheric CO2 growth rate and El-Ninos – Tropical Temperature (Wang et al. 2013)



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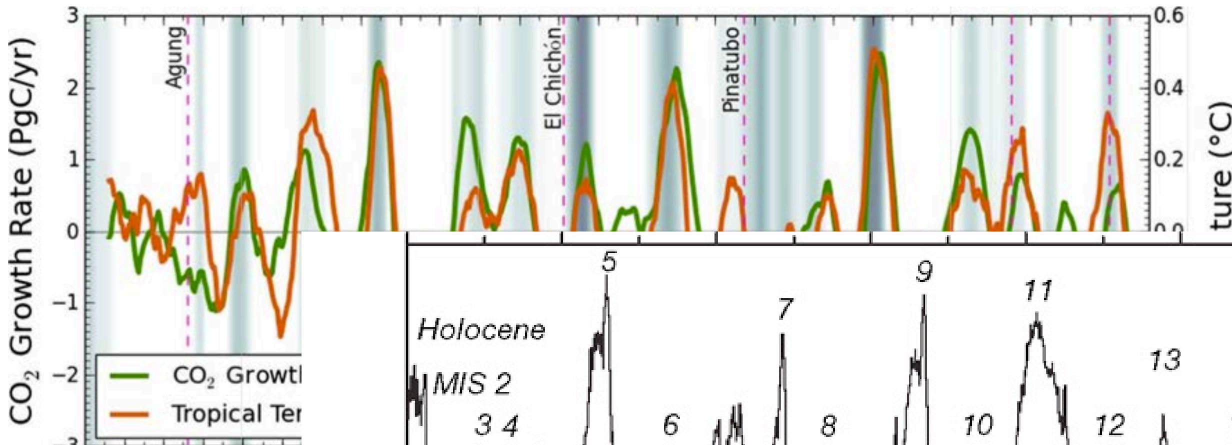
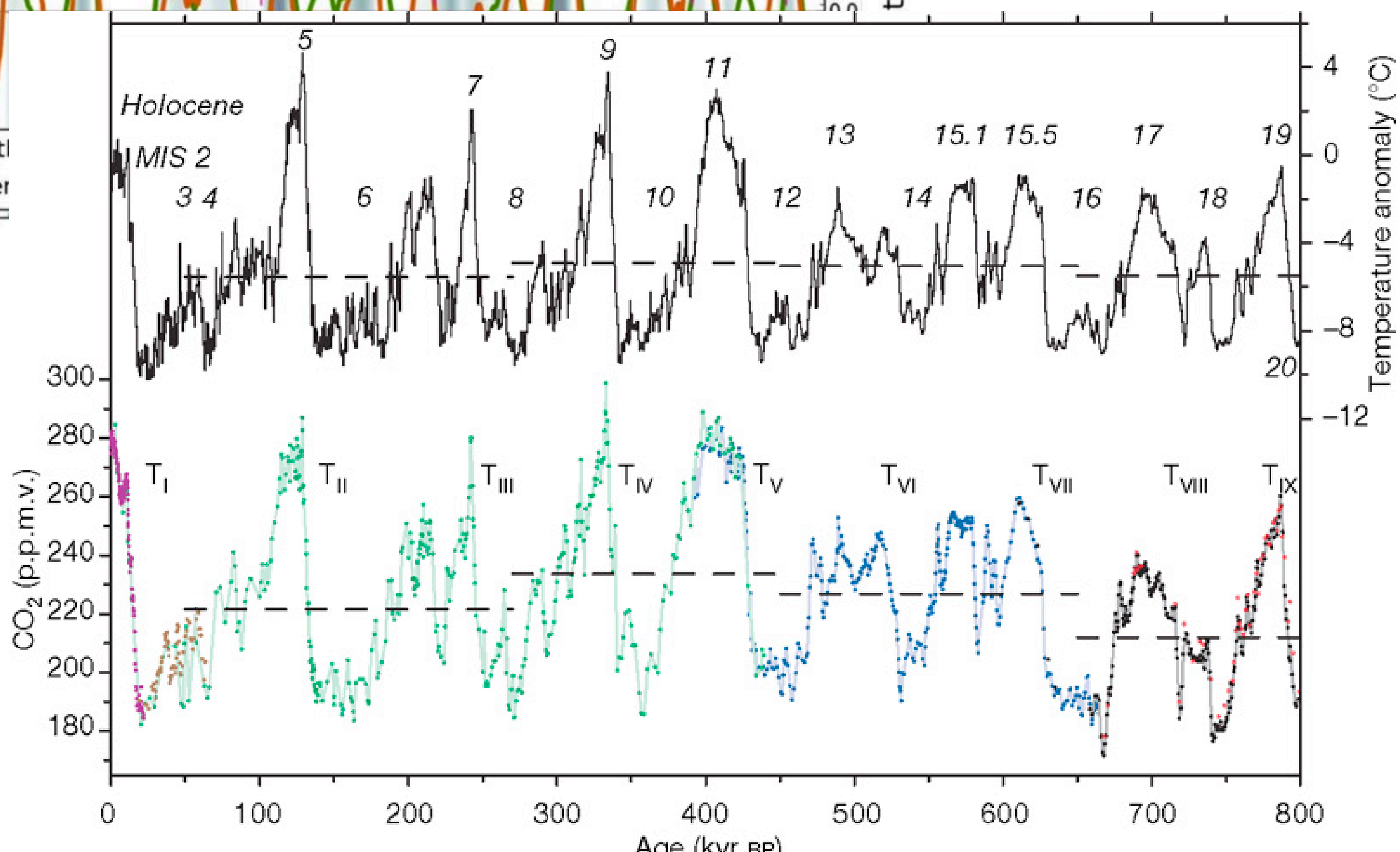
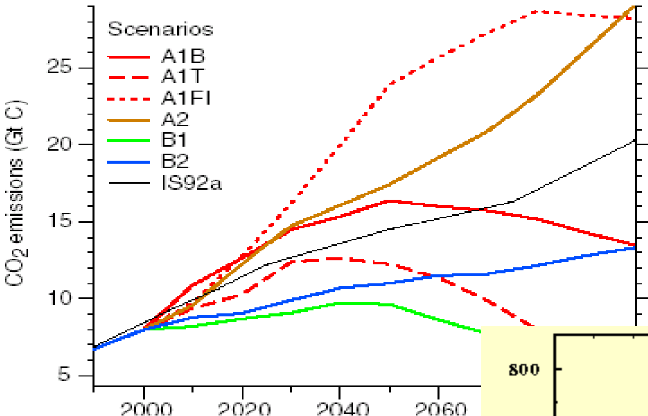


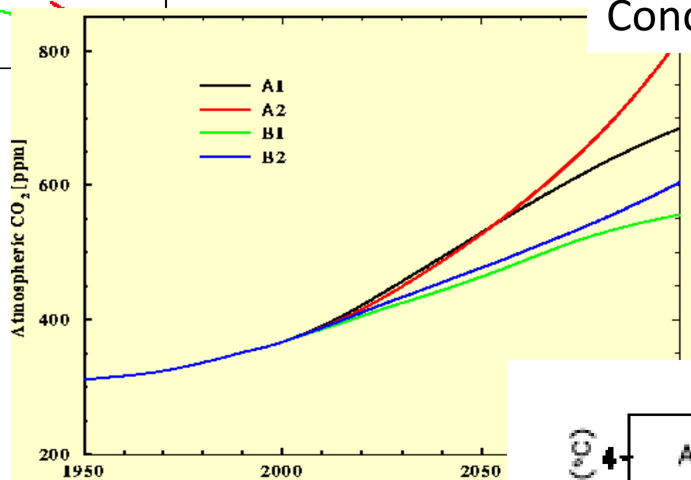


Atmospheric CO2 and temperature over glacial-interglacial cycles (Luthi et al. 2008)

Climate-Carbon coupling – a potential retroactino loop

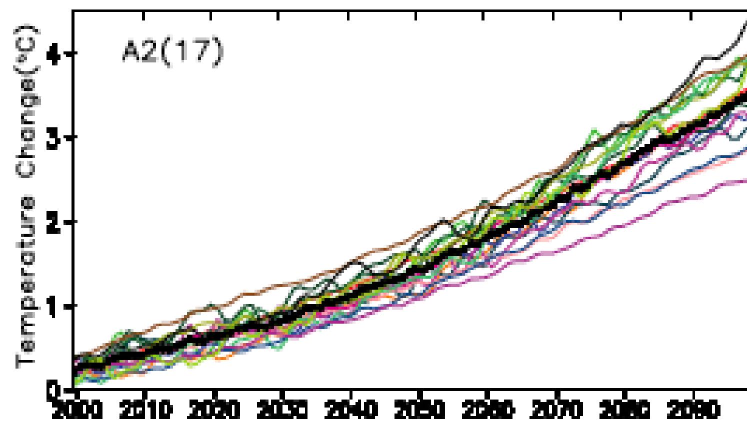


Emissions



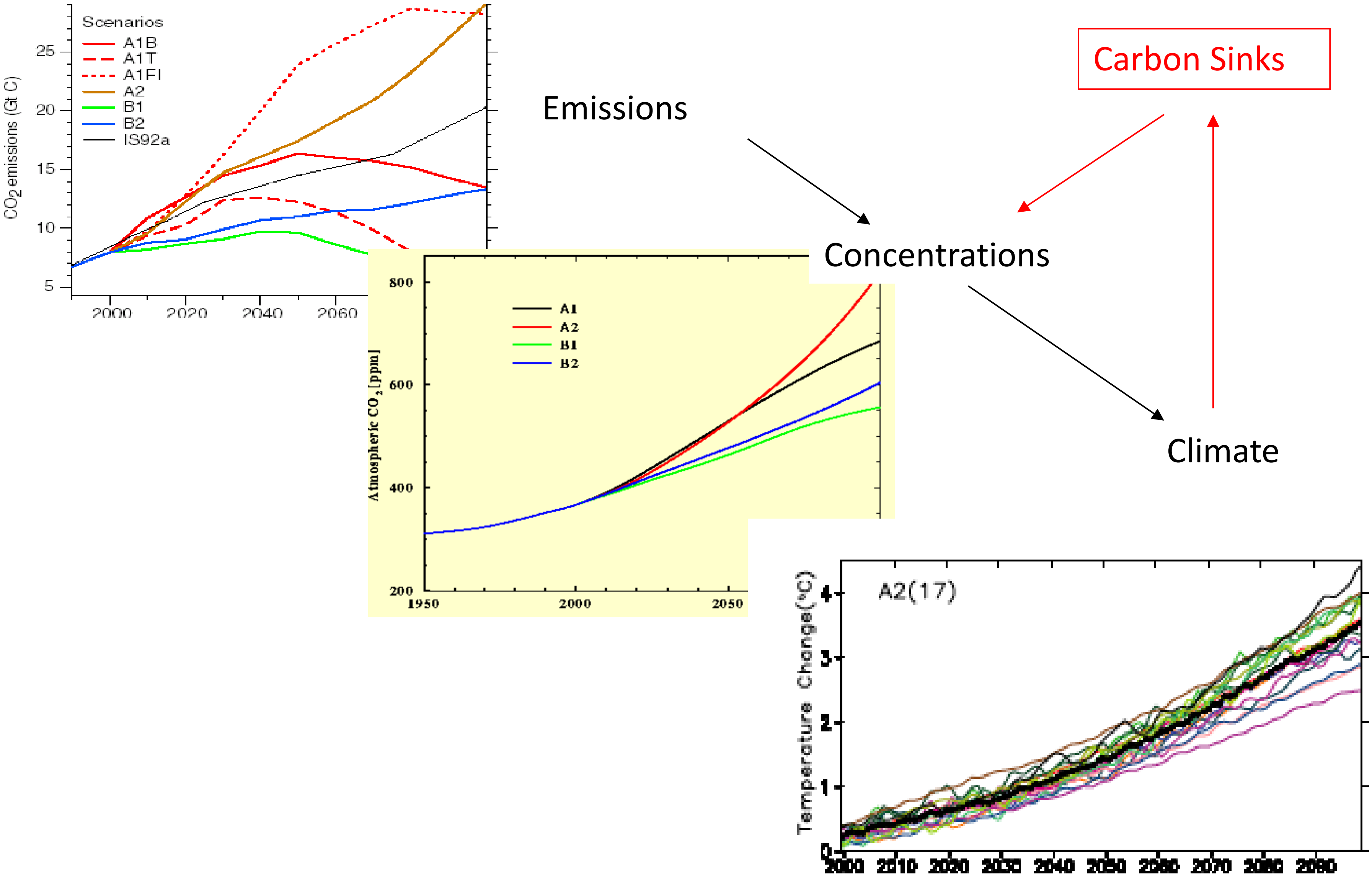
Concentrations

Climate



(IPCC, 2007)

Climate-Carbon coupling – a potential retroactino loop



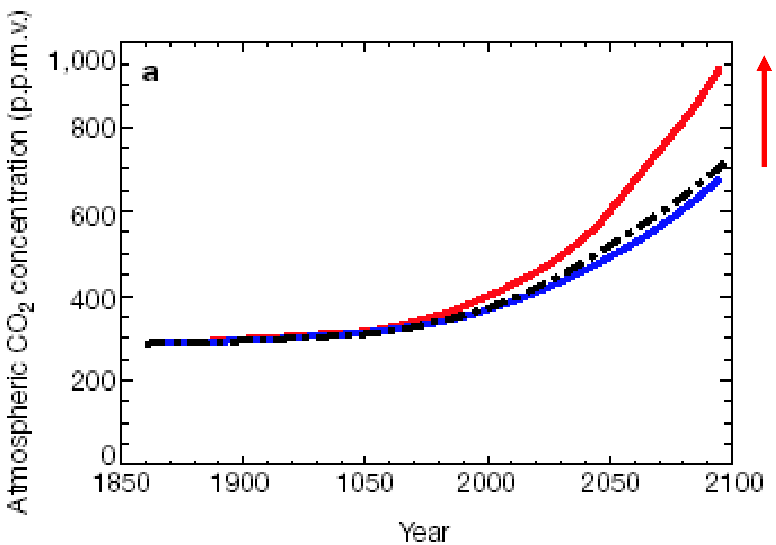
(IPCC, 2007)

Climate-Carbon coupling – Future projections

letters to nature

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

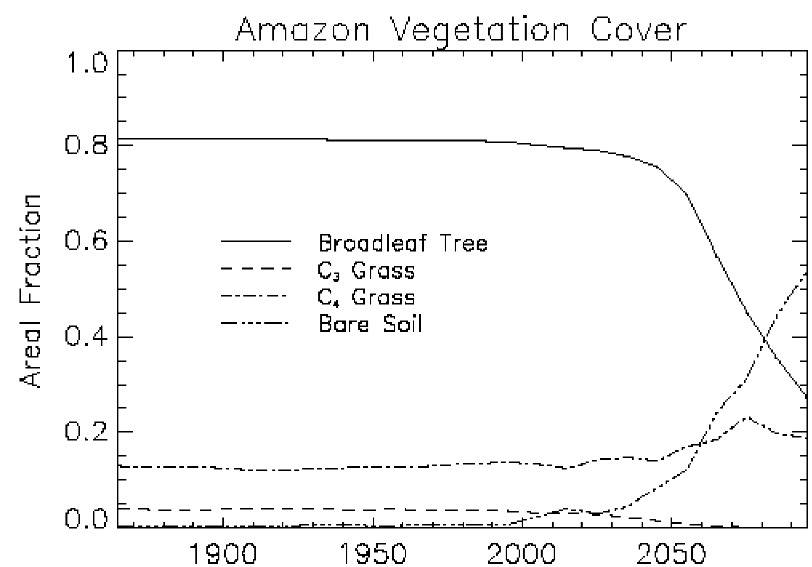
Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†



+ 220 ppm en 2100 !

Mechanisms

« Amazon die-back »



Climate-Carbon coupling – Future projections

Which processes are responsible (in the models) for the climate impact on uptakes ?

Land

Net primary productivity decreases with decreasing water availability
Heterotrophic respiration increases with temperature

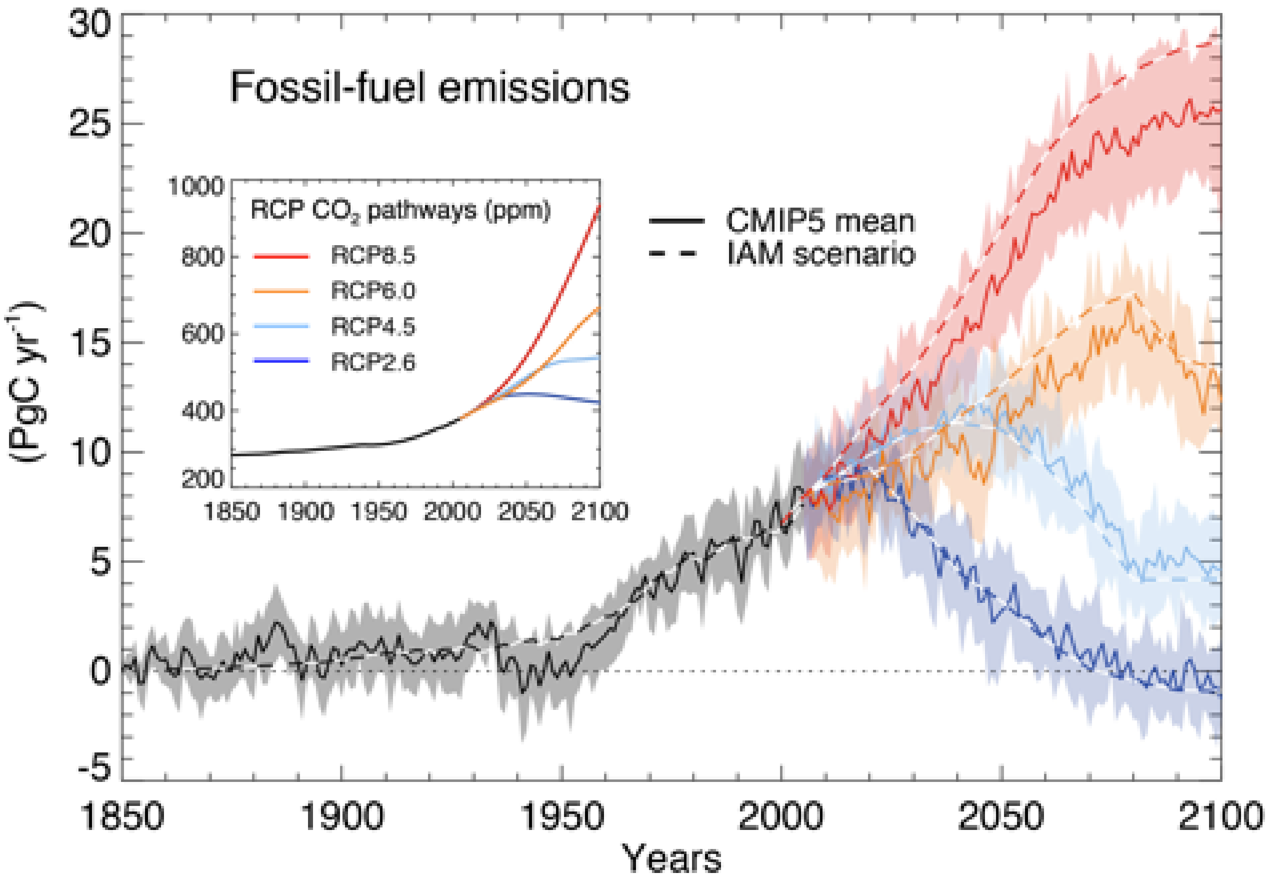
-> But no consensus. Large uncertainties

Ocean

Warming Effect : Increased T decreases CO_2 solubility
Dynamical Effect : Increases stratification prevents anthropogenic CO_2 penetration
Biological Effects ?

-> Uncertainties on the dynamical effect / biological effect.

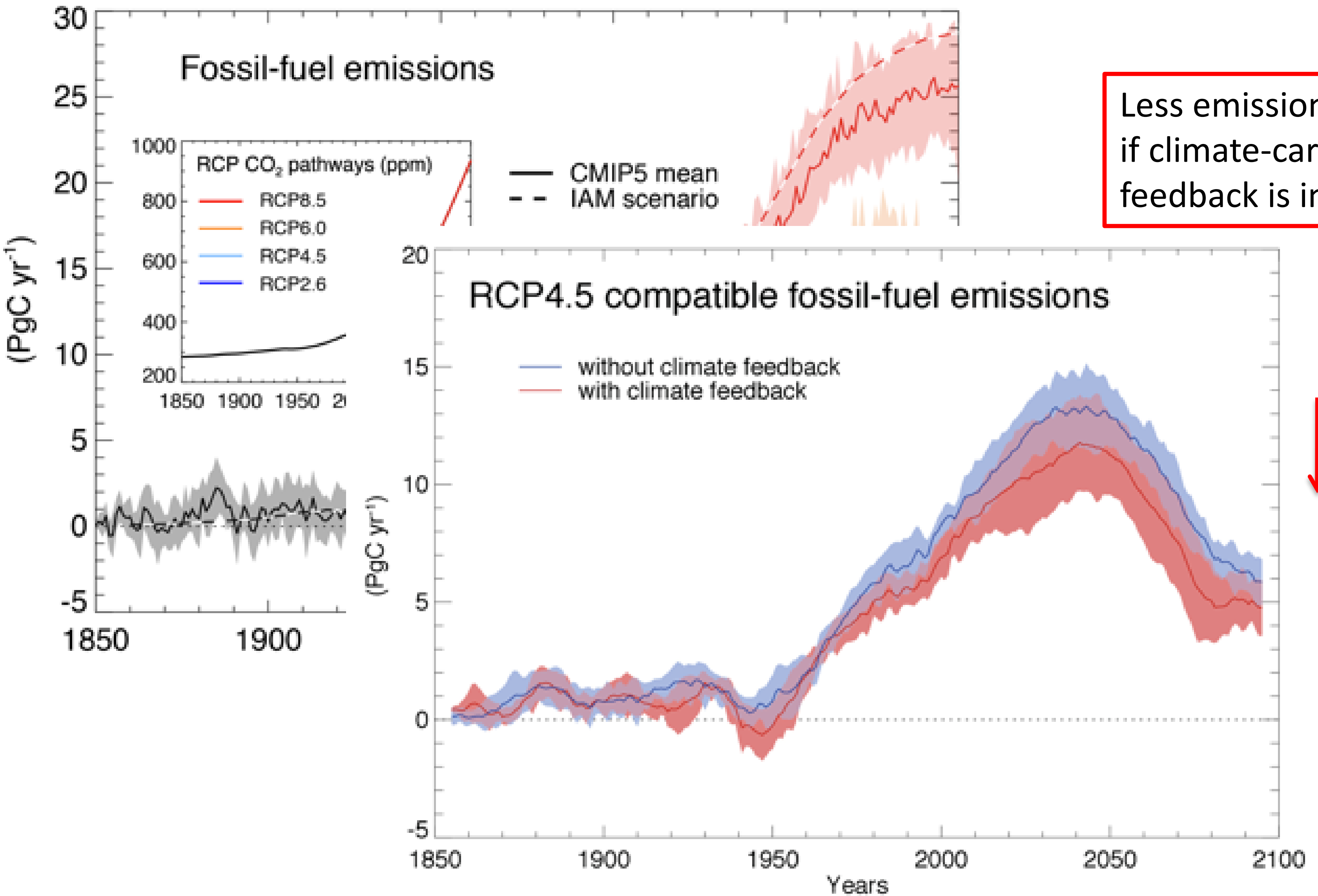
Climate-Carbon coupling – Implications on allowable emissions



Allowable FF Emissions = dCO2/dt + Focean + Fland

(computed with coupled climate-carbon models, IPCC, 2013))

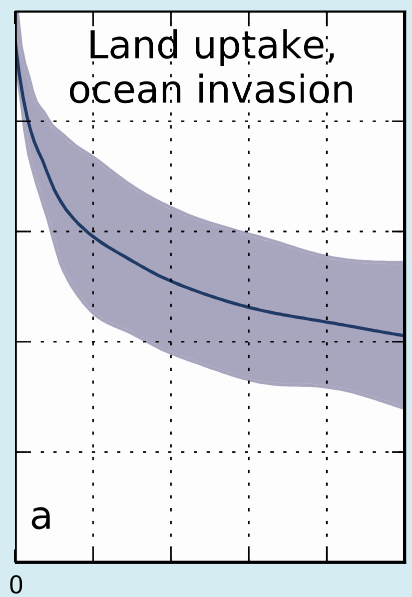
Climate-Carbon coupling – Implications on allowable emissions



Less emissions
if climate-carbon
feedback is included

Conclusions – Long time scales not mentionned here…

CO_2 remains in the atmosphere long after emissions



IPCC, 2013