



European Geosciences Union

GIFT – Geosciences Information For Teachers

The global carbon cycle and climate-carbon coupling

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LSCE



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., et al. (eds.)]



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The annual report of the Global Carbon Project

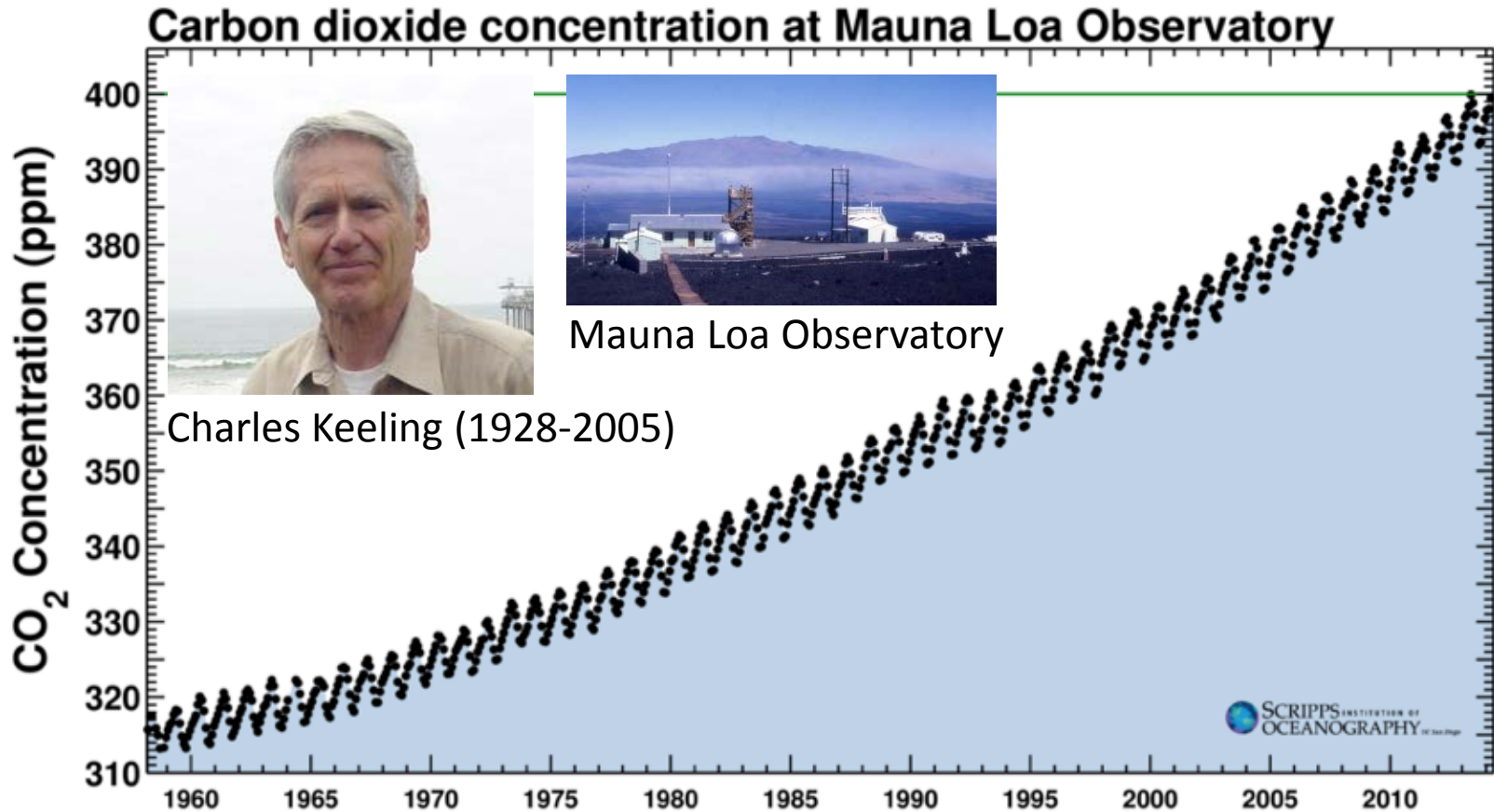
Le Quéré, C., et al. (49 authors) :
Global carbon budget 2013, Earth Syst. Sci. Data Discuss., 6, 689-760, doi:10.5194/essdd-6-689-2013, 2013.

Global Carbon Budget

Carbon Budget 2013

An annual update of the global carbon budget and trends

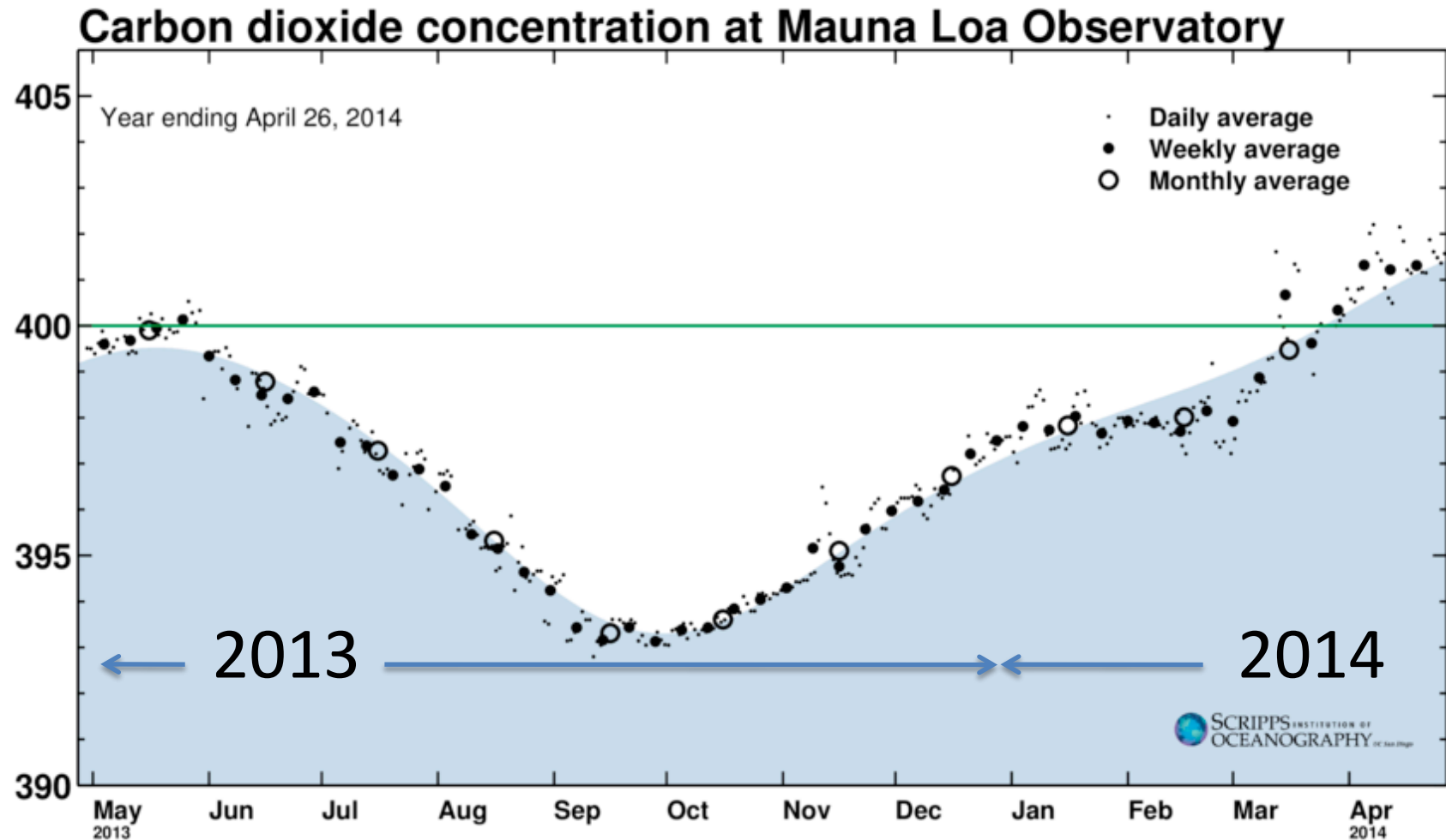
Introduction: The Keeling curve



Atmospheric CO₂ has increased from 315 ppm in 1959 to 396.5 ppm in 2013
(+ 26 % in ~50 years)

Introduction: The Keeling curve

Atmospheric CO₂ above 400 ppmv for the first time over 4 consecutive weeks



Introduction / Outline

The Global Carbon Budget – $\Delta\text{CO}_2 = \text{Emissions} - F_{\text{ocean}} - F_{\text{land}}$

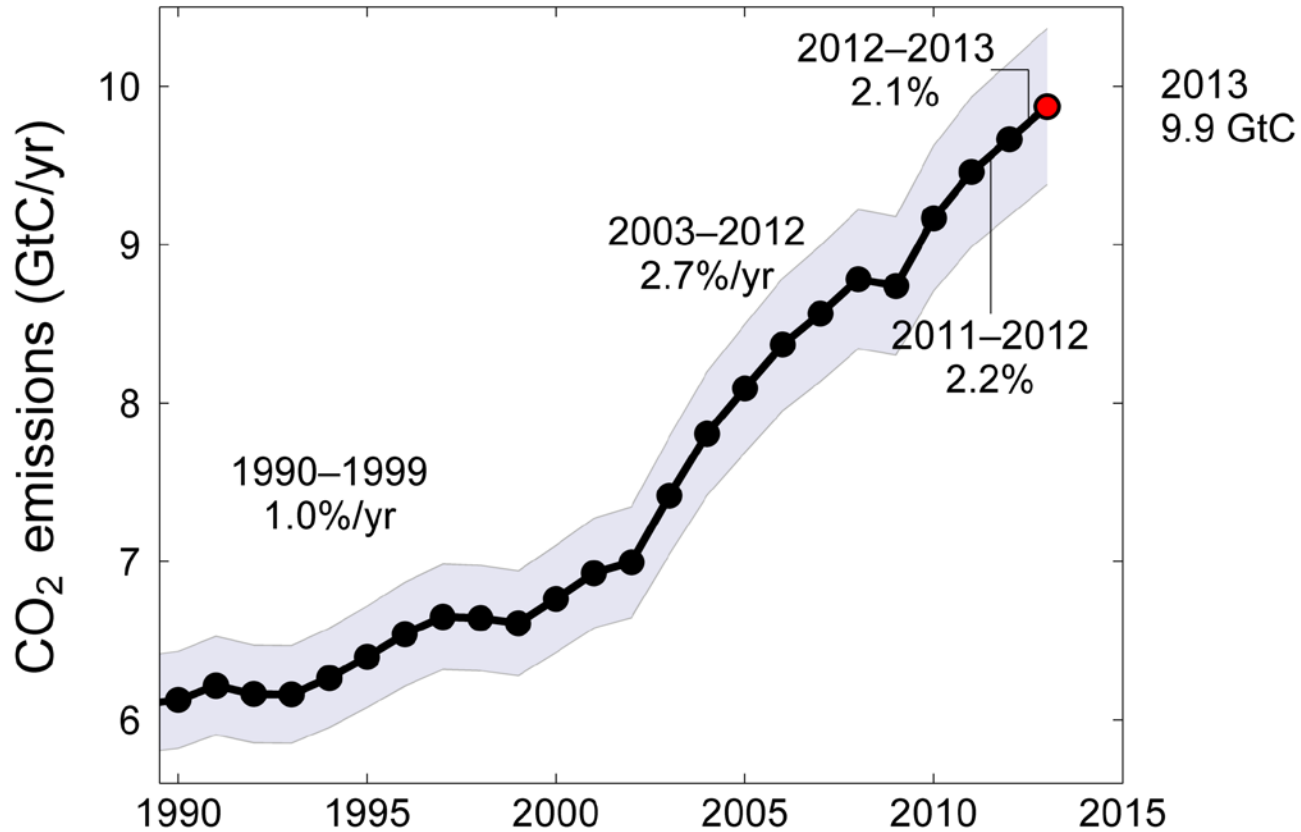
Natural Carbon Sinks – F_{ocean} and F_{land}

Climate-Carbon coupling – F_{ocean} and F_{land} influenced by climate

The Global Carbon Budget : Emissions

Billions tonnes of Carbon

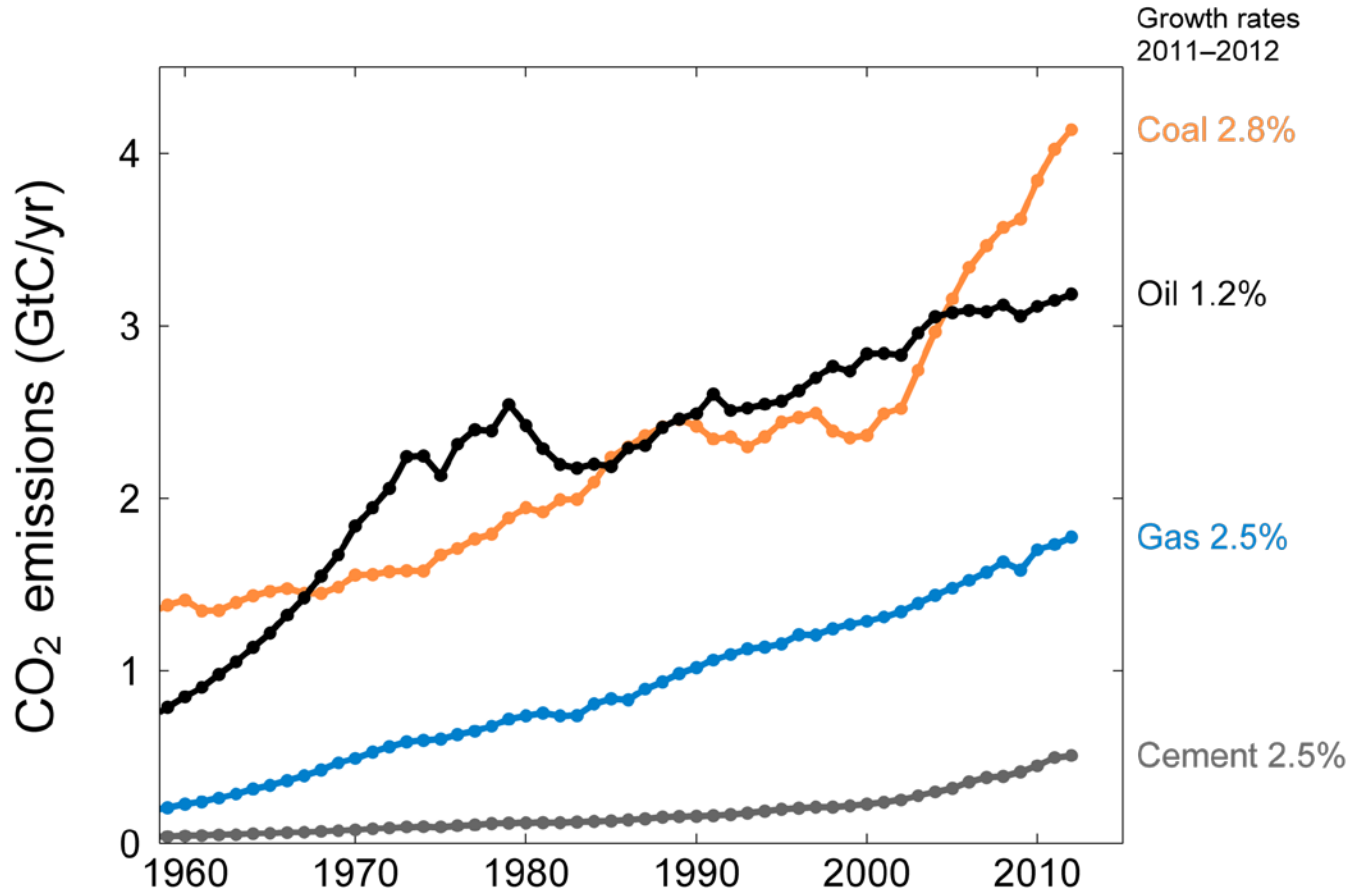
Global fossil fuel and cement emissions: 9.9 ± 0.5 GtC in 2013, 61% over 1990



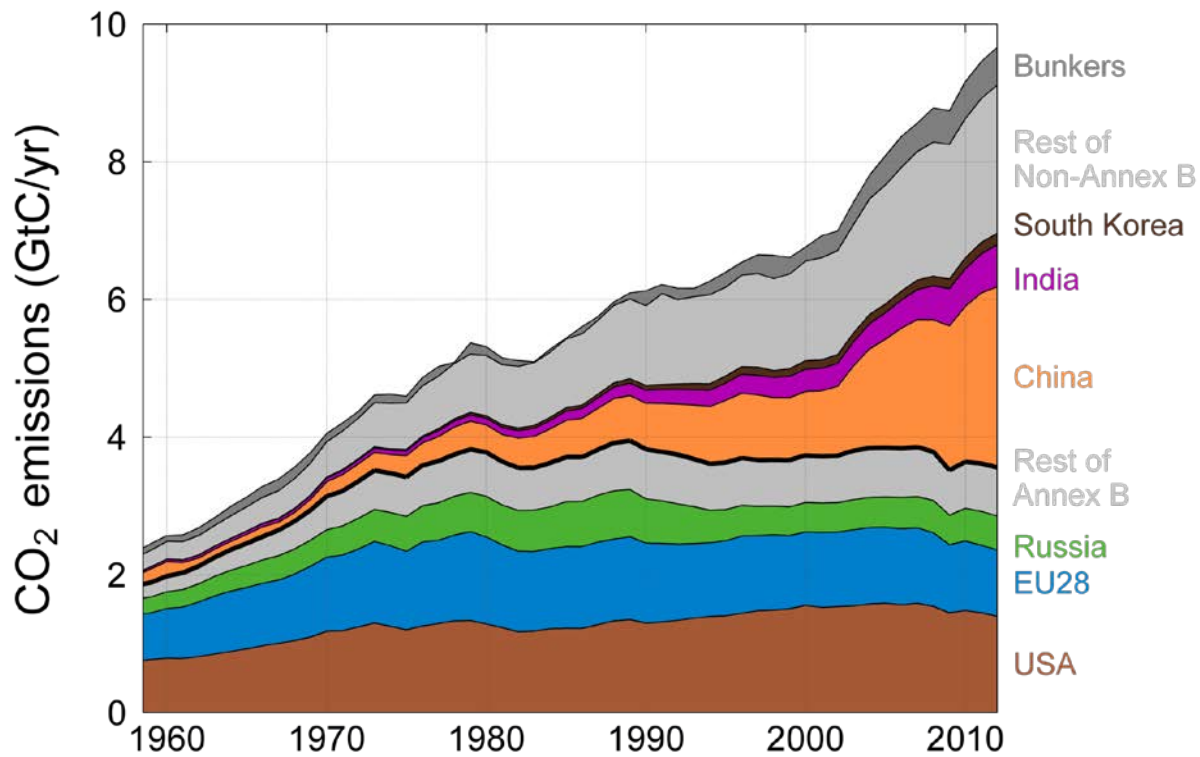
The Global Carbon Budget : Emissions

Share of global emissions in 2012:

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

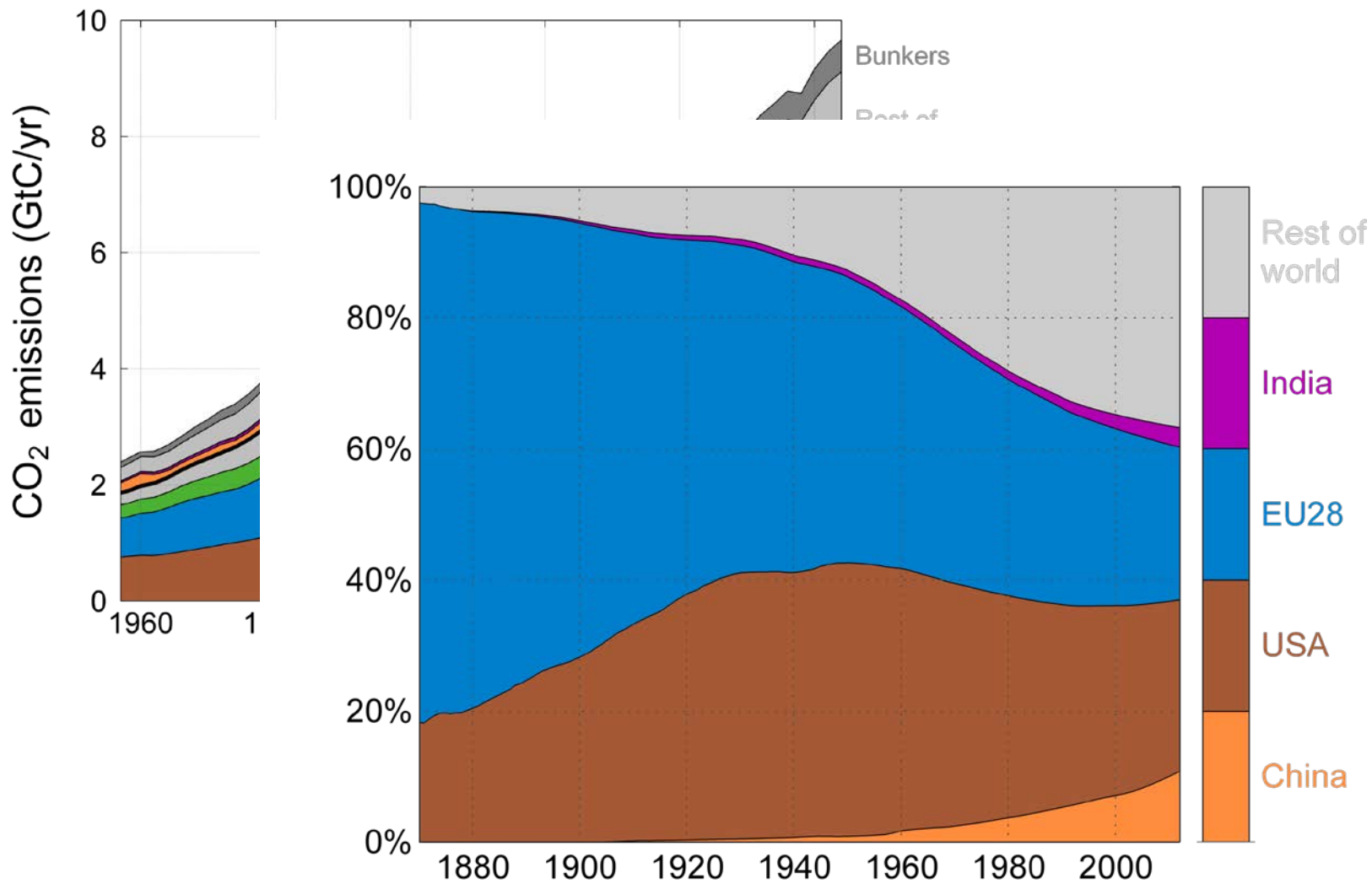


The Global Carbon Budget : Emissions per country / regions



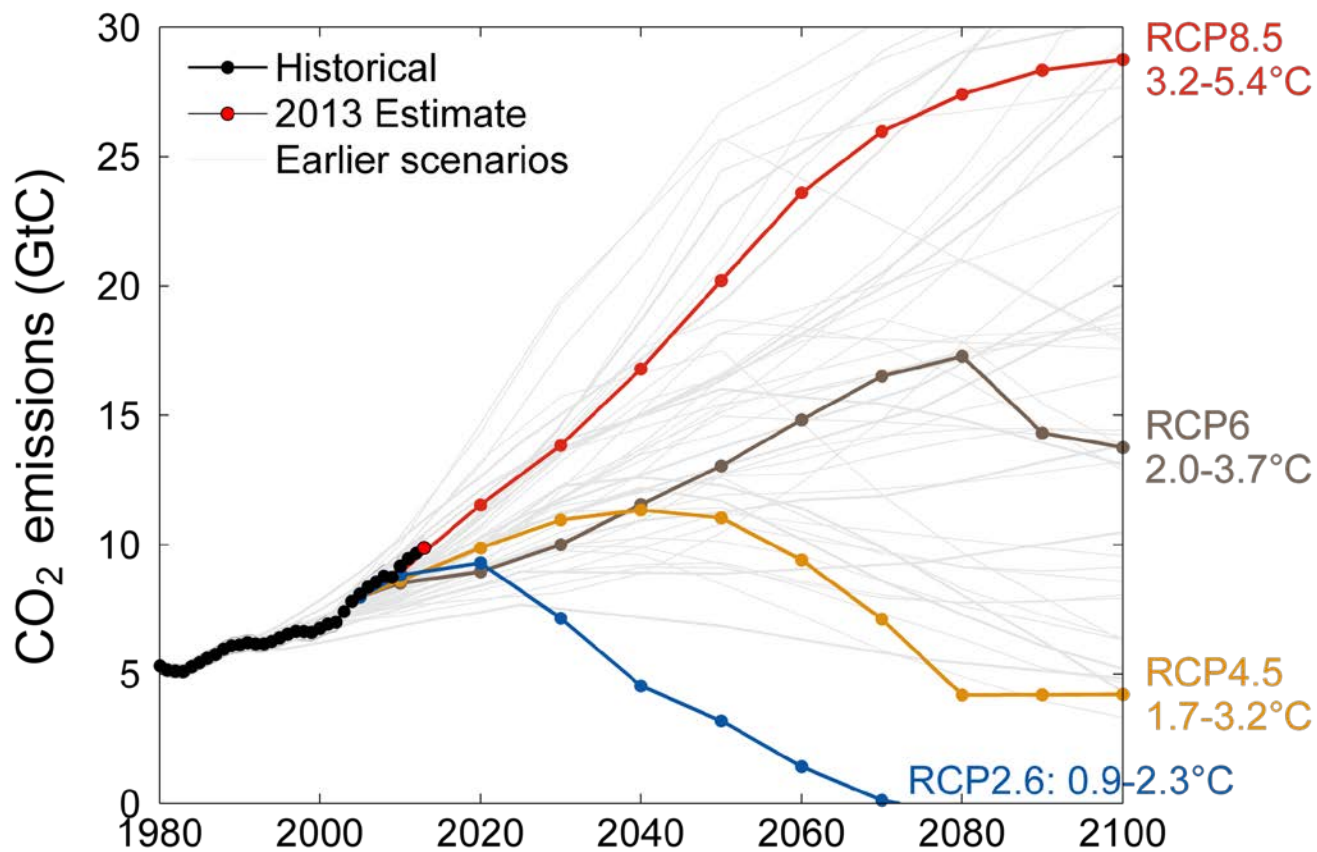
Break-Down by Country

The Global Carbon Budget : Emissions per country / regions



Break-Down by Country for Historical Cumulative Emissions

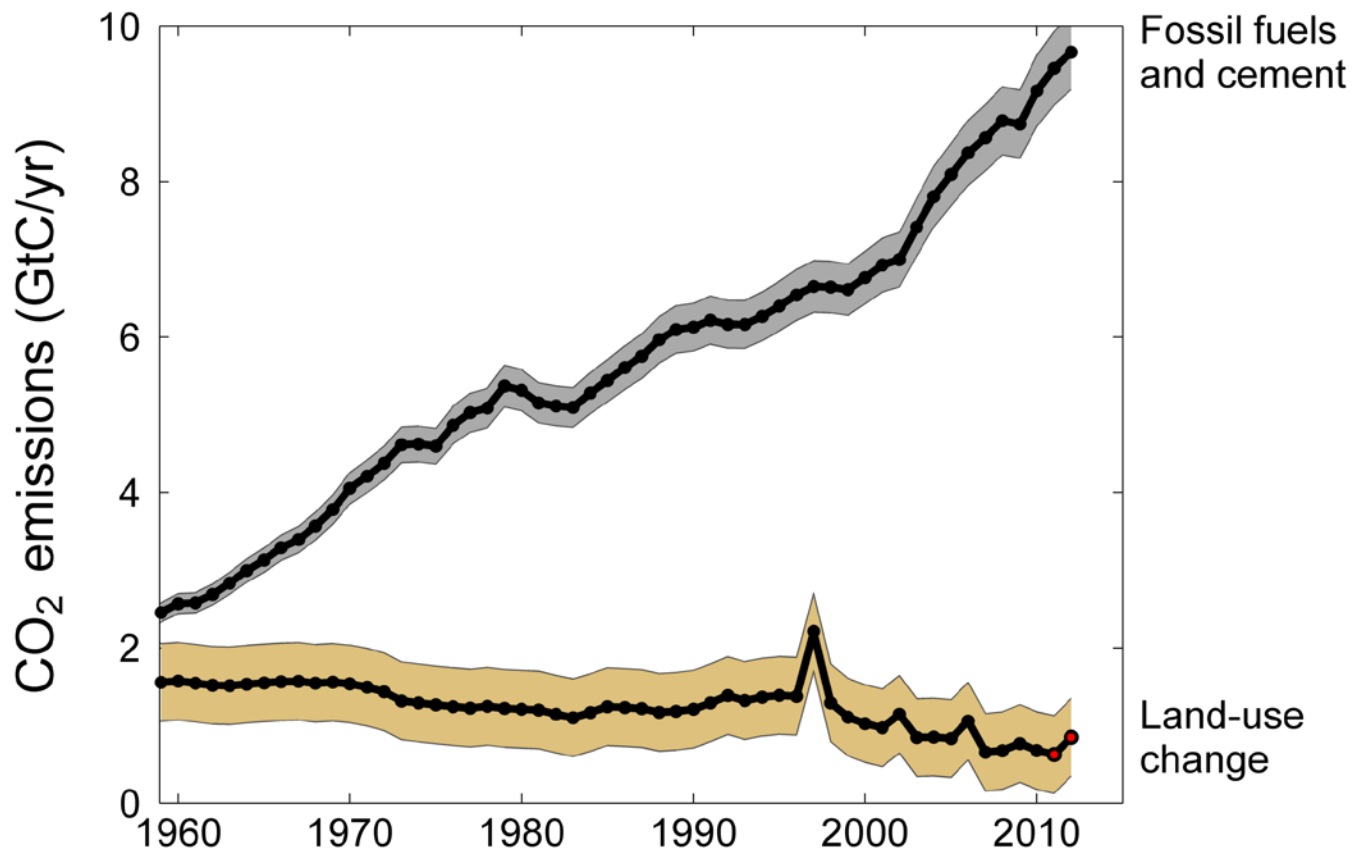
The Global Carbon Budget : Emissions vs Scenarios



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



The Global Carbon Budget : see the Global Carbon Atlas

<http://www.globalcarbonatlas.org>

The screenshot shows the homepage of the Global Carbon Atlas website. At the top left is the logo for the Global Carbon Atlas. To its right is a navigation menu with tabs for HOME, OUTREACH, EMISSIONS, and RESEARCH. A search bar is located to the right of the navigation menu. Below the navigation menu is a secondary menu with links for Overview, Contributors, Contact, and What's new?. The main content area is divided into three sections: 1. A large heading 'GLOBAL CARBON ATLAS' followed by a paragraph: 'The Global Carbon Atlas is a platform to explore and visualize the most up-to-date data on carbon fluxes resulting from human activities and natural processes.' To the right of this paragraph is another paragraph: 'Human impacts on the carbon cycle are the most important cause of climate change.' 2. An 'OUTREACH' section with a sub-heading 'Take a journey through the history and future of human development and carbon' and an orange 'GO' button. The background of this section is a cityscape illustration. 3. An 'EMISSIONS' section with a world map showing carbon emissions as black circles of varying sizes, an orange 'GO' button, and a sub-heading 'Explore and download global and country level carbon emissions from human activity.' 4. A 'RESEARCH' section with a sub-heading 'Explore and visualize research carbon data, and get access through data providers' and an orange 'GO' button. The background of this section features a line graph and a heatmap of the world.

GLOBAL CARBON ATLAS

HOME | OUTREACH | EMISSIONS | RESEARCH

Overview | Contributors | Contact | What's new?

GLOBAL CARBON ATLAS

The Global Carbon Atlas is a platform to explore and visualize the most up-to-date data on carbon fluxes resulting from human activities and natural processes.

Human impacts on the carbon cycle are the most important cause of climate change.

OUTREACH

Take a journey through the history and future of human development and carbon

GO

EMISSIONS

Explore and download global and country level carbon emissions from human activity.

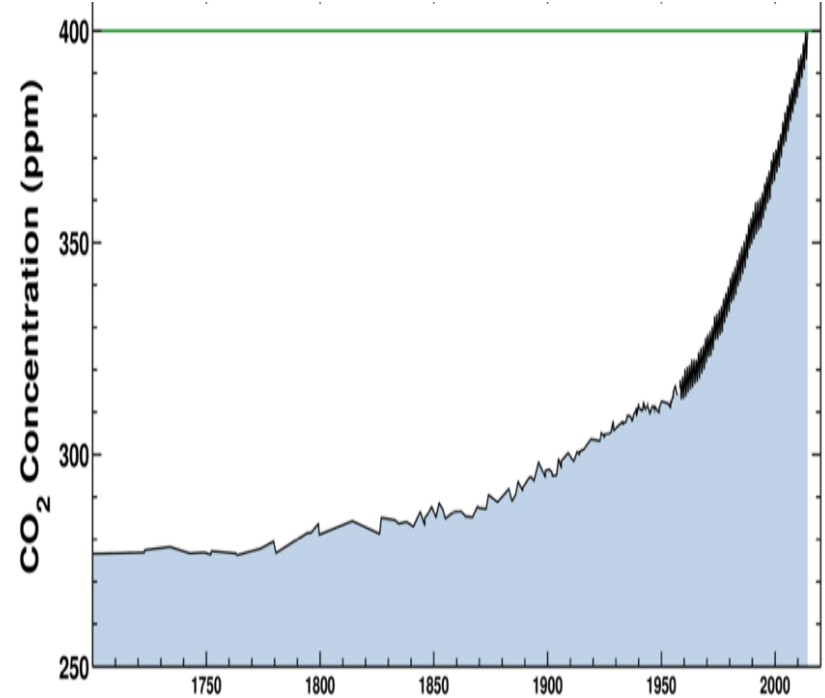
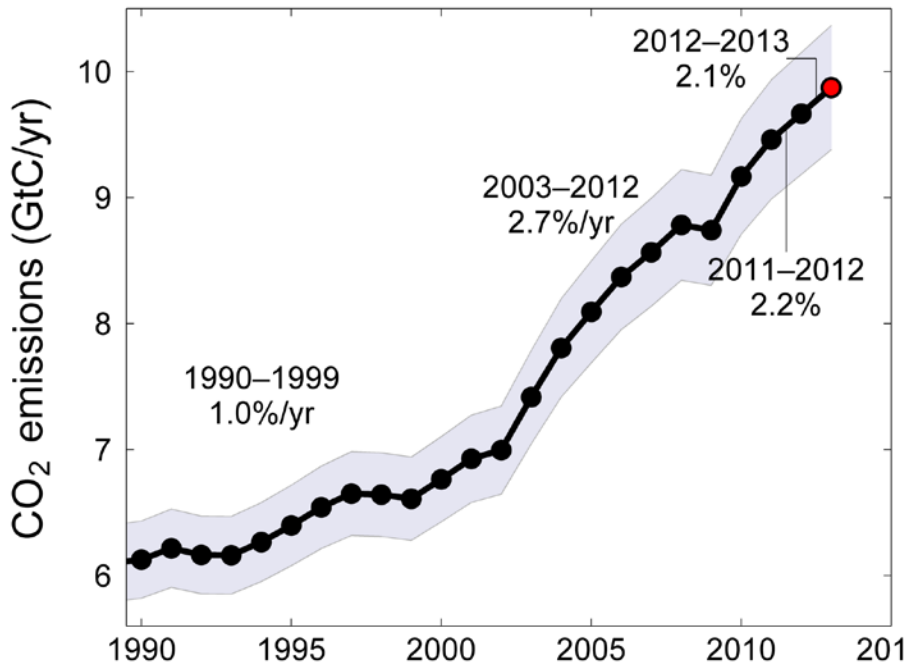
GO

RESEARCH

Explore and visualize research carbon data, and get access through data providers

GO

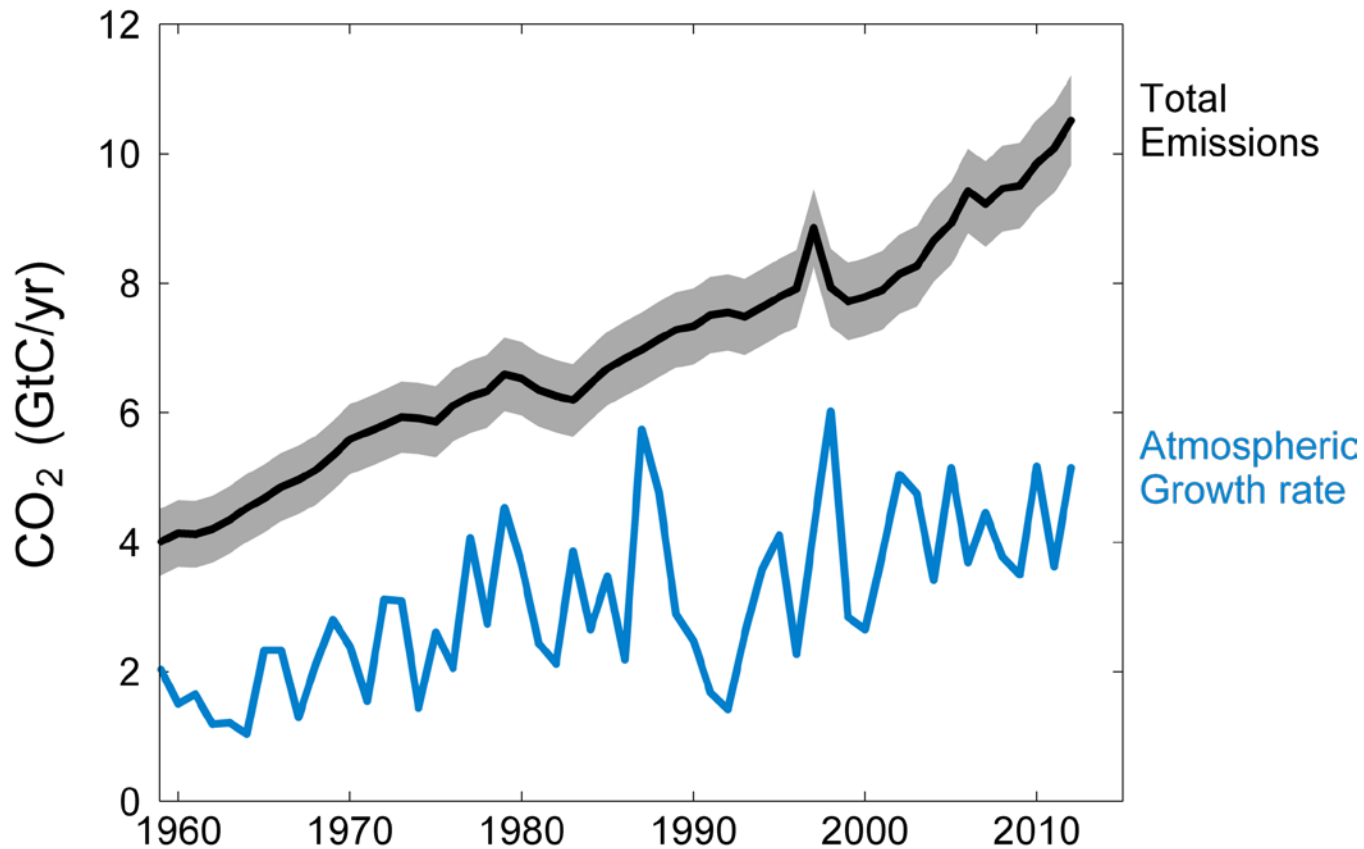
The Global Carbon Budget : emissions vs concentrations



+1 ppm of CO₂ 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
- = 2.12×3.664 Gt of CO₂

The Global Carbon Budget : emissions vs concentrations



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

$$\Delta\text{CO}_2 = \text{Emissions} - F_{\text{ocean}} - F_{\text{land}}$$

→ Atmospheric growth much more variable than the total emissions

The Global Carbon Budget : separating the sinks ?

$$\Delta\text{CO}_2 = \text{Emissions} - F_{\text{ocean}} - F_{\text{land}} \quad \dots 1 \text{ equation and 2 unknowns}$$

The Global Carbon Budget : separating the sinks – CO₂/O₂ method

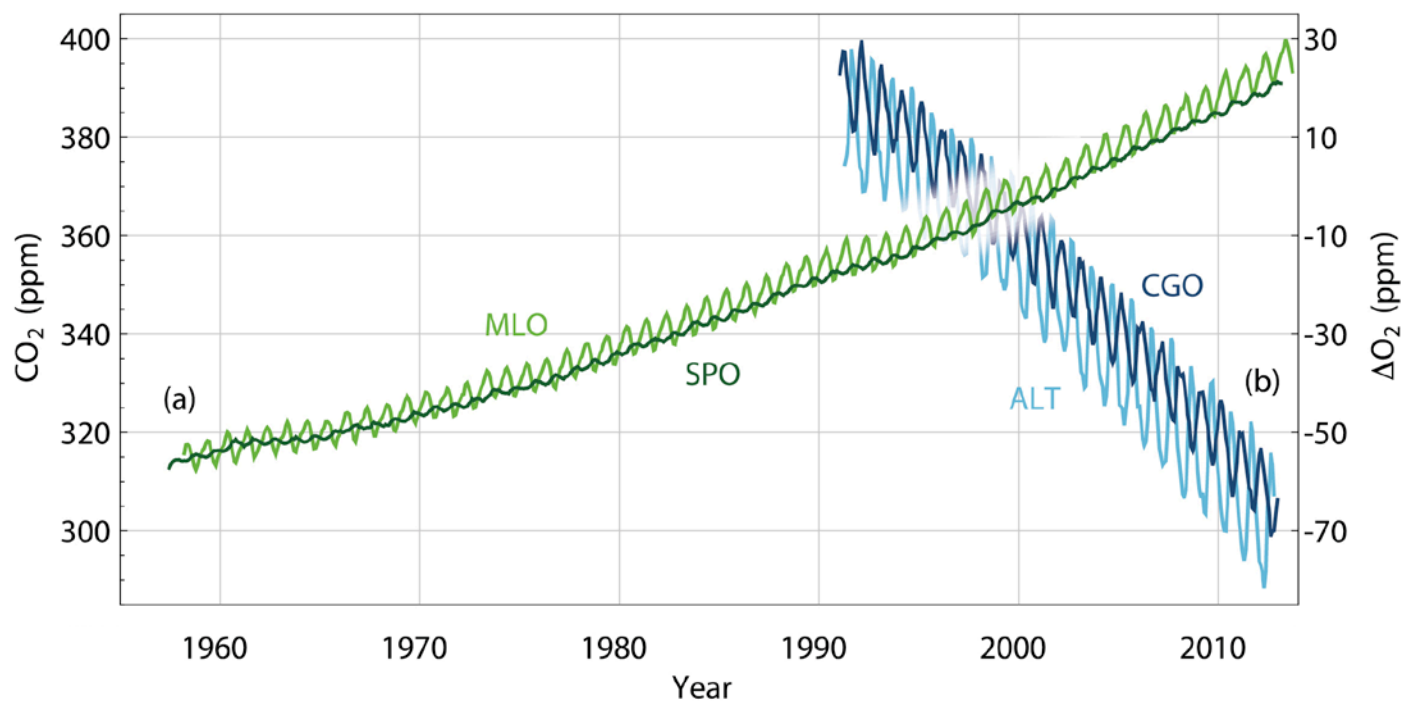
$$\Delta\text{CO}_2 = \text{Emissions} - F_{\text{ocean}} - F_{\text{land}}$$

$$\Delta\text{O}_2 = -\alpha \cdot \text{Emissions} + \beta \cdot F_{\text{land}} \quad \text{with}$$

$$\alpha = 1.4$$
$$\beta = 1.1$$

Combustion of FF
(coal, oil, ..)

Photosynthesis, Respiration



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%

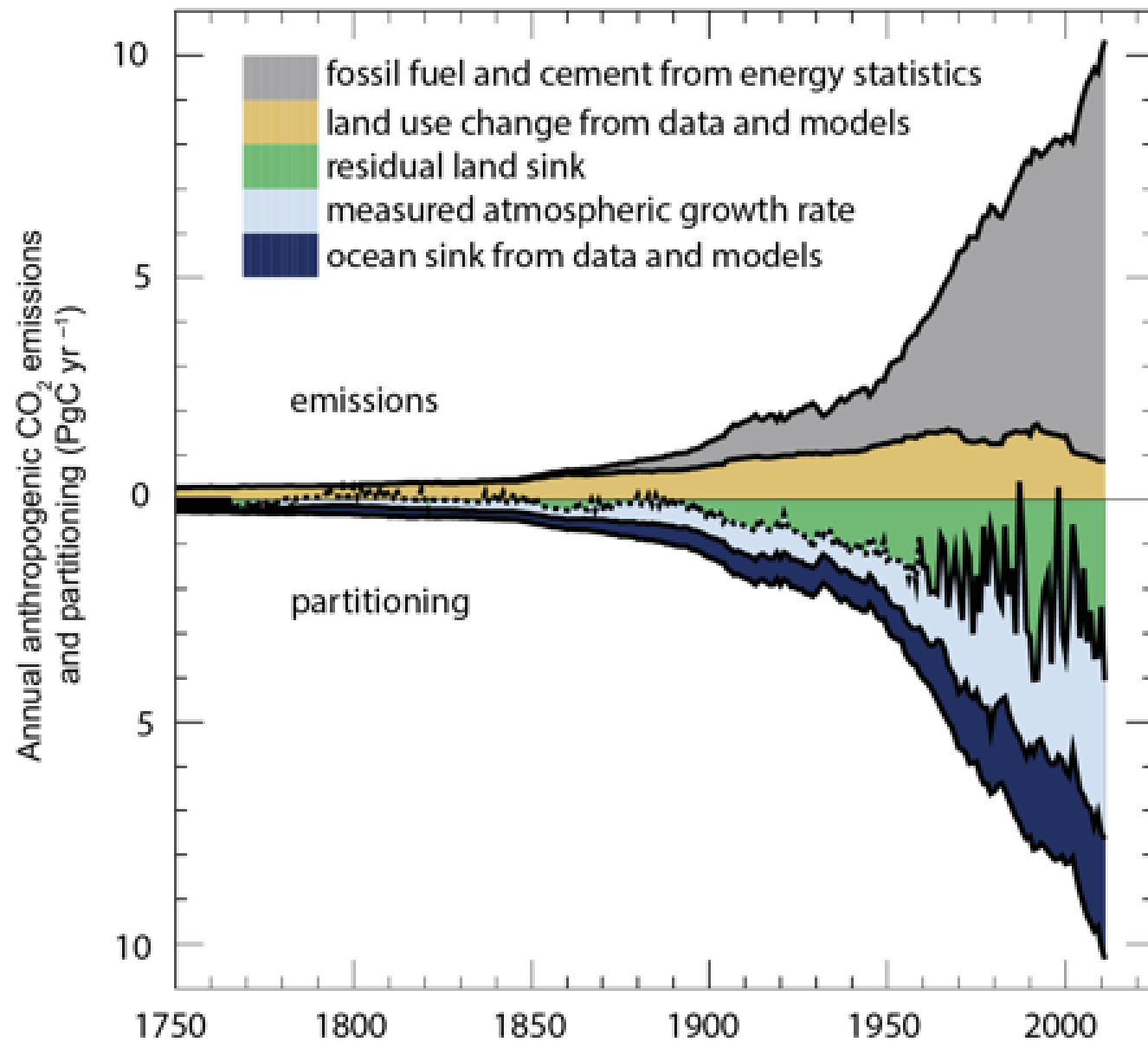


2.6 ± 0.8 GtC/yr
27%



Calculated as the residual
of all other flux components

The Global Carbon Budget : over 1750 - 2012

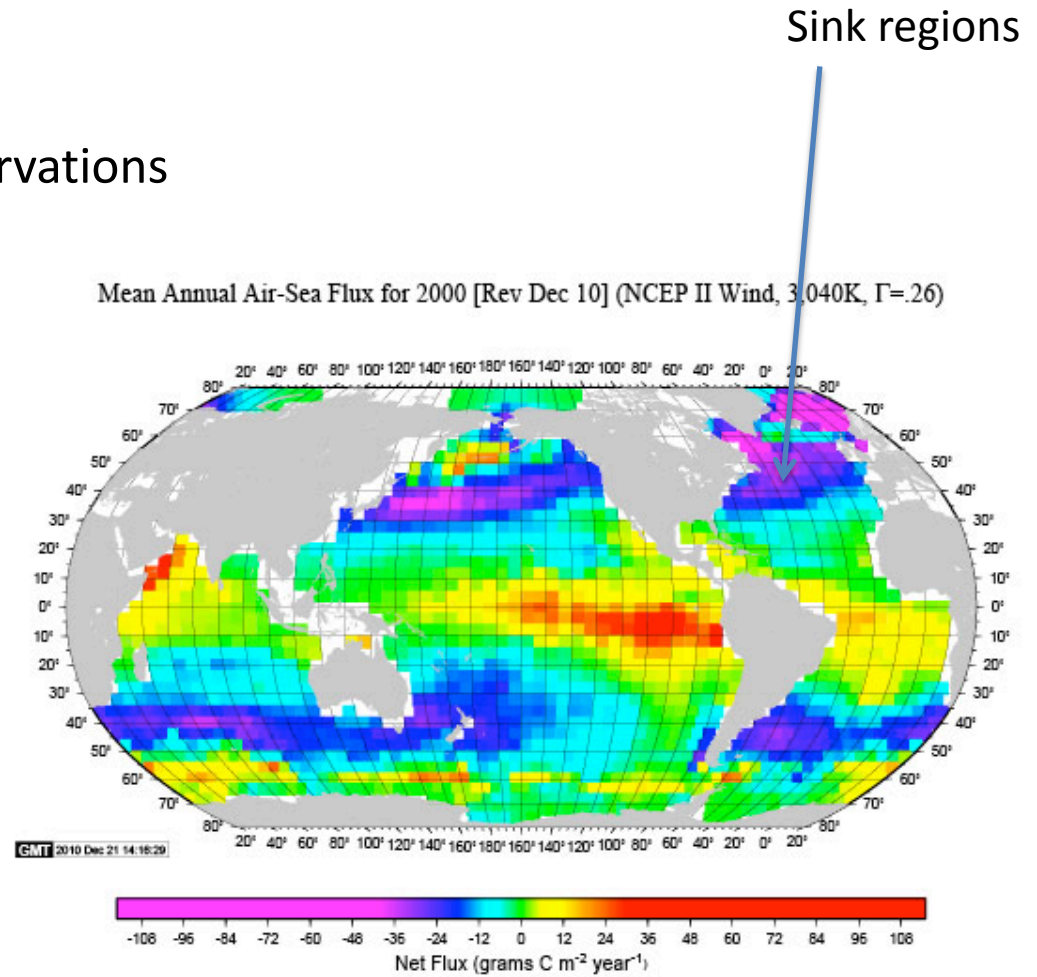


Natural Carbon Sinks : going regional

1. Direct measurements / observations

→ e.g., for the Ocean

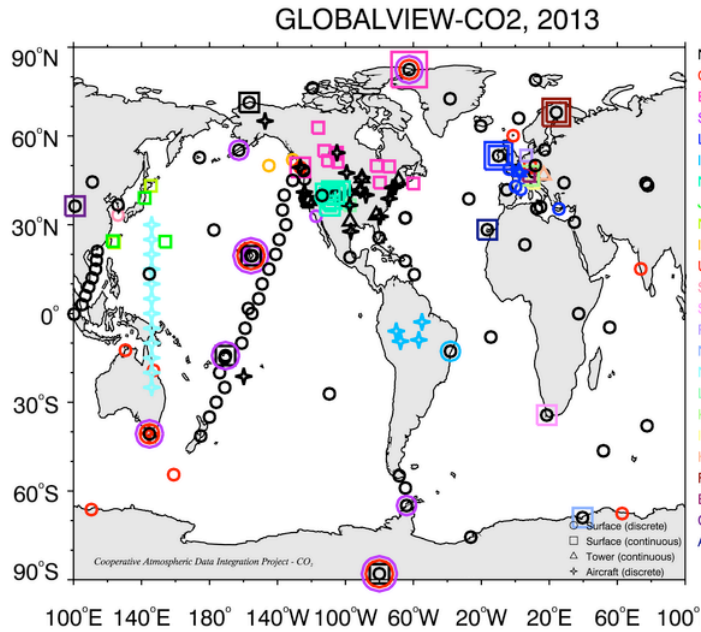
$$F = kw (p\text{CO}_2 \text{ sea} - p\text{CO}_2 \text{ air})$$



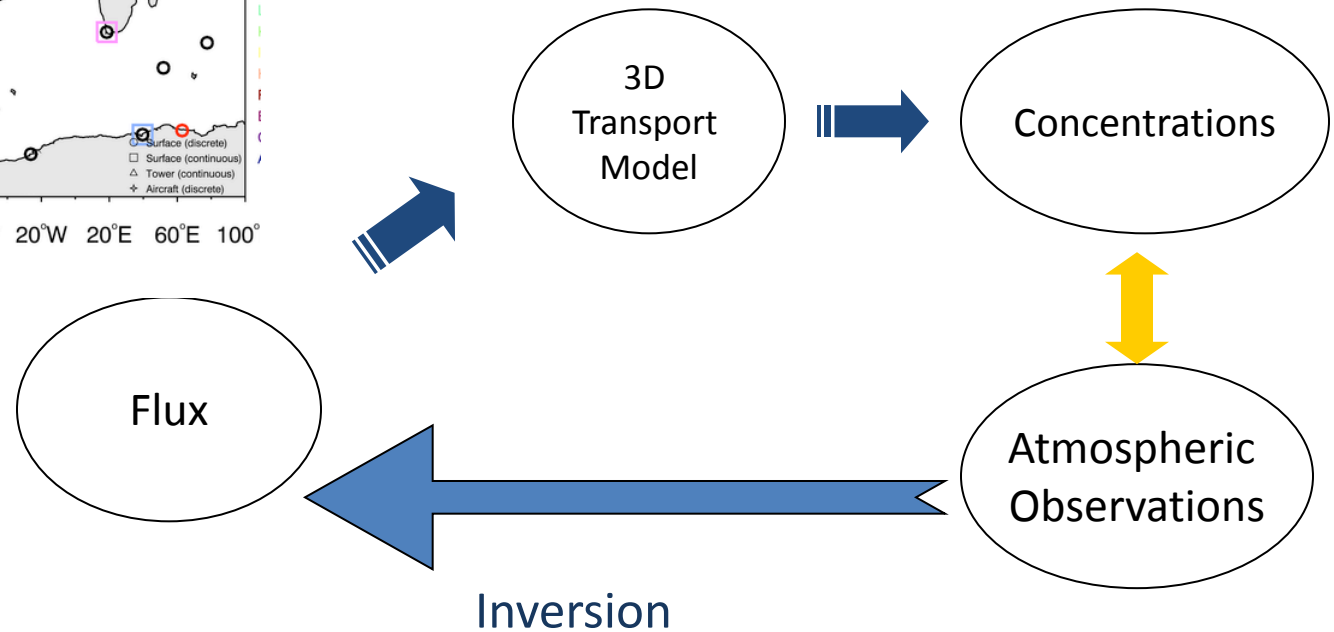
Takahashi et al. 2009

Natural Carbon Sinks : going regional

2 . Atmospheric Inversions to estimate regional fluxes

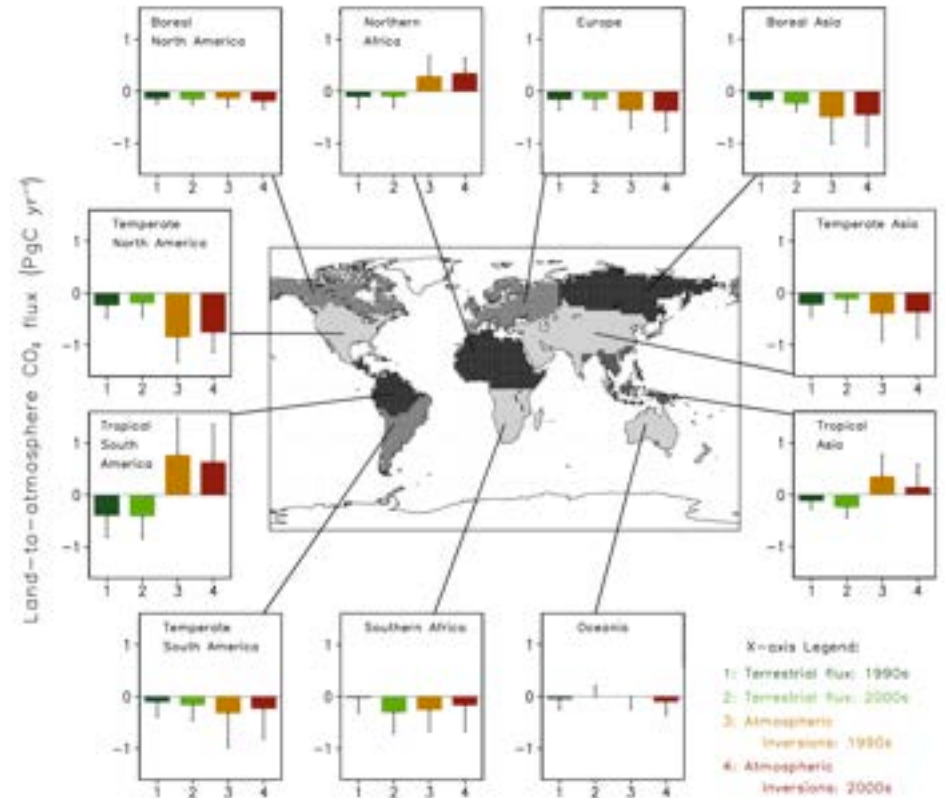
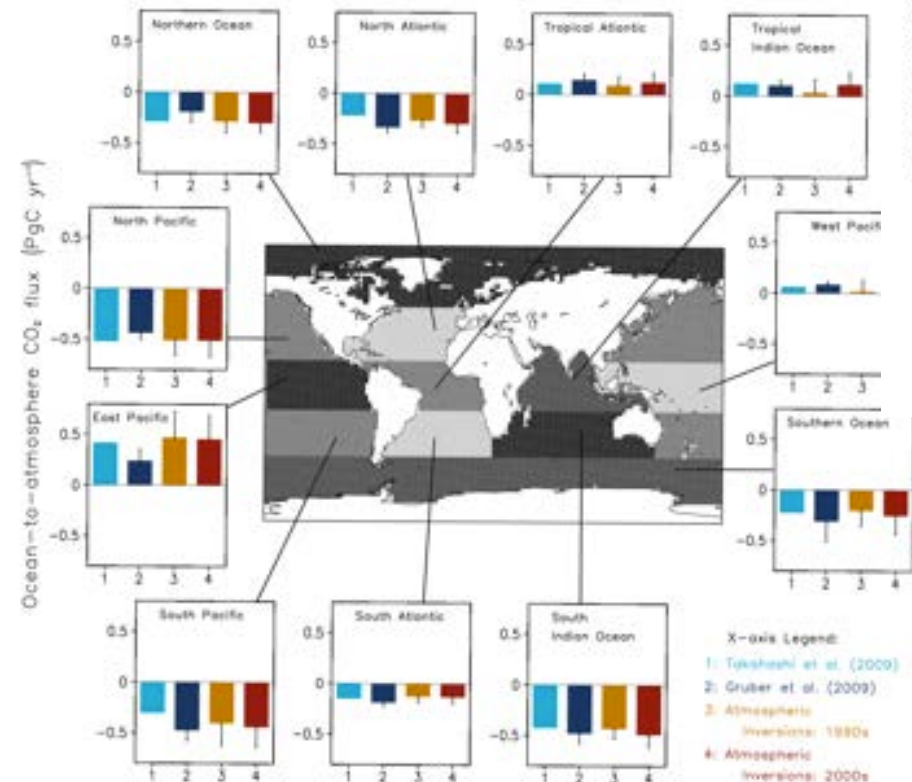


Direct Approach



Natural Carbon Sinks : going regional

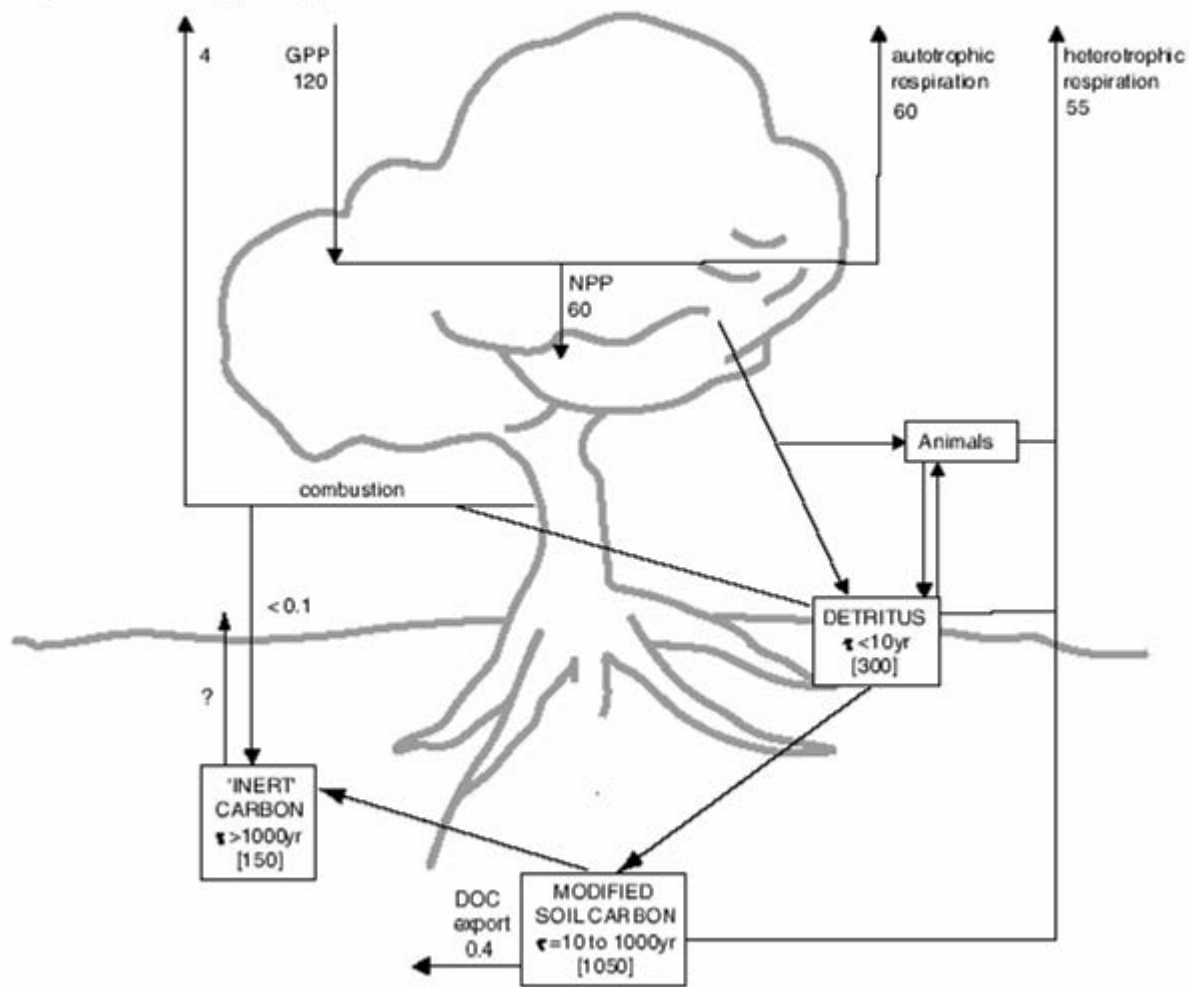
Estimated Ocean Sink



Estimated Land Sink

Natural Carbon Sinks : Processes for the Land Sink

d) Carbon cycling on land



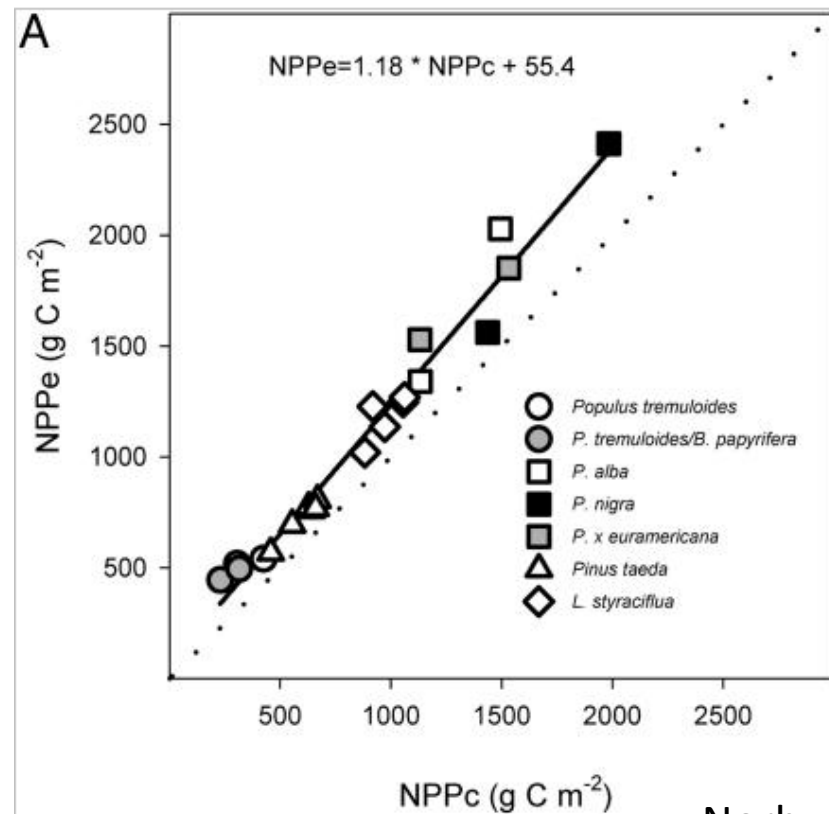
Natural Carbon Sinks : Processes for the Land Sink

Which processes are responsible for the terrestrial sink ?

- CO₂ fertilization



FACE Experiments



Norby et al; 2005

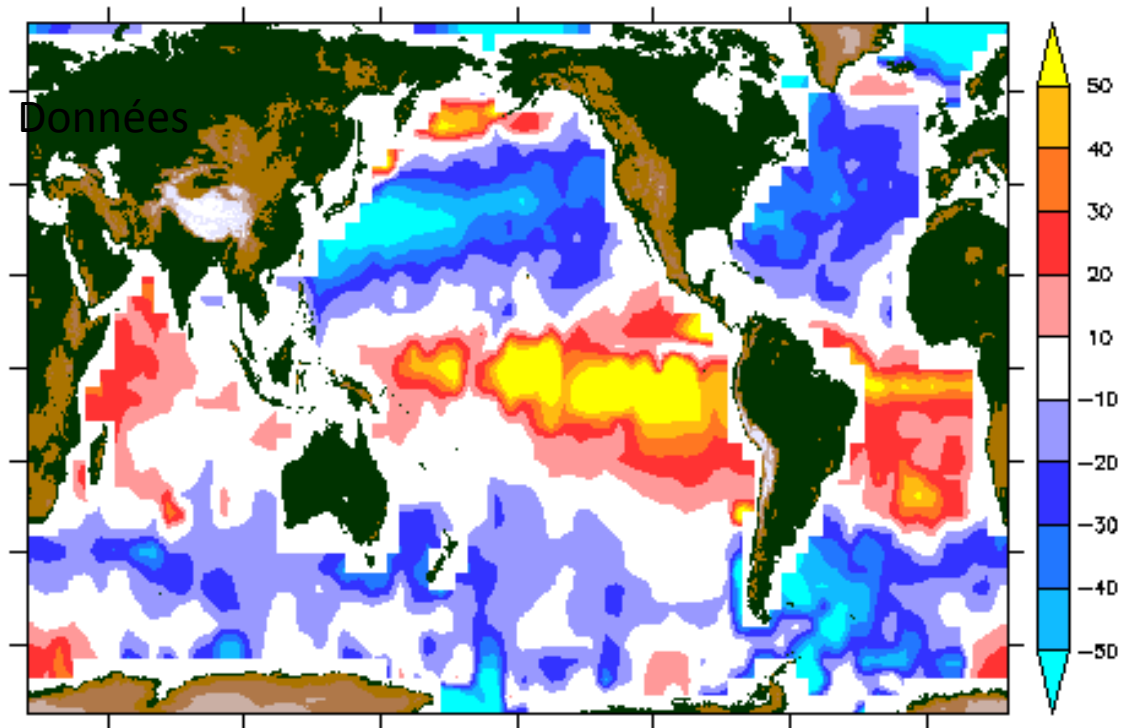
Natural Carbon Sinks : Processes for the Land Sink

Which processes are responsible for the terrestrial sink ?

- CO₂ fertilization
- Anthropogenic nitrogen deposition
- Climatic Variability
- Land-use changes

Natural Carbon Sinks : Processes for the Ocean Sink

- Carbon Sink
- Carbon Source

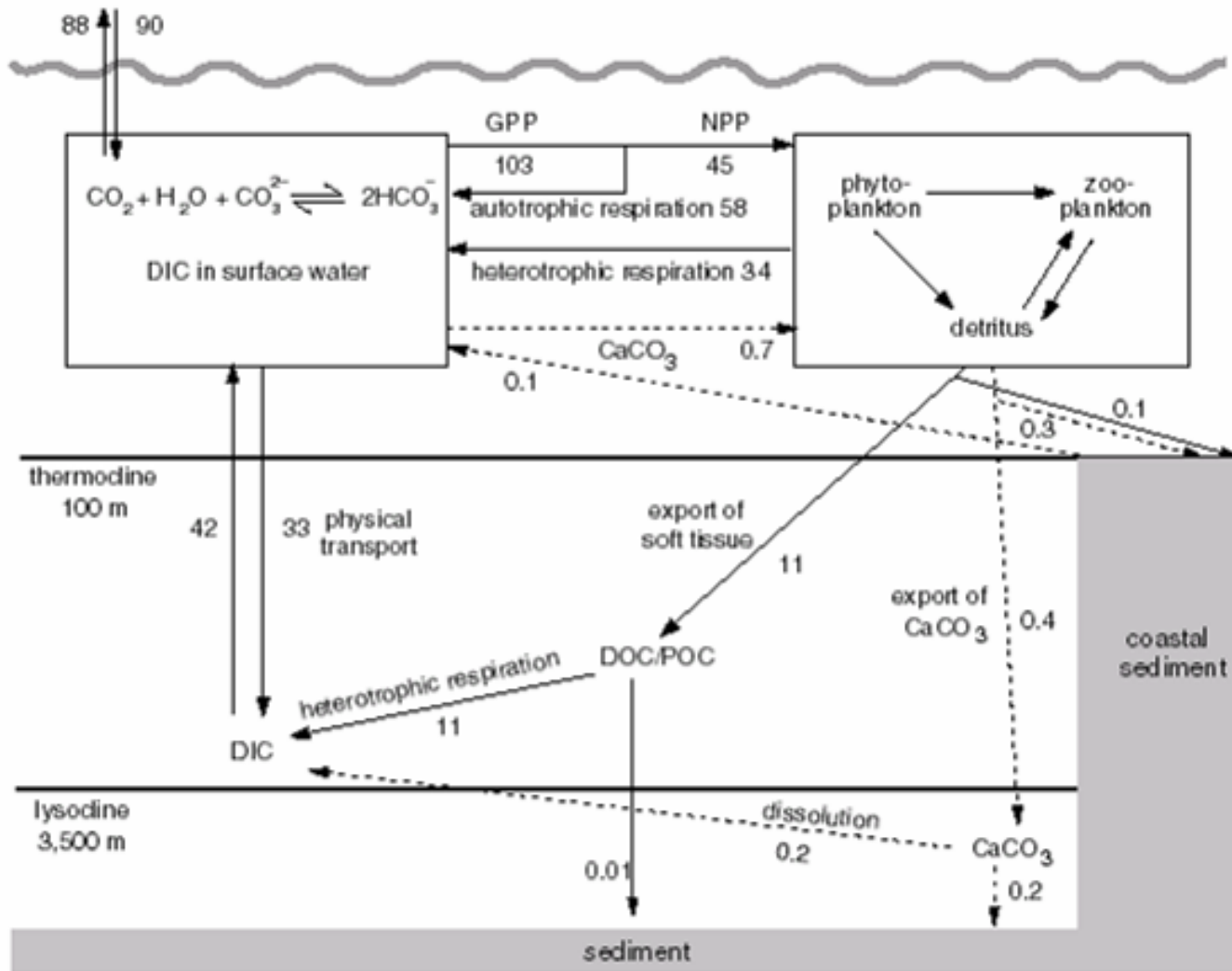


(Takahashi et al. 2009)

Janvier

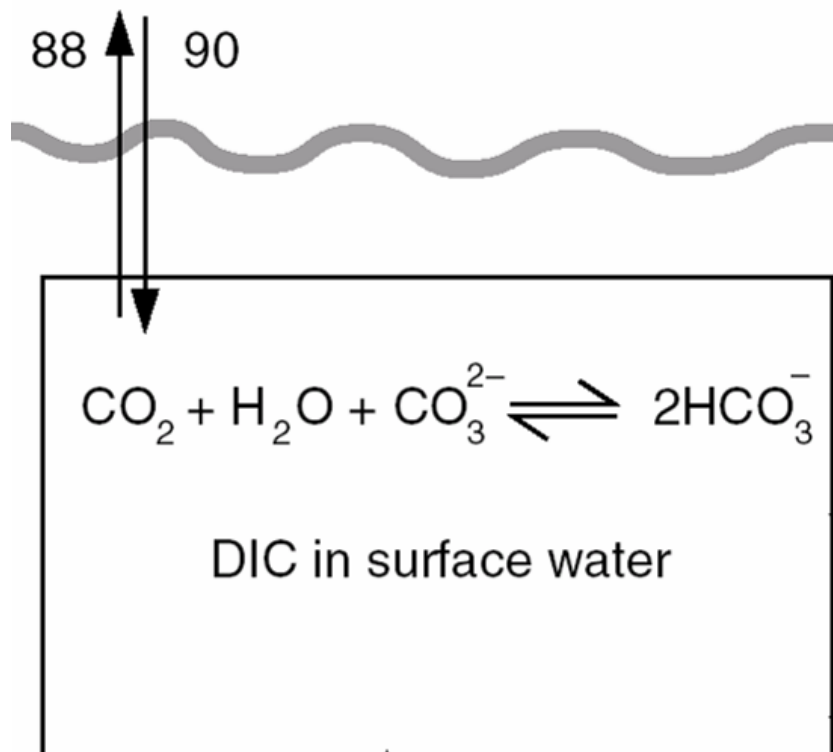
Natural Carbon Sinks : Processes for the Ocean Sink

Carbon cycling in the ocean

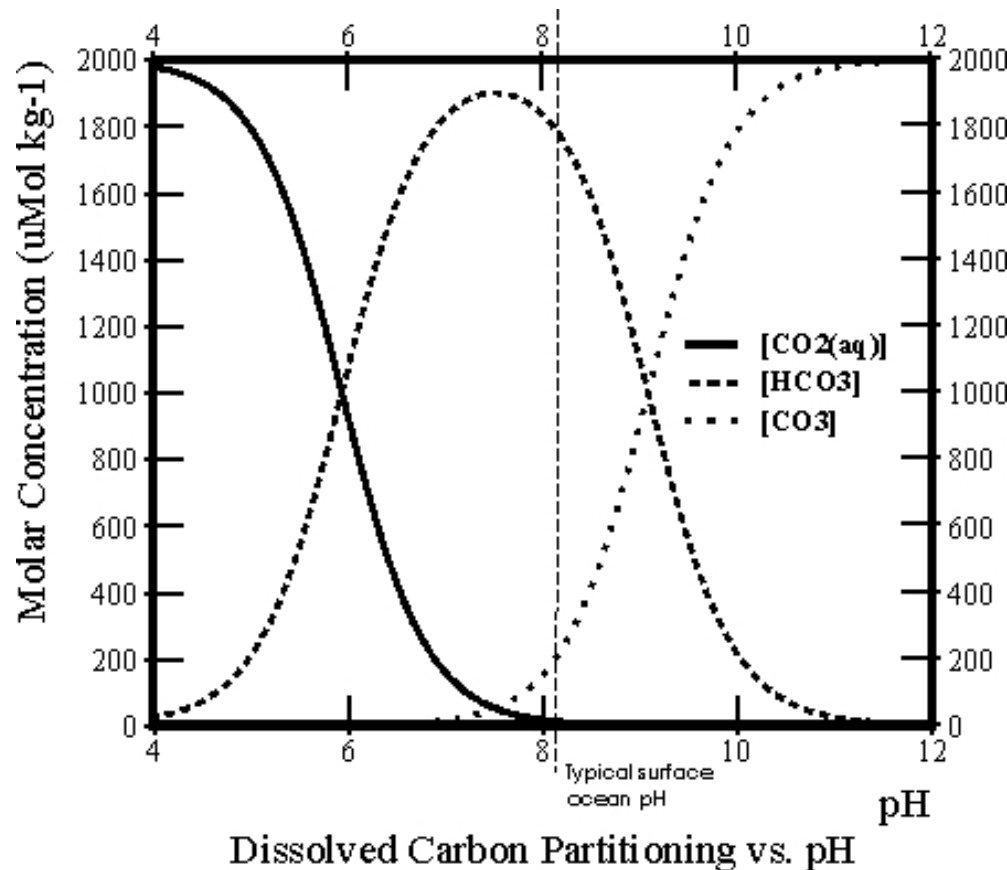


Marine Carbon Cycle : Physics / Chemistry / Biology

Natural Carbon Sinks : Processes for the Ocean Sink



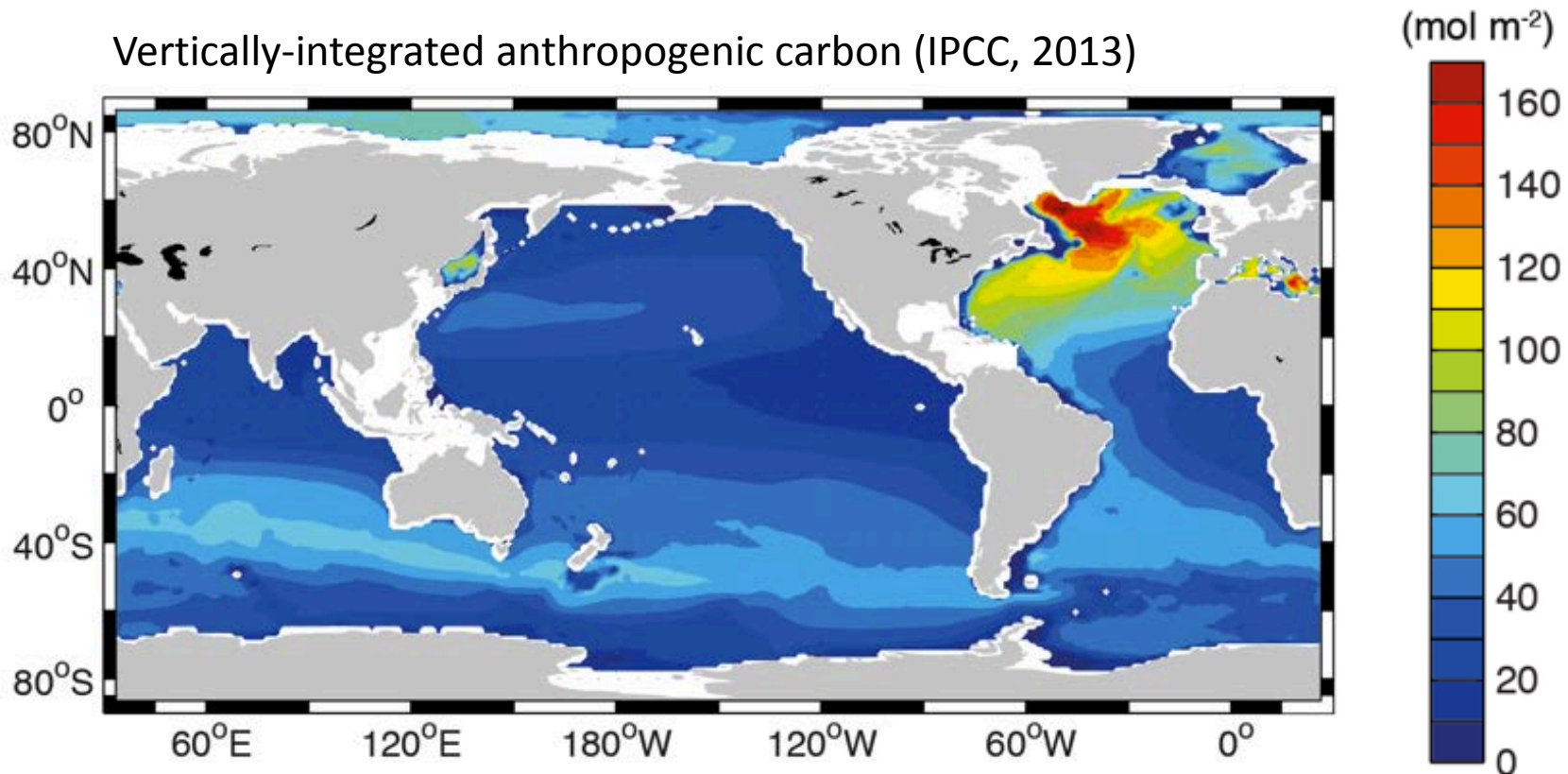
Chemistry



Natural Carbon Sinks : Processes for the Ocean Sink

Which processes are responsible for today's marine sink ?

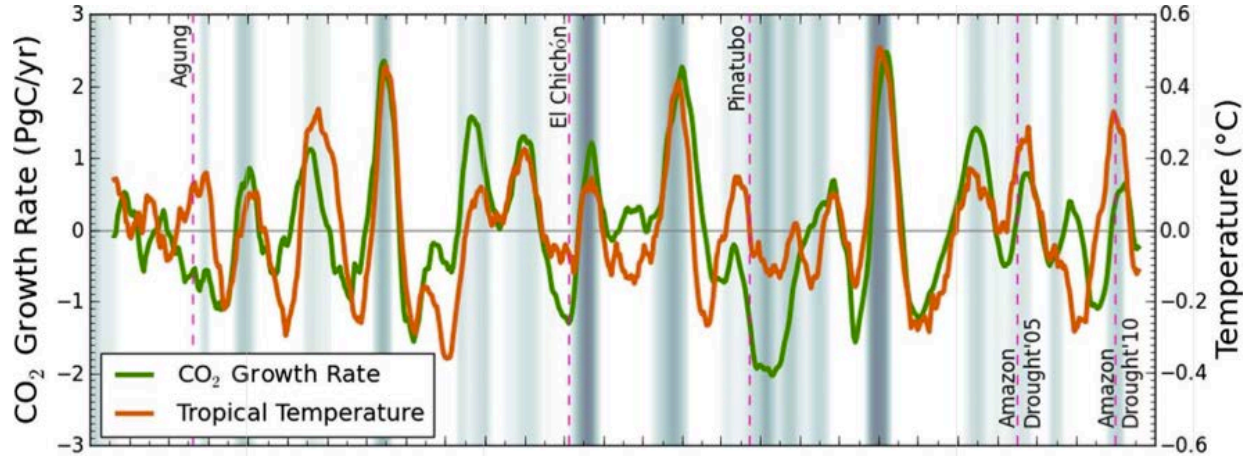
Vertically-integrated anthropogenic carbon (IPCC, 2013)



“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 biologically driven carbon cycle that is close to steady state” (IPCC, 2001)

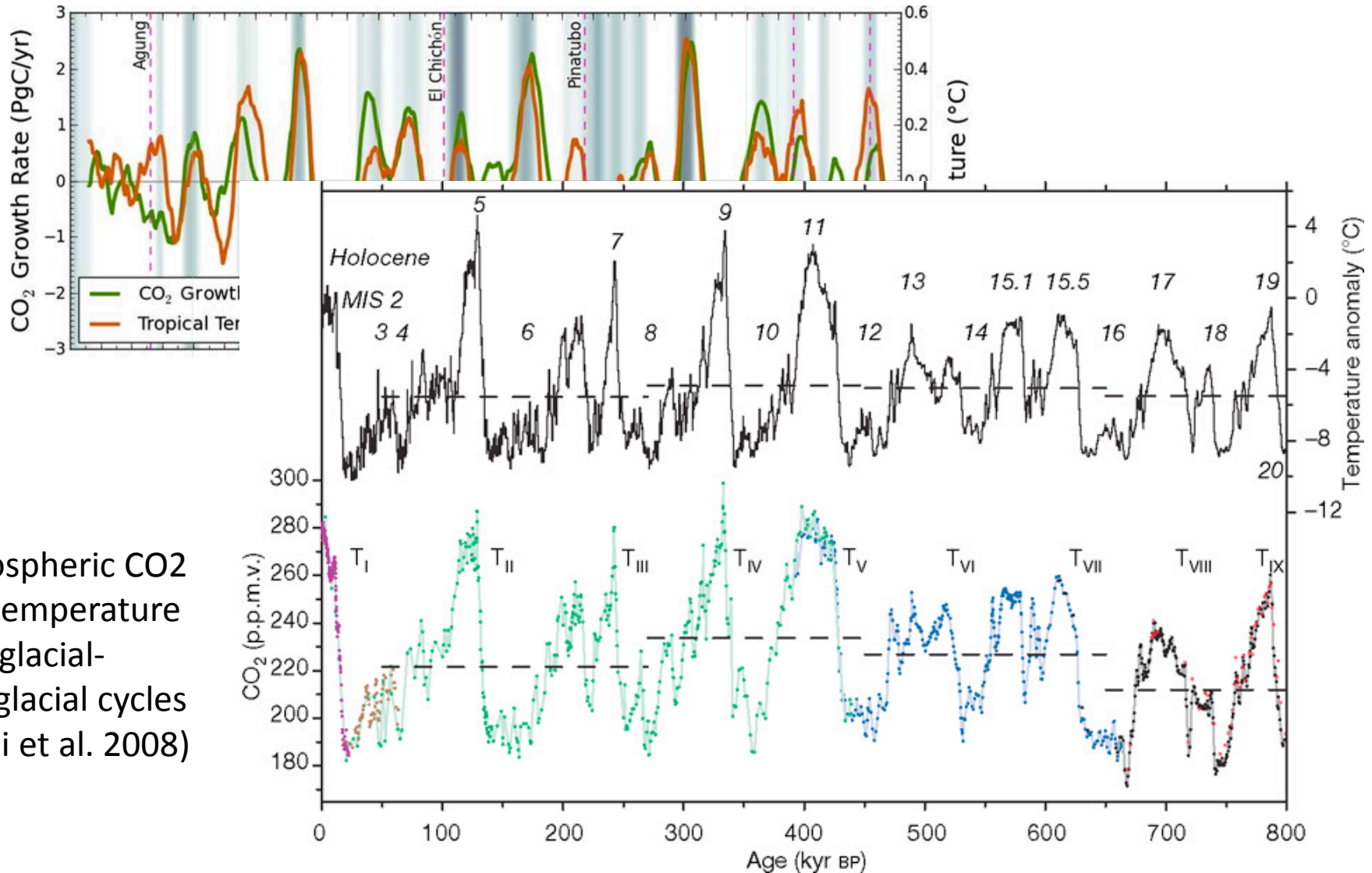
Climate-Carbon coupling – evidence on very different time-scales

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



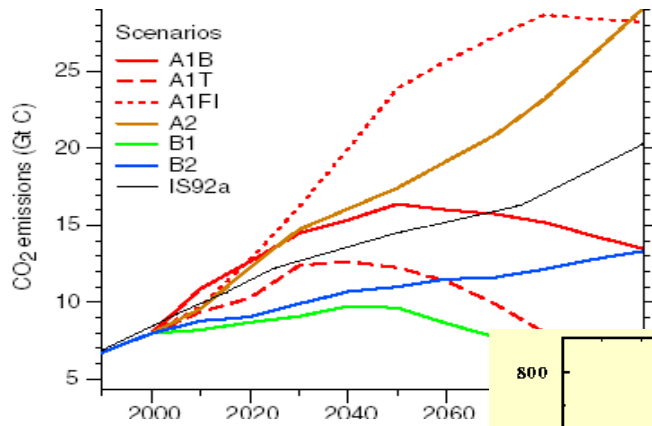
Climate-Carbon coupling – evidence on very different time-scales

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



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

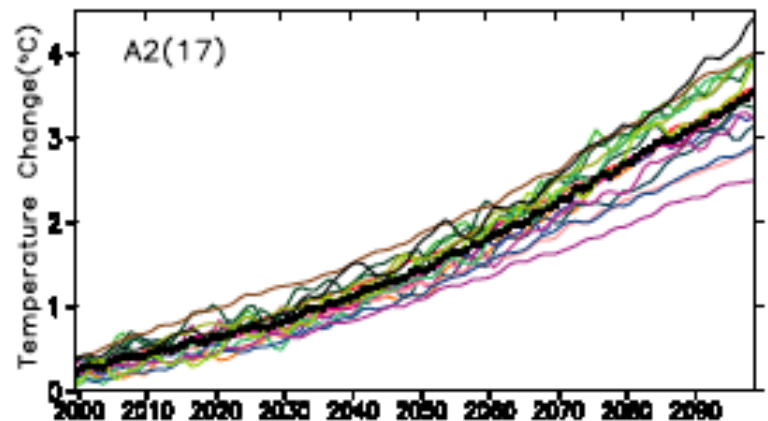
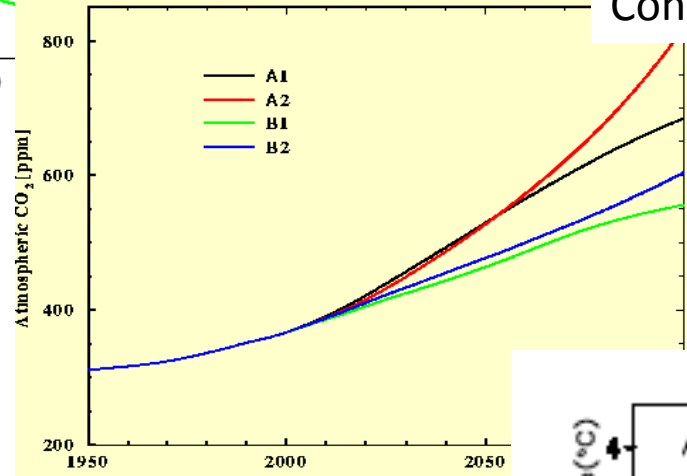
Climate-Carbon coupling – a potential retroactino loop



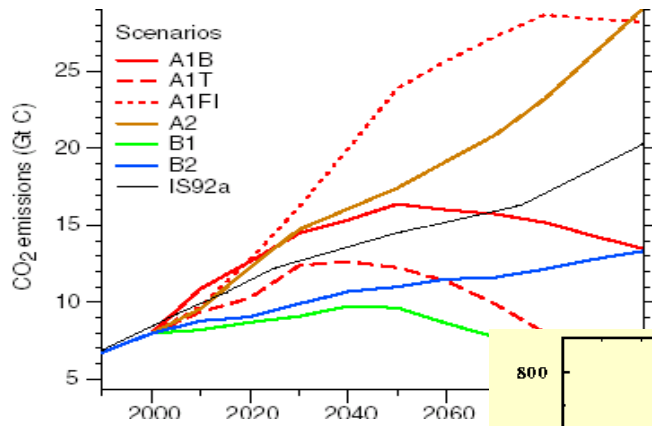
Emissions

Concentrations

Climate



Climate-Carbon coupling – a potential retroactino loop

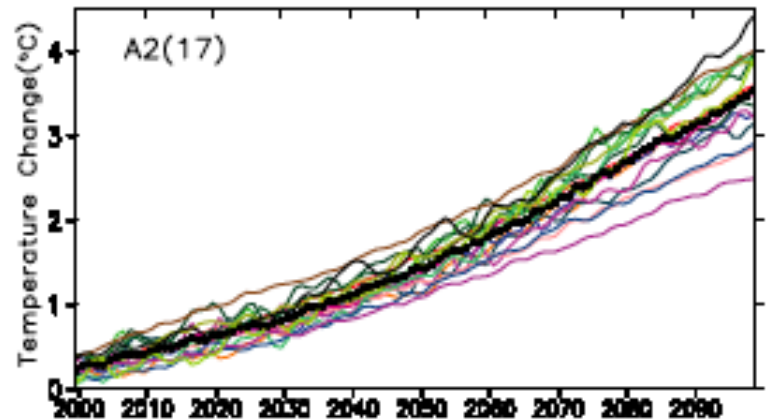
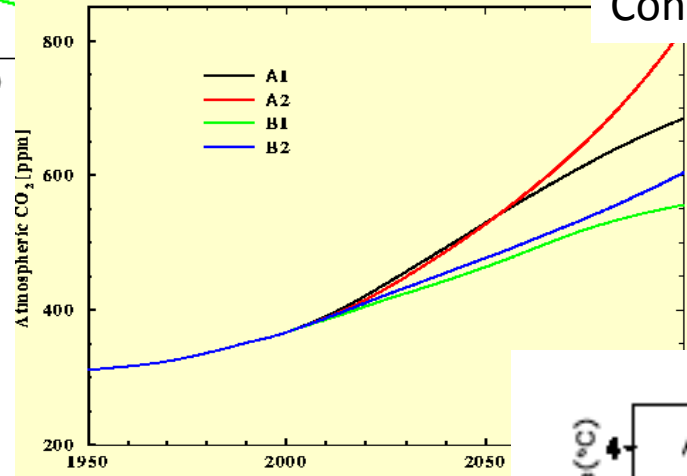


Emissions

Concentrations

Climate

Carbon Sinks

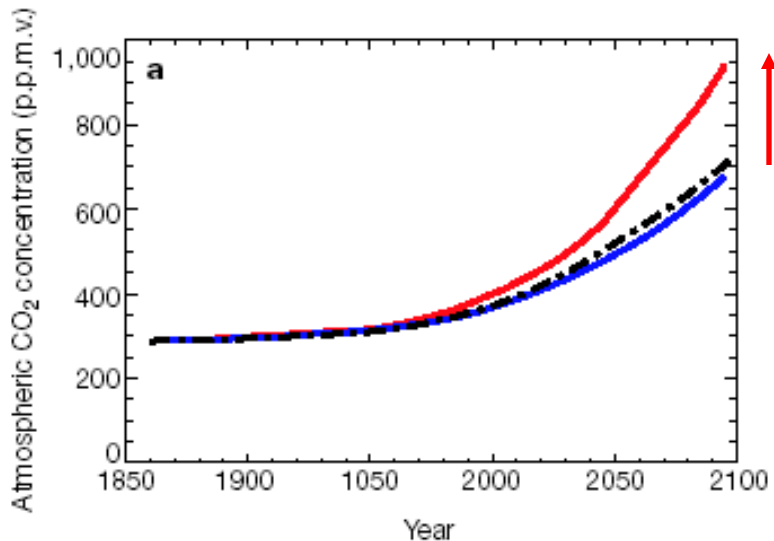


Climate-Carbon coupling – Future projections

letters to nature

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

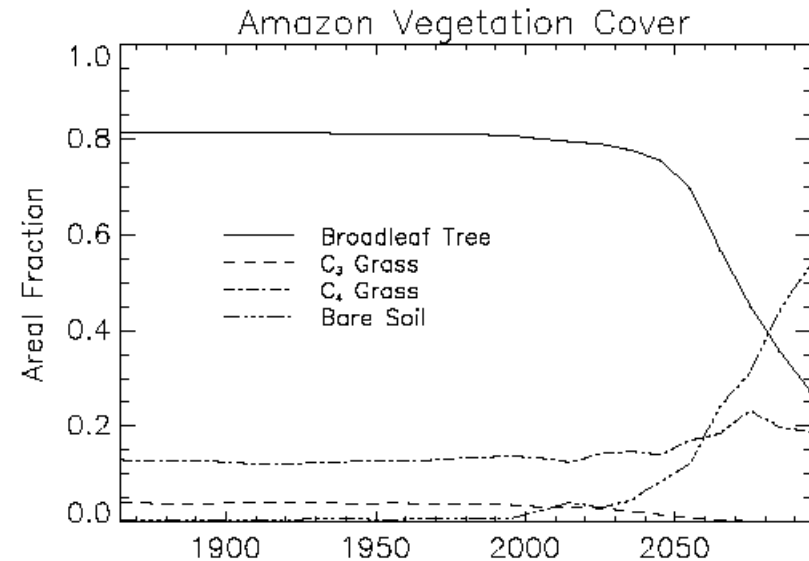
Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†



+ 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

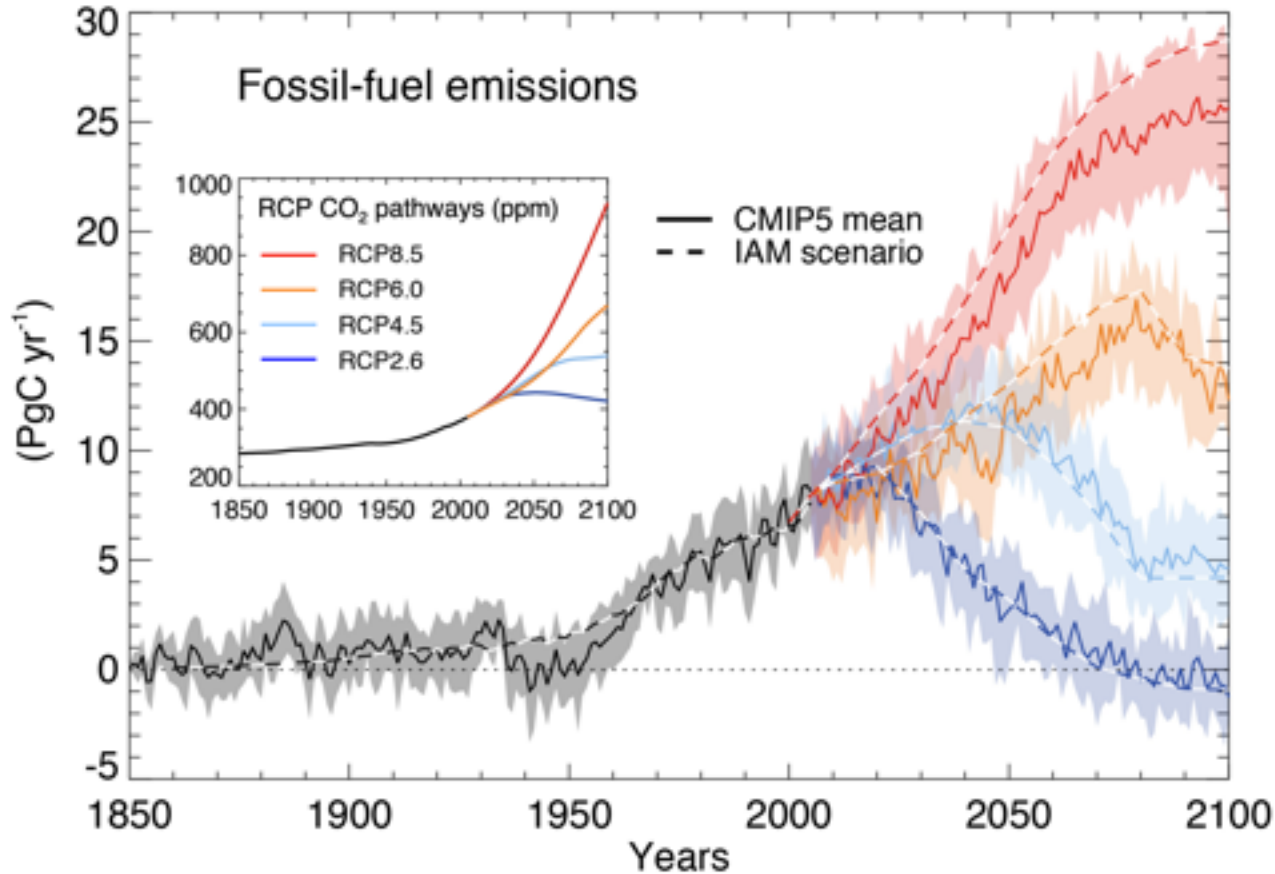
-> **But no consensus. Large uncertainties**

Ocean

Warming Effect : Increased T decreases CO₂ solubility
Dynamical Effect : Increases stratification prevents anthropogenic CO₂ penetration
Biological Effects ?

-> **Uncertainties on the dynamical effect / biological effect.**

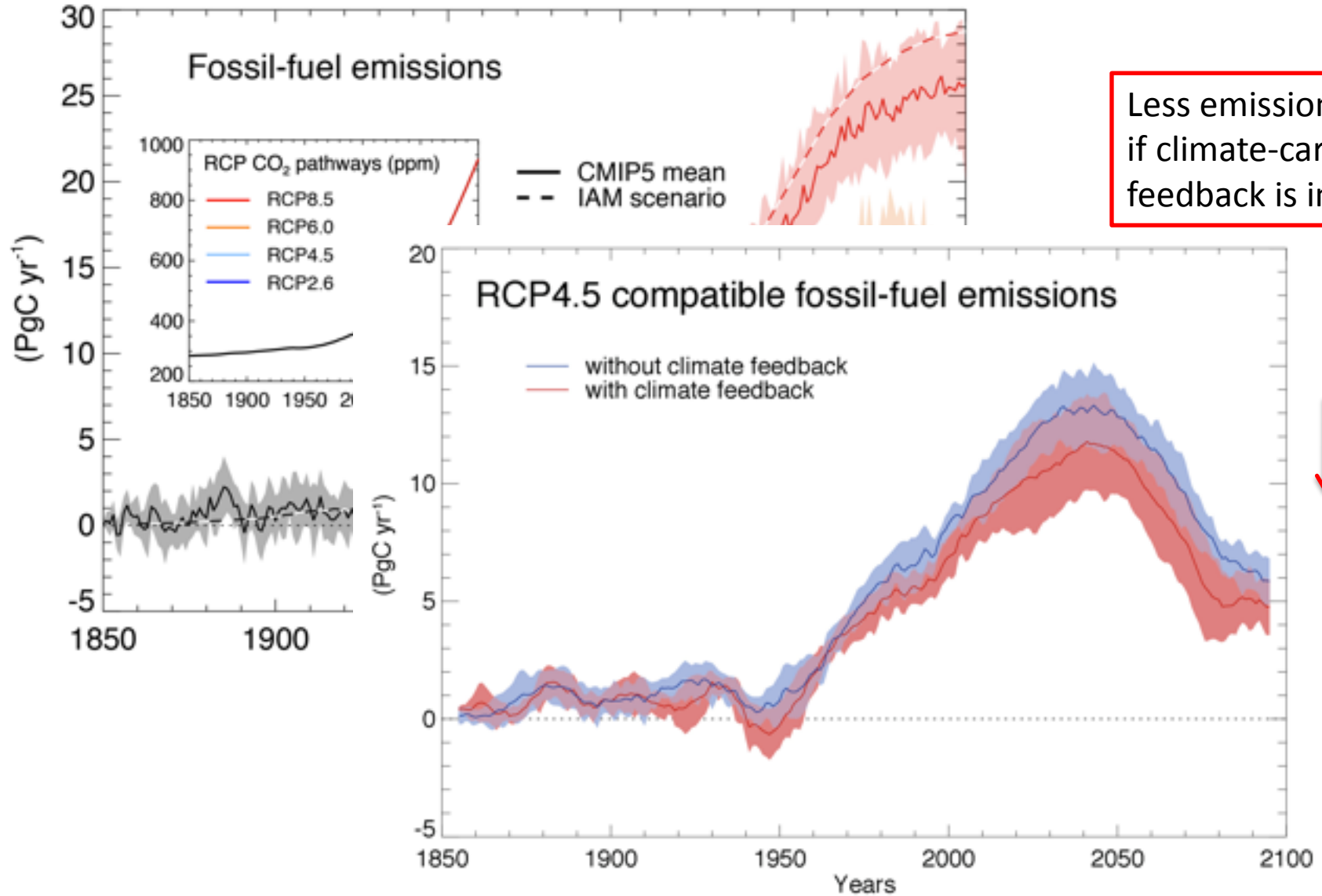
Climate-Carbon coupling – Implications on allowable emissions



Allowable FF Emissions = $dCO_2/dt + F_{ocean} + F_{land}$

(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 mentioned here...

CO₂ remains in the atmosphere long after emissions

