EcoClim – 2021

Le cycle du carbone dans un climat perturbé !

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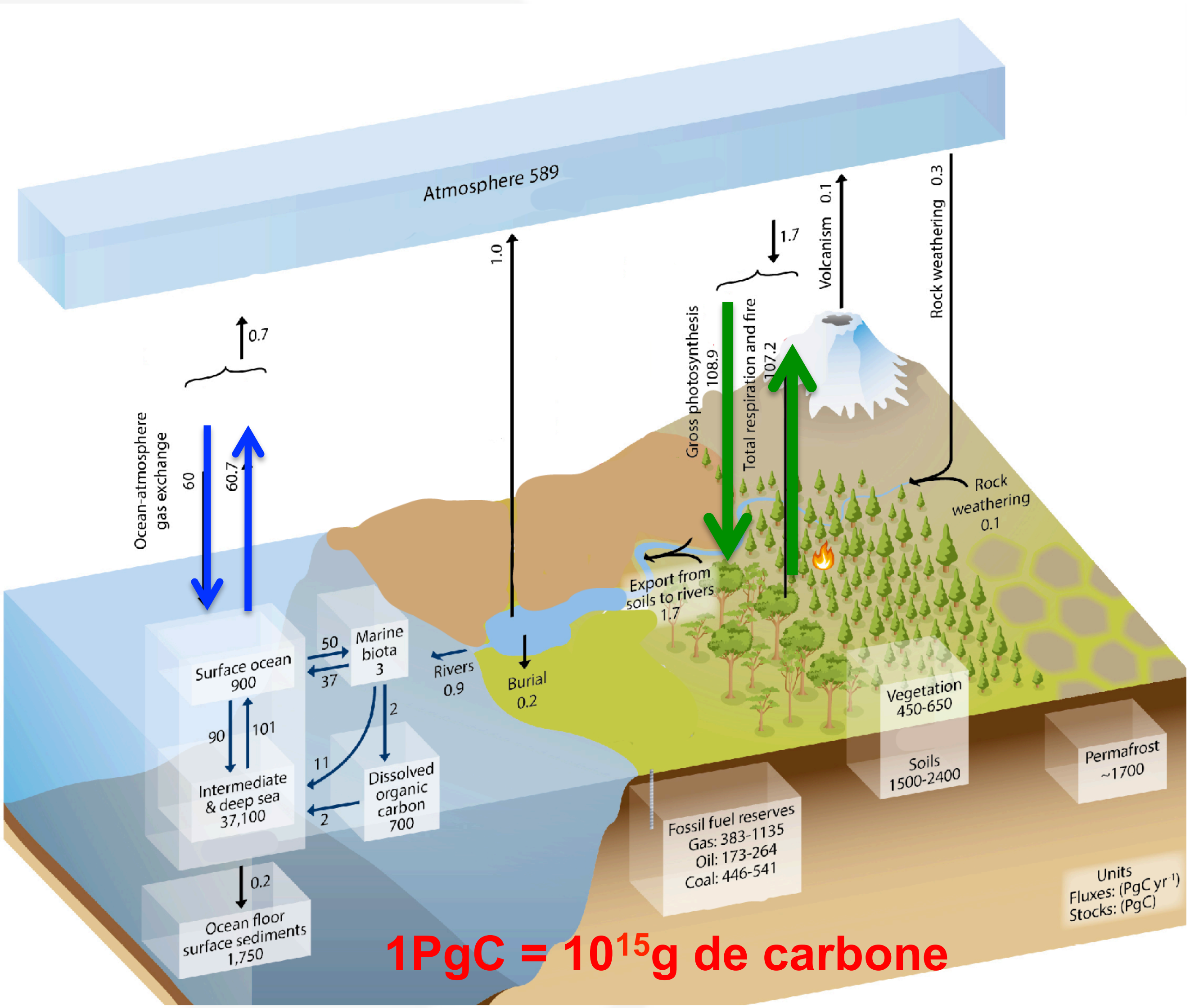
Plan

1. Le cycle du carbone naturel
2. La perturbation anthropique
3. Réponse des écosystèmes à la perturbation
4. Evolution future du cycle du carbone et incertitudes
5. La modélisation continentale du cycle du Carbone
6. L'impact de la pandémie sur les flux de CO2

Cycle naturel pré-industriel du CO_2



1PgC = 10^{15}g de carbone

Photosynthèse brute 108.9 PgC/an

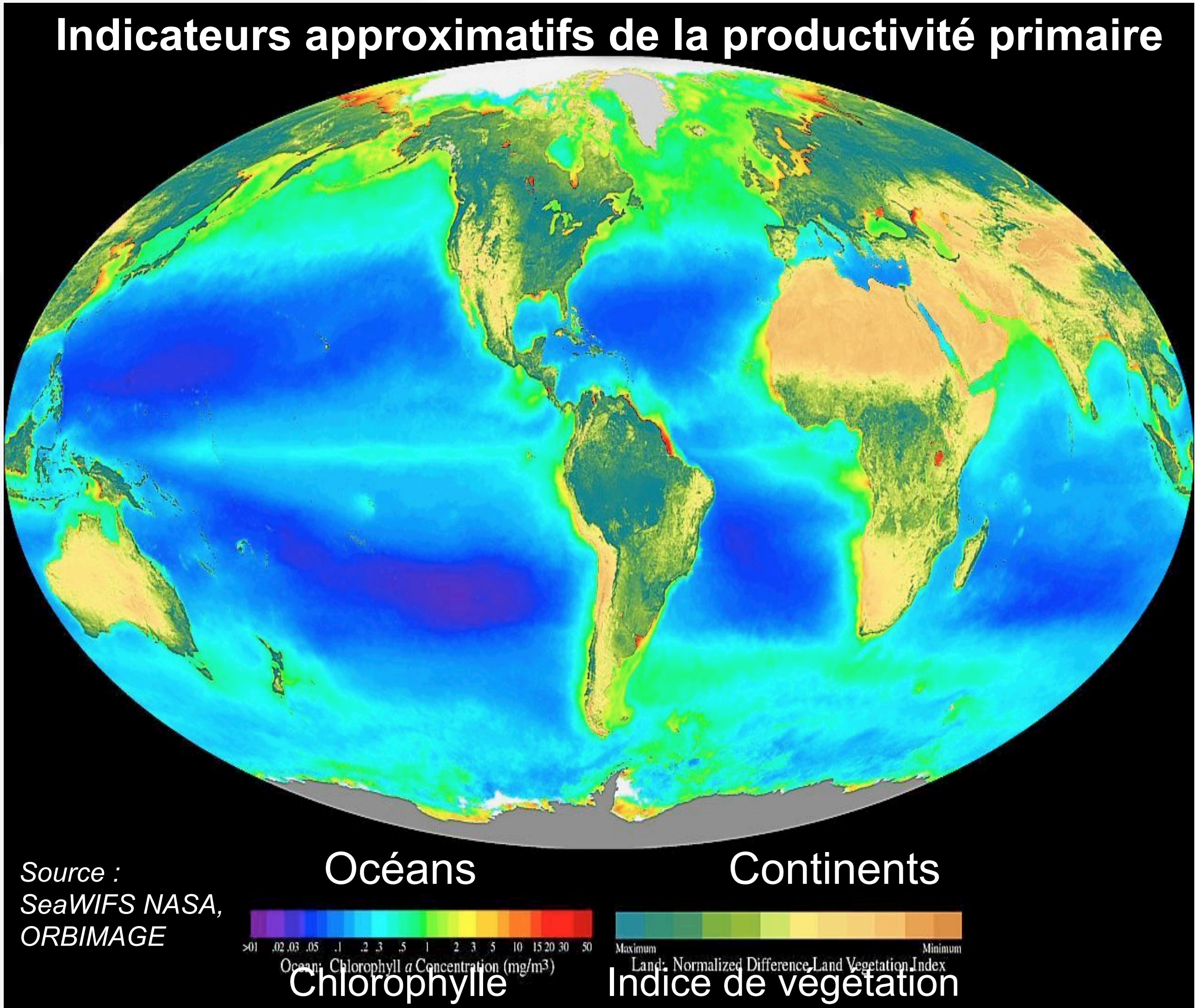
Respiration et feux 107.2 PgC/an

Absorption océans 60 Pg/an

Dégazage océans 60.7 Pg/an

Erosions, rivières, volcans, sédimentation 2 PgC/an

Productivité Primaire continentale et océanique



CONTINENTS

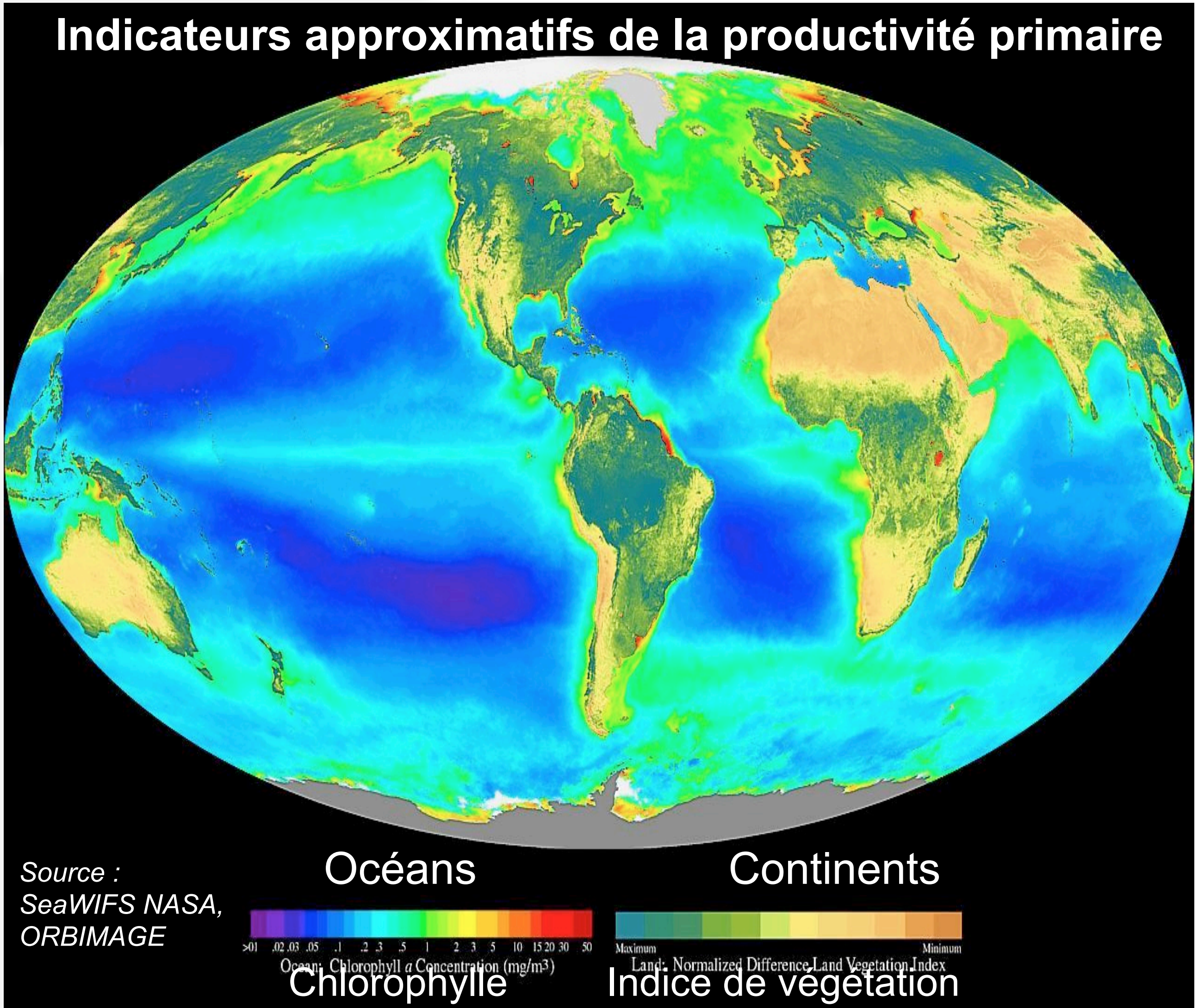
~ 60 PgC/an

Assurée par les Plantes vasculaires

Limitée par:
- **Lumière**
- **Température**
- **Eau**
- **Nutriments (C, N, P,...)**

Productivité Primaire Nette = Photosynthèse brute - Respiration végétale

Productivité Primaire continentale et océanique



OCEANS

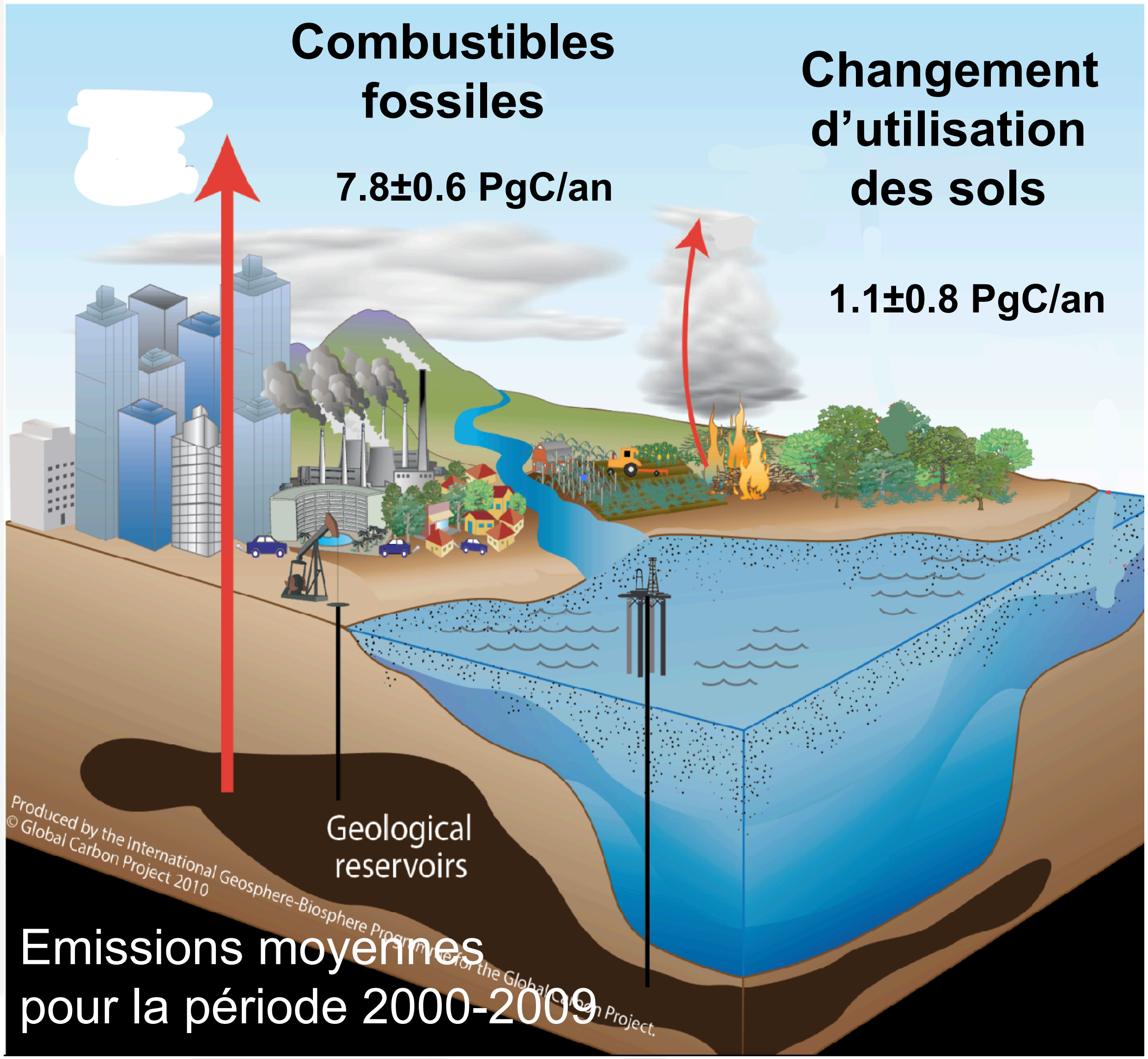
~ 50 PgC/an

Assurée par le phytoplancton

Limitée par :
- **Lumière**
- **Nutriments (C, N, P,...)**
- **Fer**

Productivité Primaire Nette = Photosynthèse brute - Respiration végétale

Perturbation du cycle naturel du carbone



Combustion de charbon, de pétrole et de gaz

7.8±0.6 PgC/an

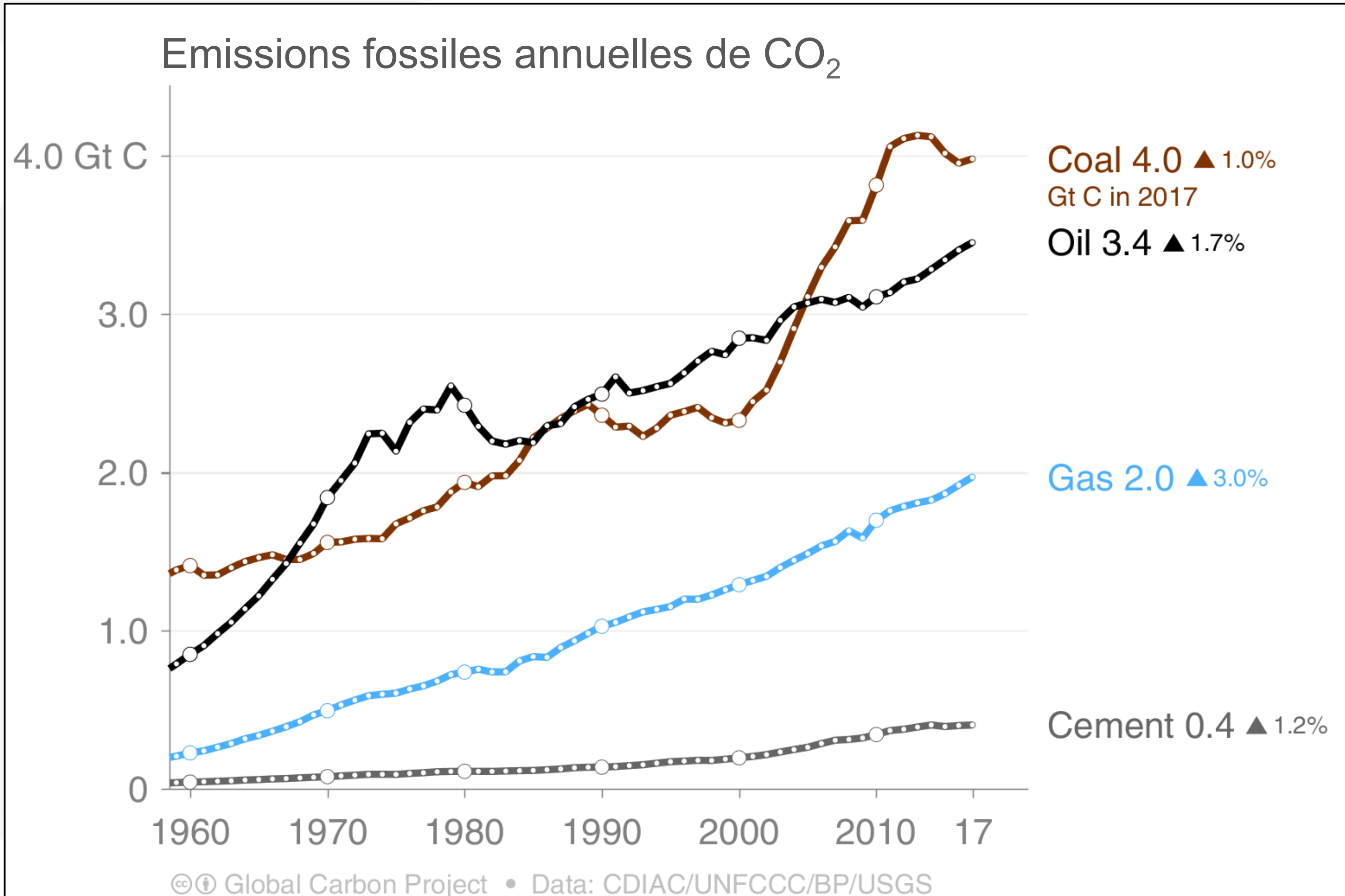
Changement d'utilisation des sols (déforestation incluant les feux de biomasse et de biofuels, conversions de terres)

1.1±0.8 PgC/an

Source : IPCC

Emissions fossile de CO_2 par catégorie

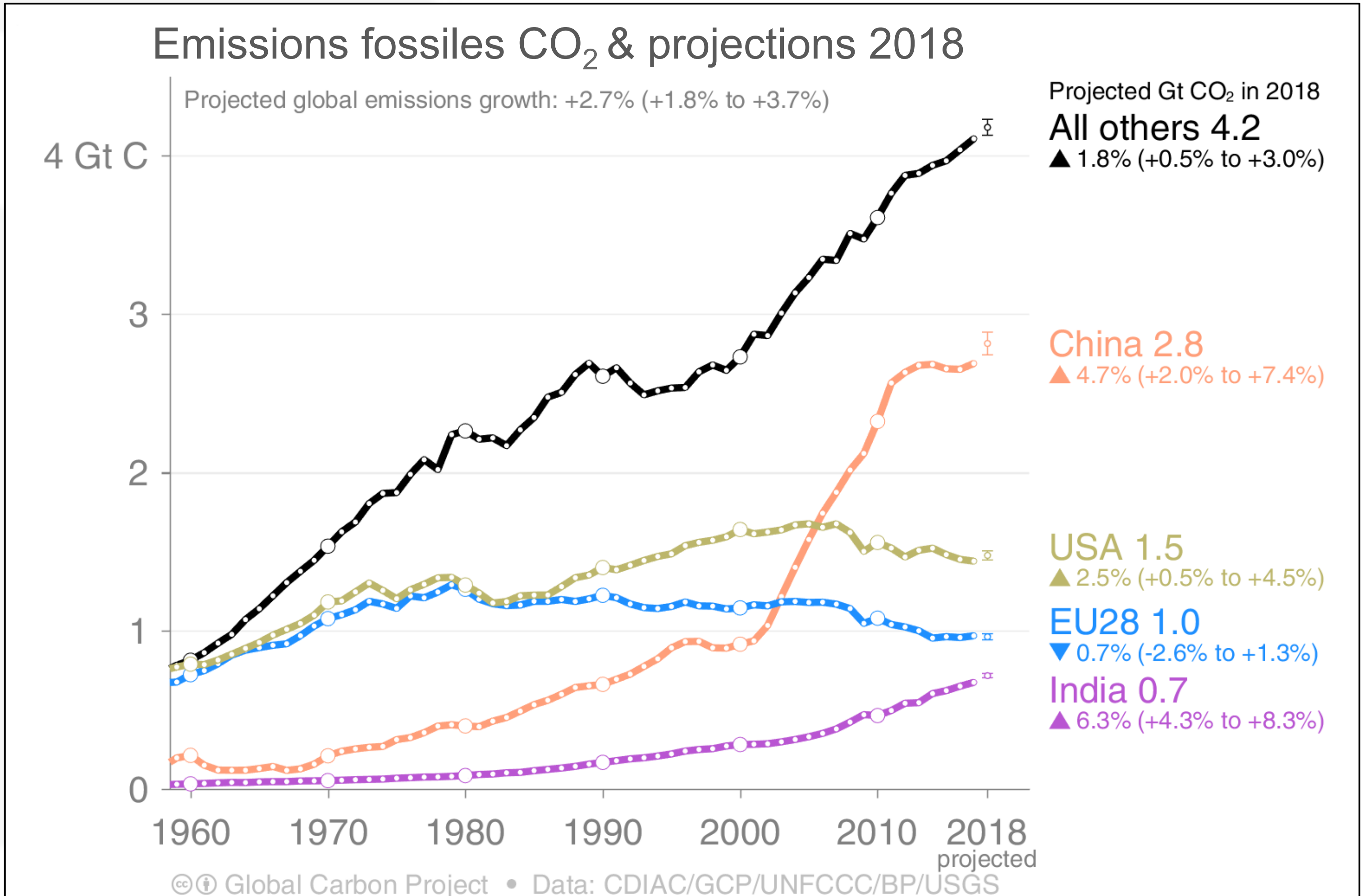
Partage des émissions fossiles de CO_2 en 2017:
Charbon (40%), Pétrole (35%), Gaz (20%), Ciment (4%), Torchère (1%, not shown)



Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

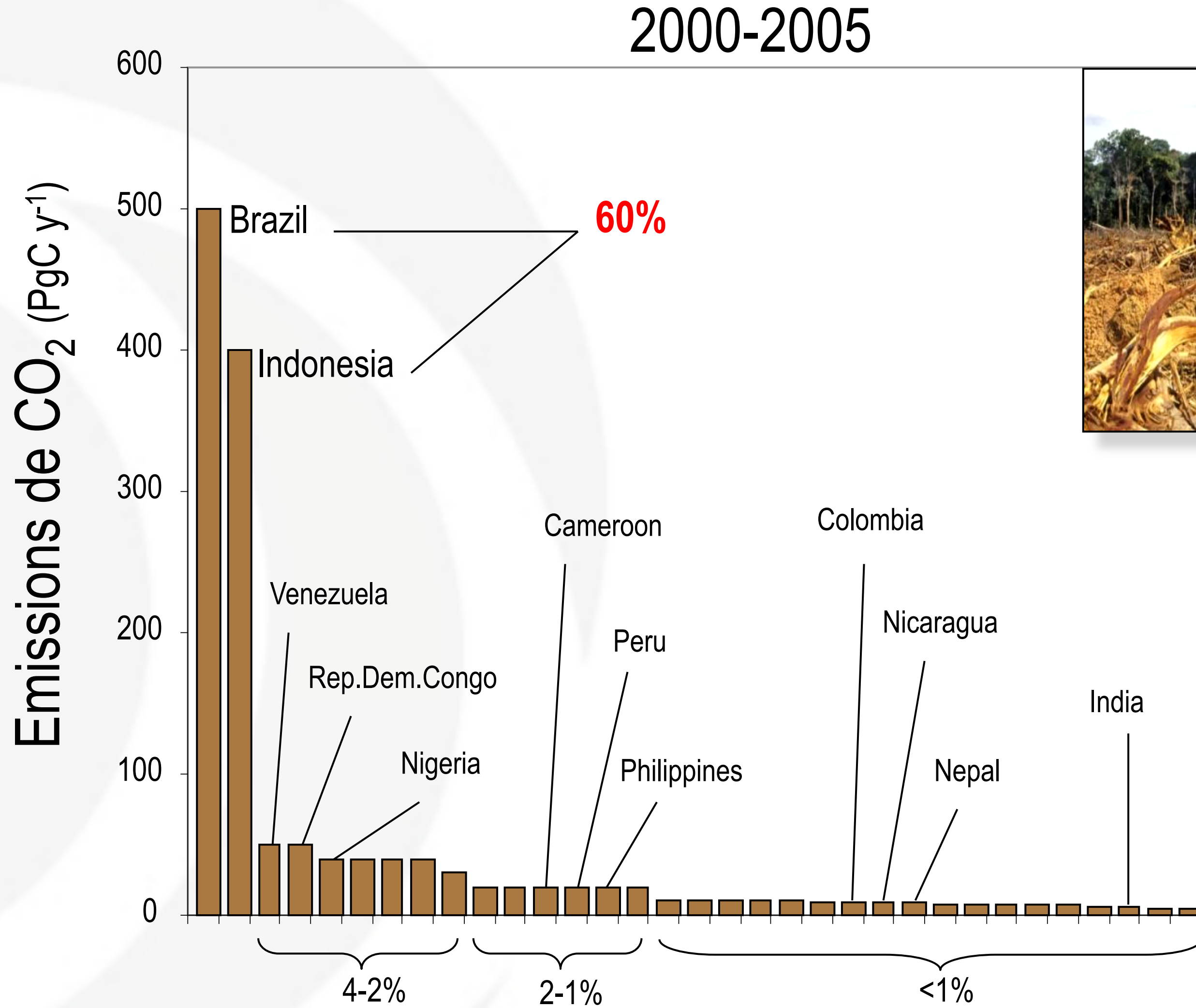
Emissions par “pays” & Projections pour 2018

Projection des émissions fossil de CO_2 : augmentation de 2.7% in 2018 [+1.8% - +3.7%]
La croissance global repose sur les dynamiques de chaque pays.



Source: CDIAC; Jackson et al 2018; Le Quéré et al 2018; Global Carbon Budget 2018

Emissions de CO_2 dues à la déforestation

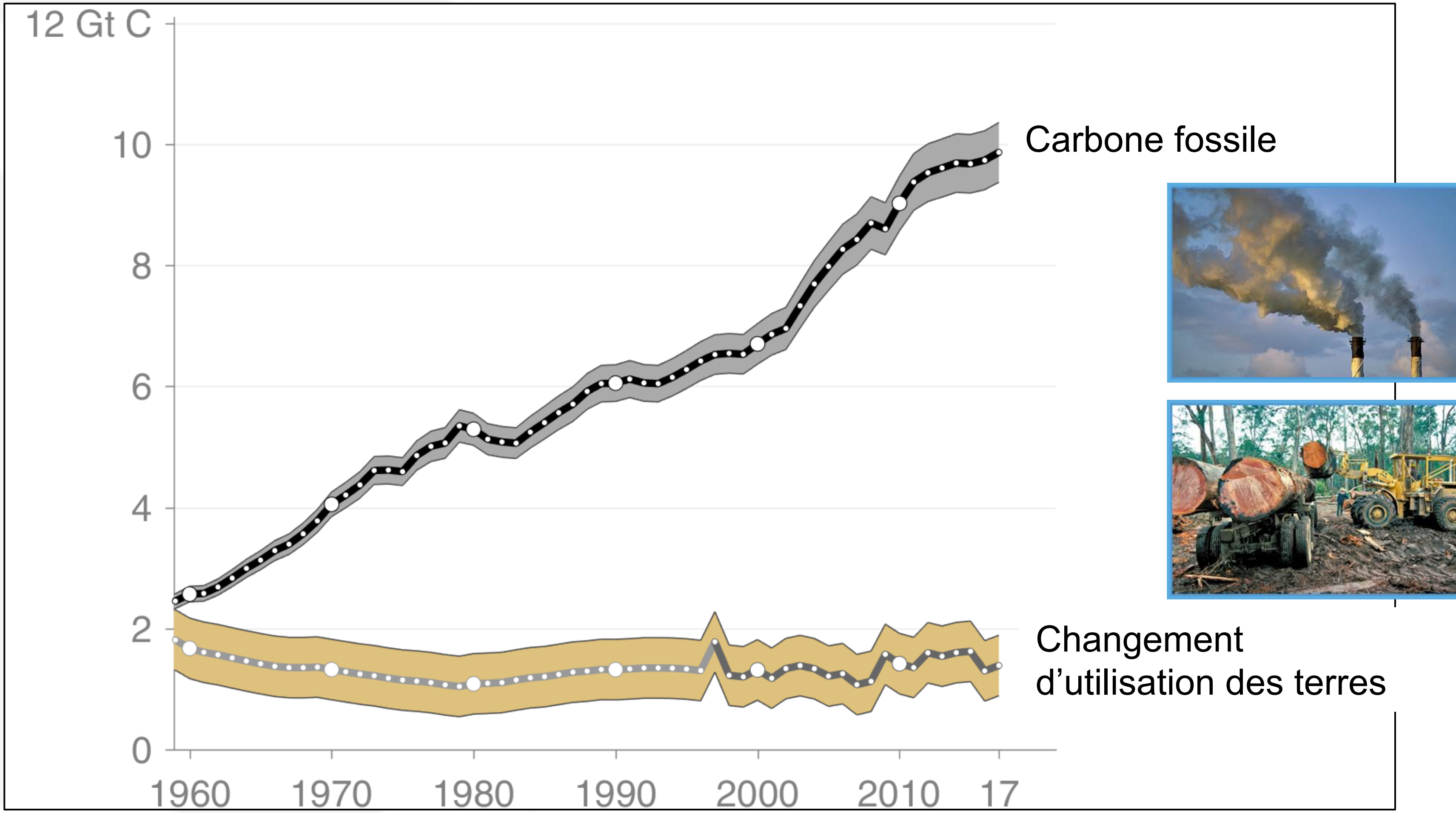


Source : Global Carbon Project

Emissions anthropiques globales

Émissions totales globales : 11.2 ± 0.8 GtC en 2017

Contribution de utilisation des terres: 43% en1960, 13% en moyenne sur 2008–2017

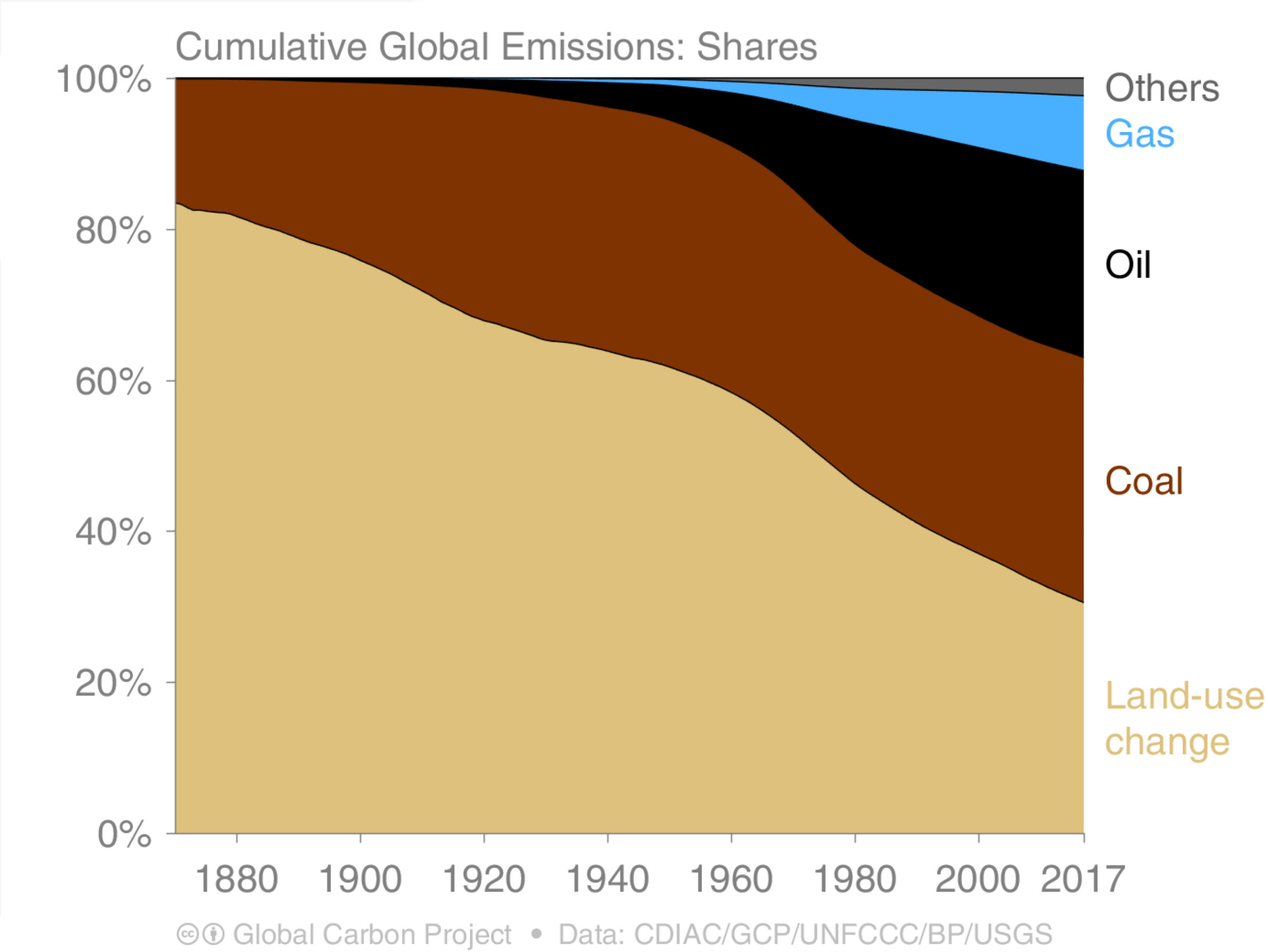


Estimation du flux liés à la déforestation selon 2 modèles à partir des surfaces brulées depuis 1997.

Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Emissions cumulées par type de source

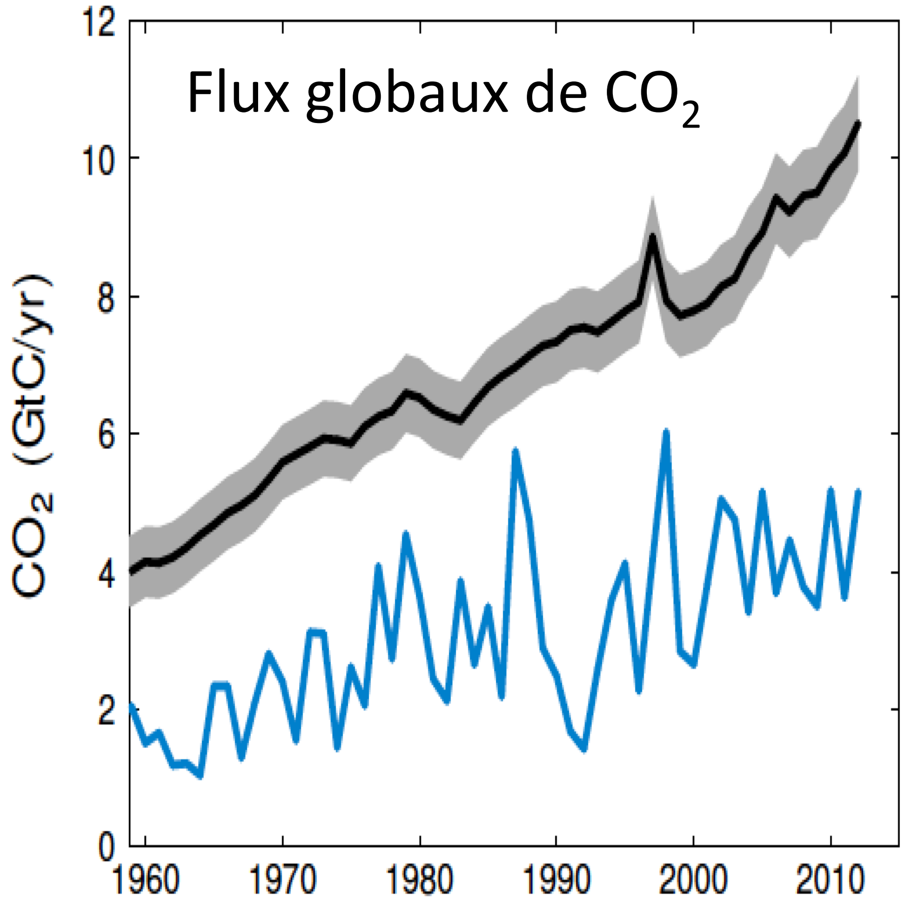
Land-use change represents about 31% of cumulative emissions over 1870–2017, coal 32%, oil 25%, gas 10%, and others 2%



Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Absorption partielle des émissions de CO_2



Moyenne 2008-2017

Emissions totales 10.8 ± 0.6 PgC/an

Taux de Croissance observé 4.7 ± 0.1 PgC/an

Absorption par les écosystèmes terrestres et océaniques (≈ la moitié)

Source: CDIAC Data; Global Carbon Project 2018

1PgC = 10^{15}g de carbone

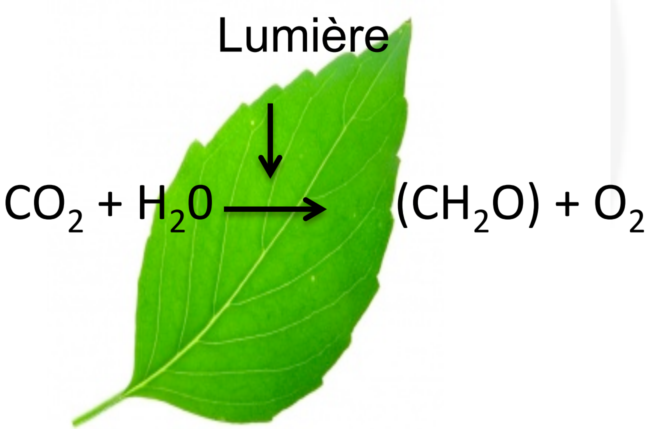
Absorption par la biosphère terrestre

➔ Effet fertilisant du CO_2 atmosphérique

Photosynthèse (principe)

CO_2 atmos : substrat limitant

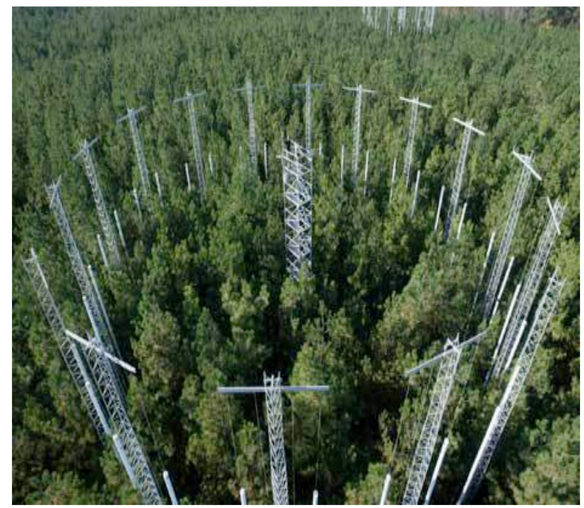
↗ $[CO_2]_{atm}$ ➡ ↗ Assimilation C



Plante chlorophyllienne

Mise en évidence expérimentale

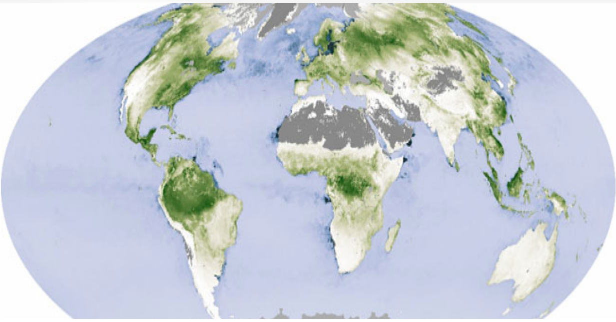
Expérience FACE (doublement CO_2)



➔ Augmentation de la productivité primaire nette ≈ 20-40%
(Norby et al. 2010)

Absorption par la biosphère terrestre

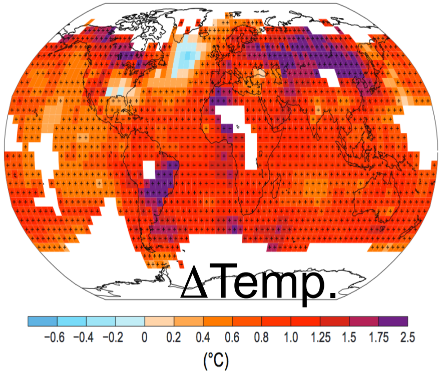
- Effet fertilisant du CO_2



➔ Lié à la productivité primaire

- Impact du changement climatique

✧ sur la photosynthèse
✧ sur la dégradation du C organique des sols



- Gestion des écosystèmes

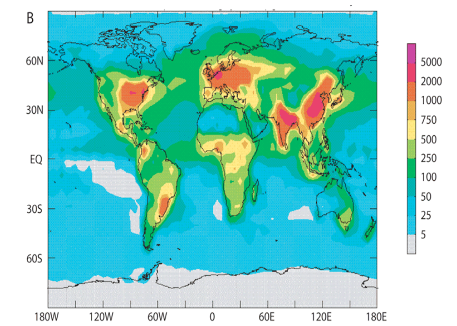
Extensif vs Intensif

?

depuis 1750: 150 PgC ± 60%
Variations temporelles & spatiales du puits incertaines
➔ Enjeux de recherche

- Disponibilité en nutriments (dépots d'azote)

Dépot de N inorganique (mg m^{-2} an^{-1})



Bilans nets variables selon les écosystèmes

Importance des sols:

- Dynamique du C sol
- Impactée par CC ?
- effet « priming » ?

➔Temps de résidence moyen du « carbone aérien » très variable

Forêts tempérées

Temps de résidence : 20 ans

Forêts boréales

Temps de résidence : 80 ans

Forêts tropicales

Temps de résidence : 30 ans

Devenir des émissions anthropiques de CO_2 (2008–2017)

Sources = Puits

9.4 GtC/yr

87%

13%

1,4 GtC/yr

4.7 GtC/yr

44%

29%

3.2 GtC/yr

22%

2.4 GtC/yr

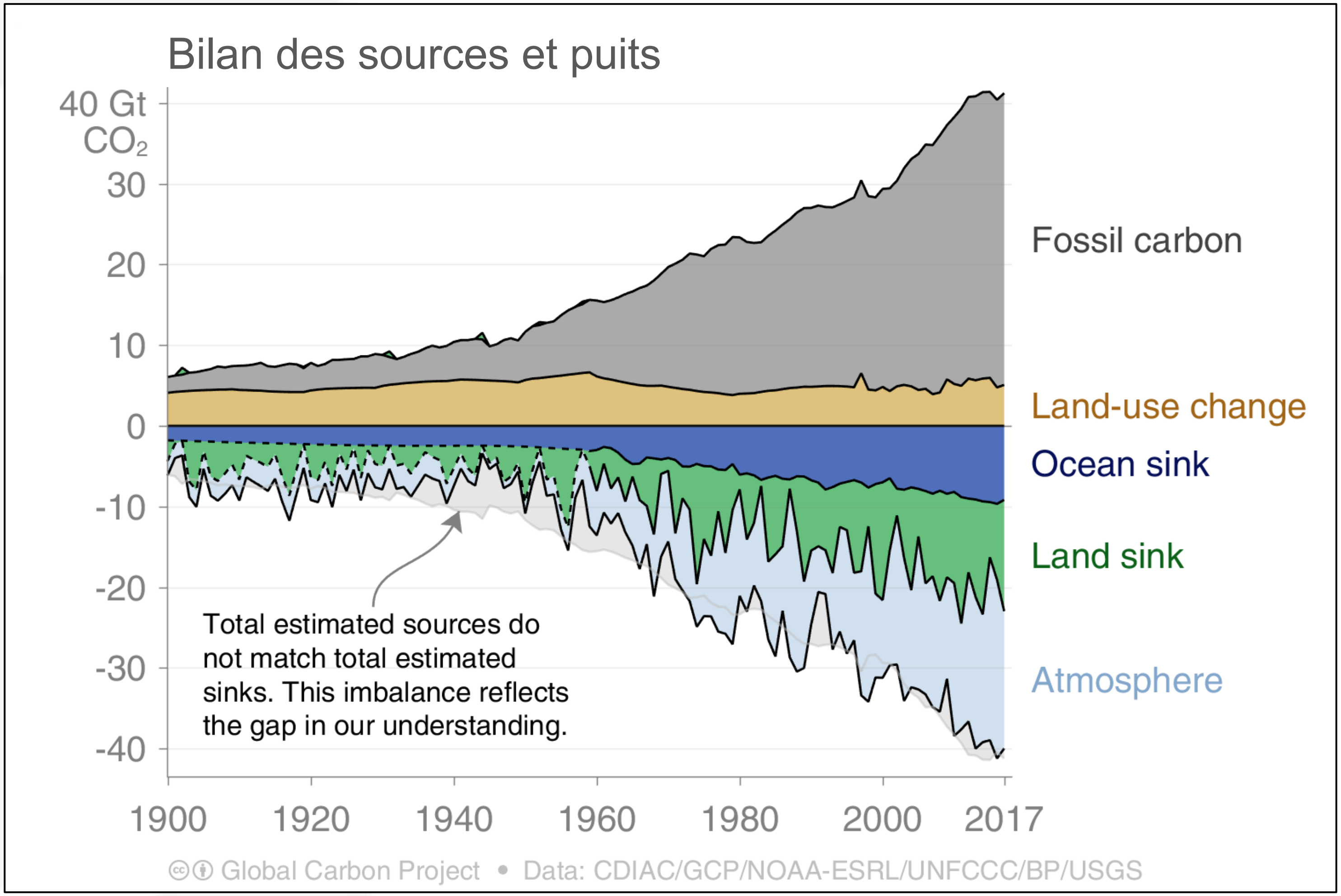
Déséquilibre du budget:
(différence entre les sources et puits estimés)

5%
0.5 GtC/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Bilan global du CO_2

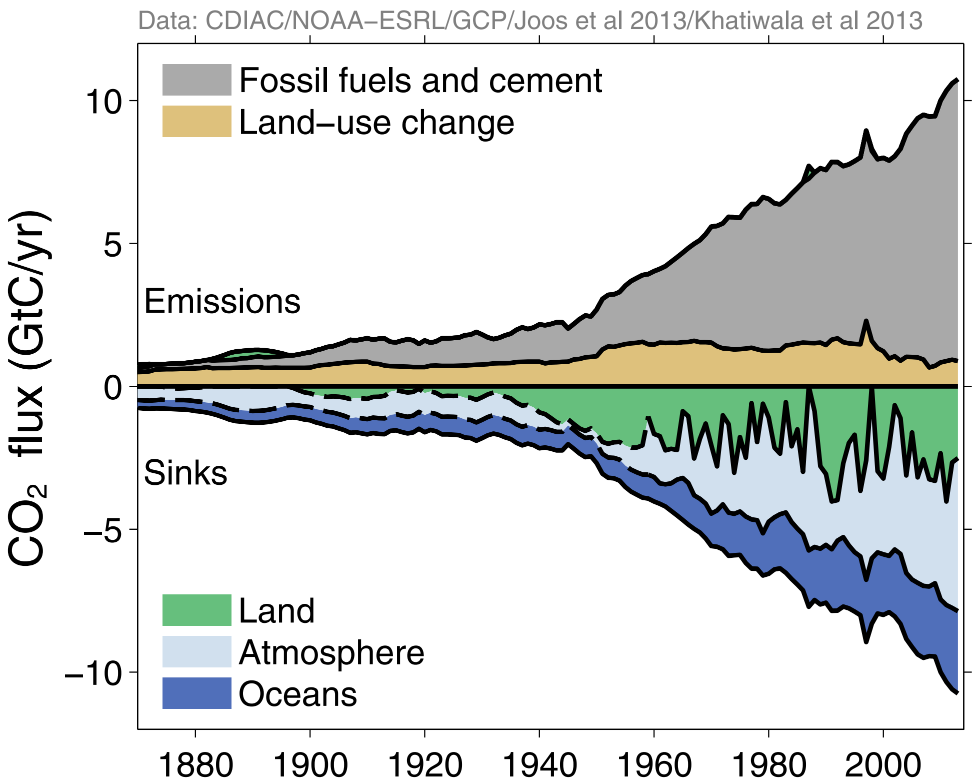
Depuis 1750, les activités humaines ont émis 555 ± 85 PgC (fossil & Land use)



Le terme "déséquilibre" entre émissions et puits totaux révèle notre manque de compréhension!

Source: CDIAC; NOAA-ESRL; Global Carbon Budget 2018

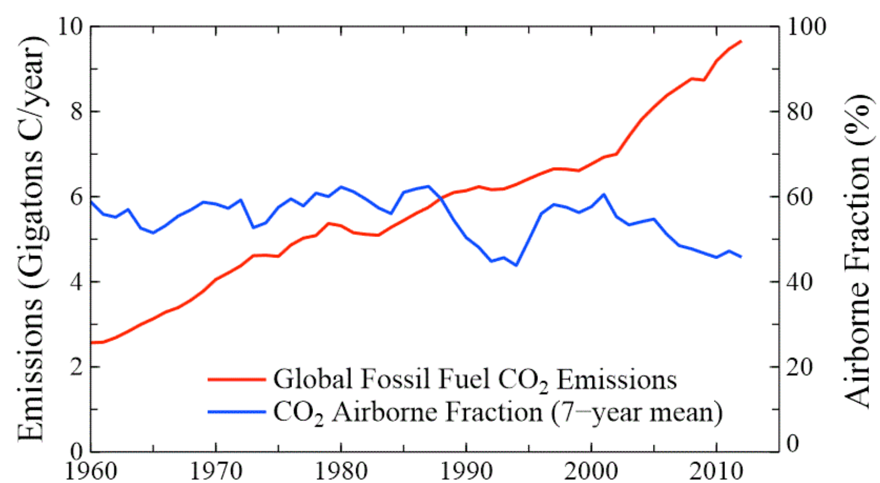
Retro-actions du cycle du carbone



- Fraction atmosphérique (AF)

$$AF = \frac{S_{ATM}}{\left(E_{FF} + E_{LUC}\right)}$$

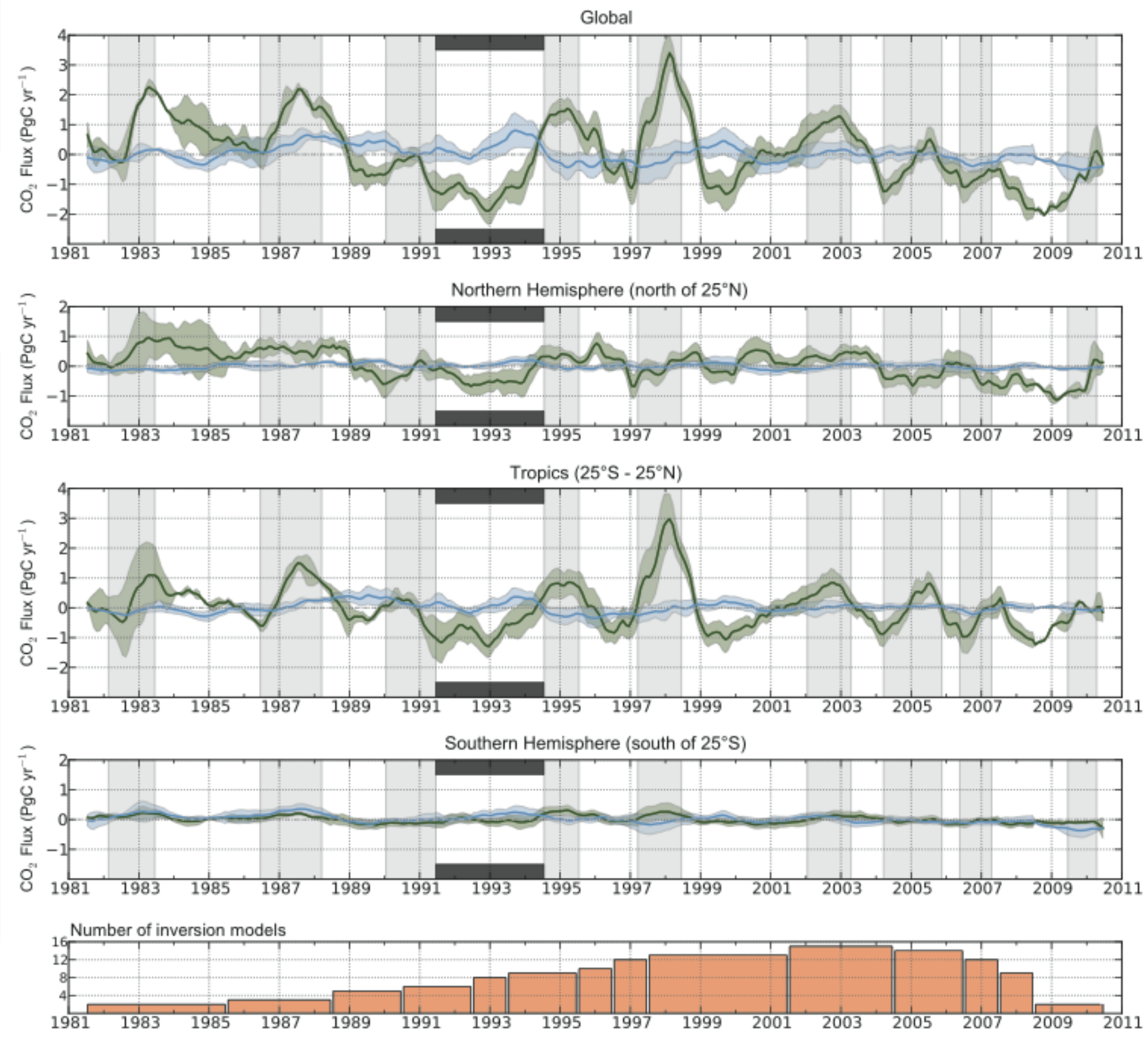
- AF constant et controlée par:
  - Changement climat
  - Fertilization CO2
  - Dépot N
  - Utilisation des terres



Global Carbon Project

Anomalies du flux de carbone (terrestre / océanique)

(from atmospheric CO2 inversion)



Global

North Hemis.

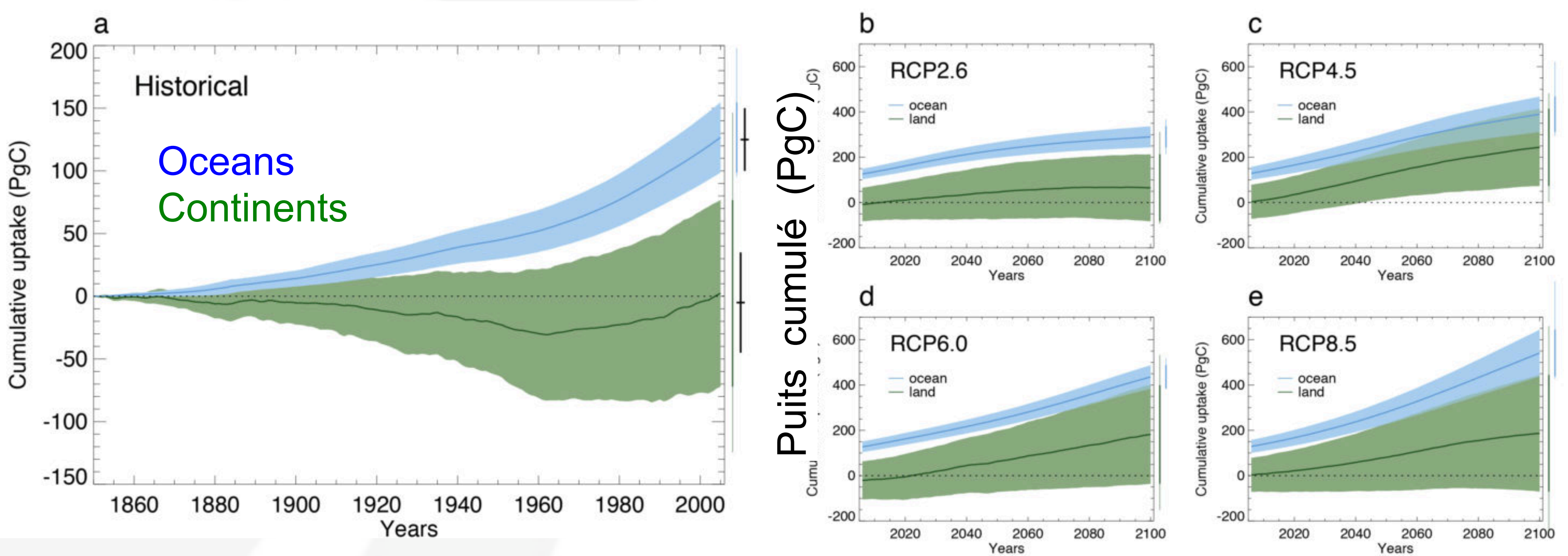
Tropics

South Hemis.

Simulation du stockage futur de carbone par les océans et les continents: modèles CMIP5

Historique

Futur: trajectoires représentatives de concentration en GhG (RCP)

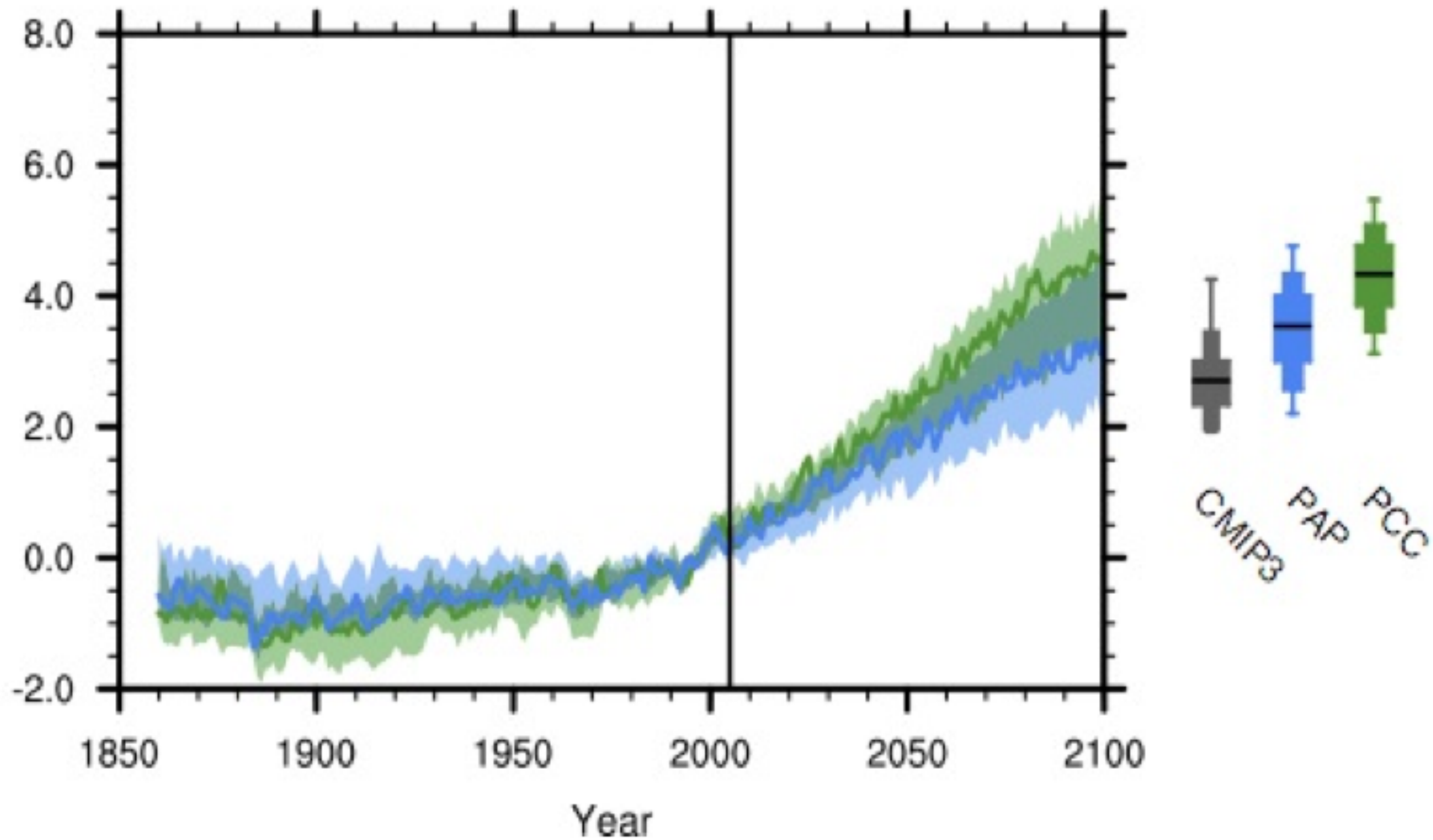


Très forte incertitude associée aux projections du stockage de C sur les continents

Incertitudes: paramètres Carbone vs Physique

Analyse de sensibilité avec 1 modèlde (HadCM3 – SRES-A1B) variant:
Paramètres de la physique atmosphérique
Parmètres du cycle du carbone terrestre

Changement de la Température moyenne globale (°C)

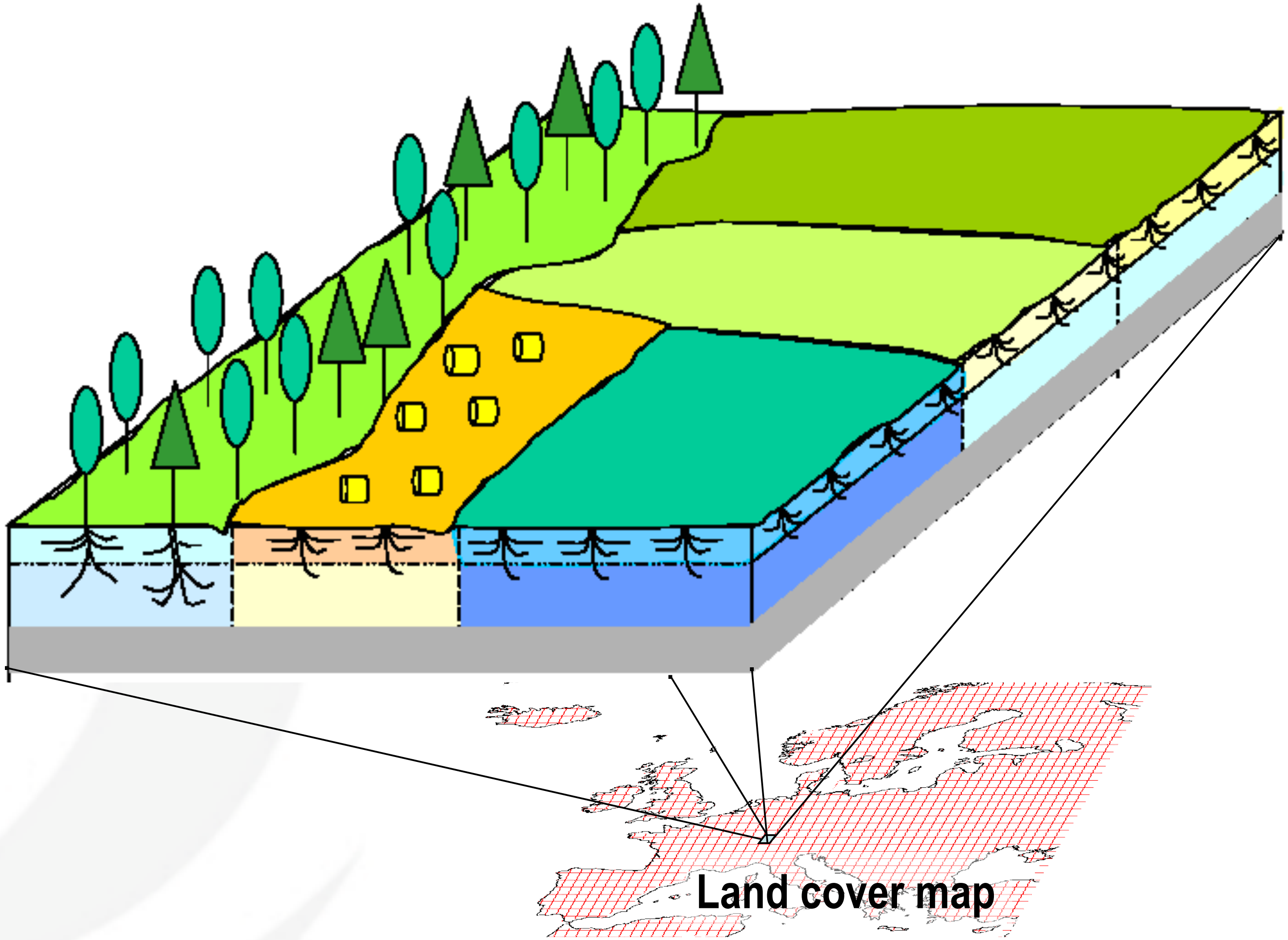


Booth et al. 2012

Modélisation du bilan de carbone des écosystèmes terrestres !

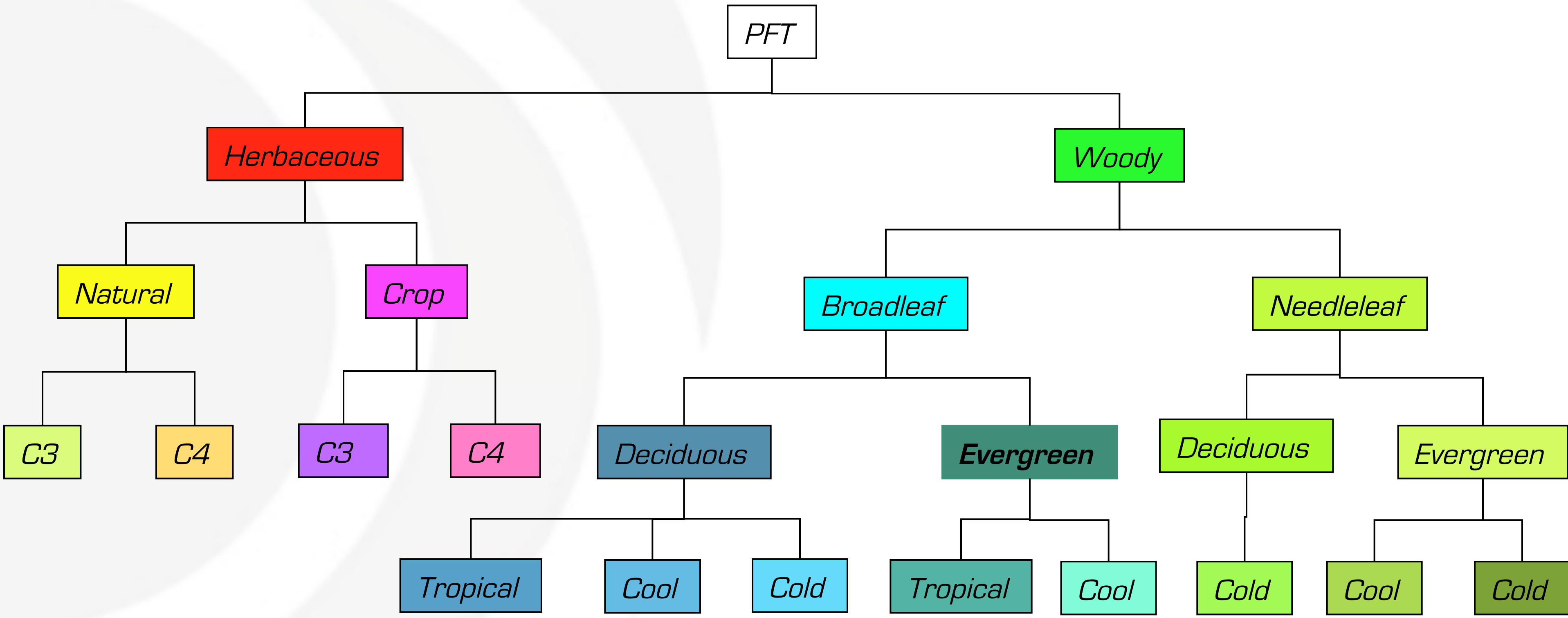
Modèles de surface continentale…

- A mosaïc of vegetation

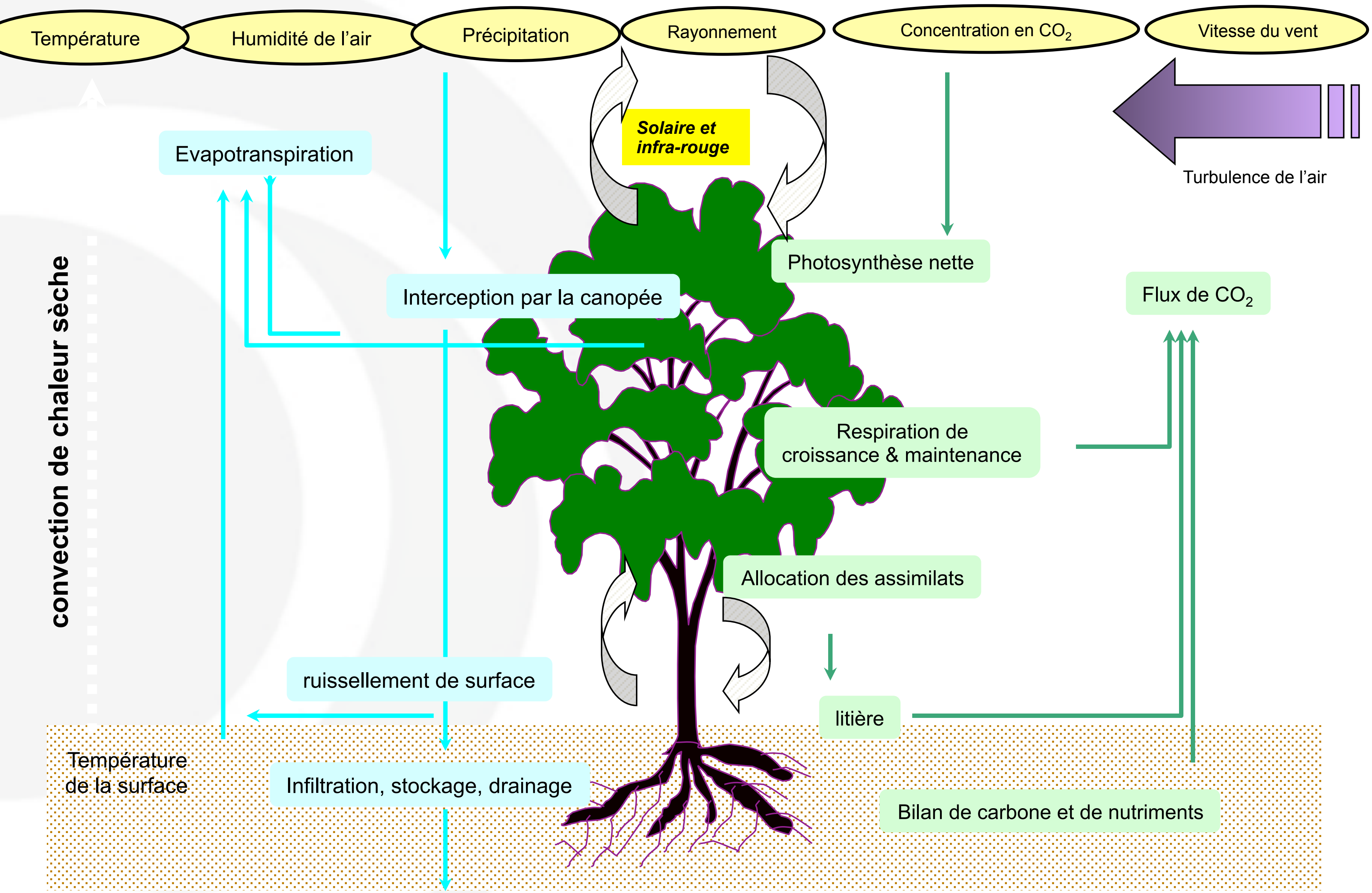


Représentation de la végétation

- Concept de ‘Type fonctionnel de plante’ (PFT)
- Définit selon des critères systématiques, physiologiques, phénologiques, climatiques



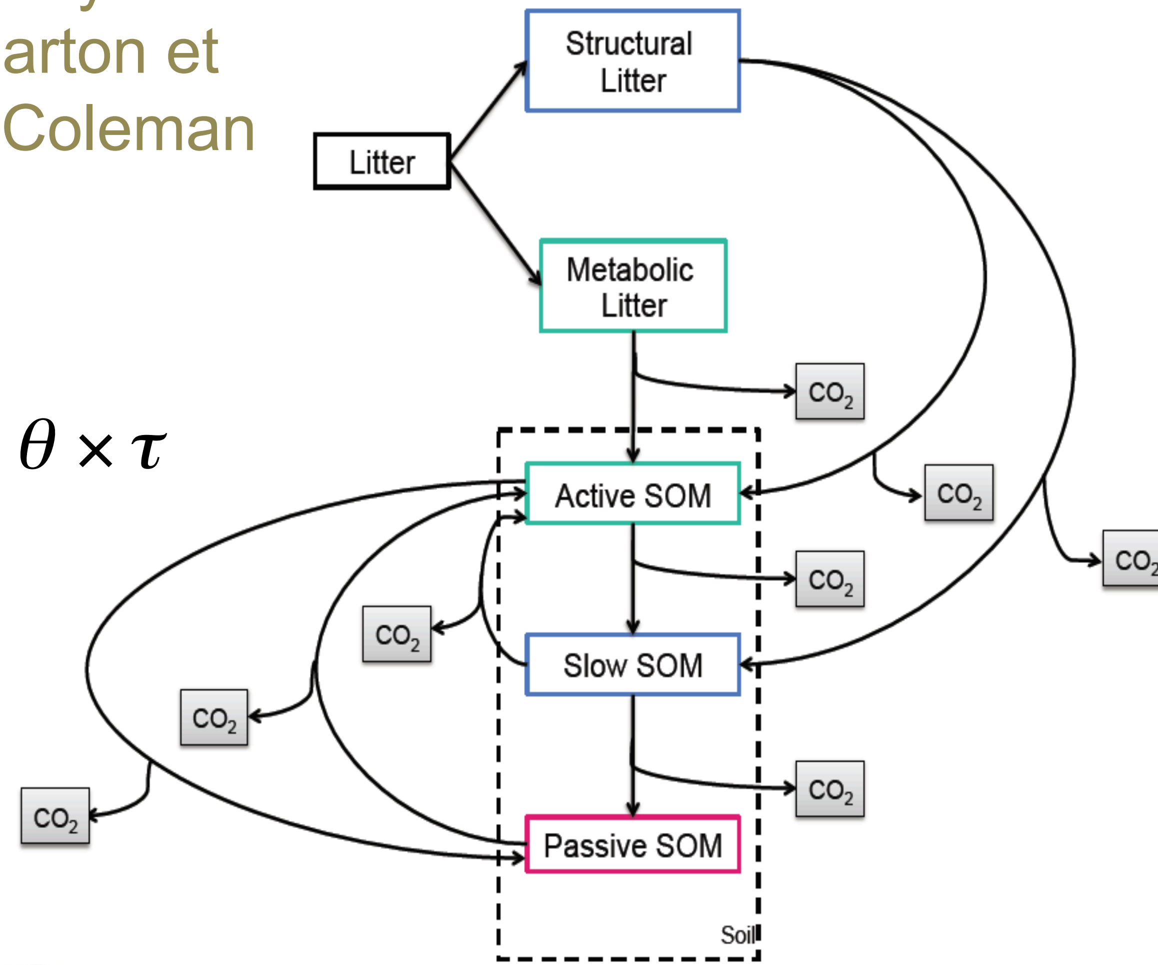
Les processus clés simulés par un modèle de biosphère



Représentation du carbone des sols (tous les modèles)

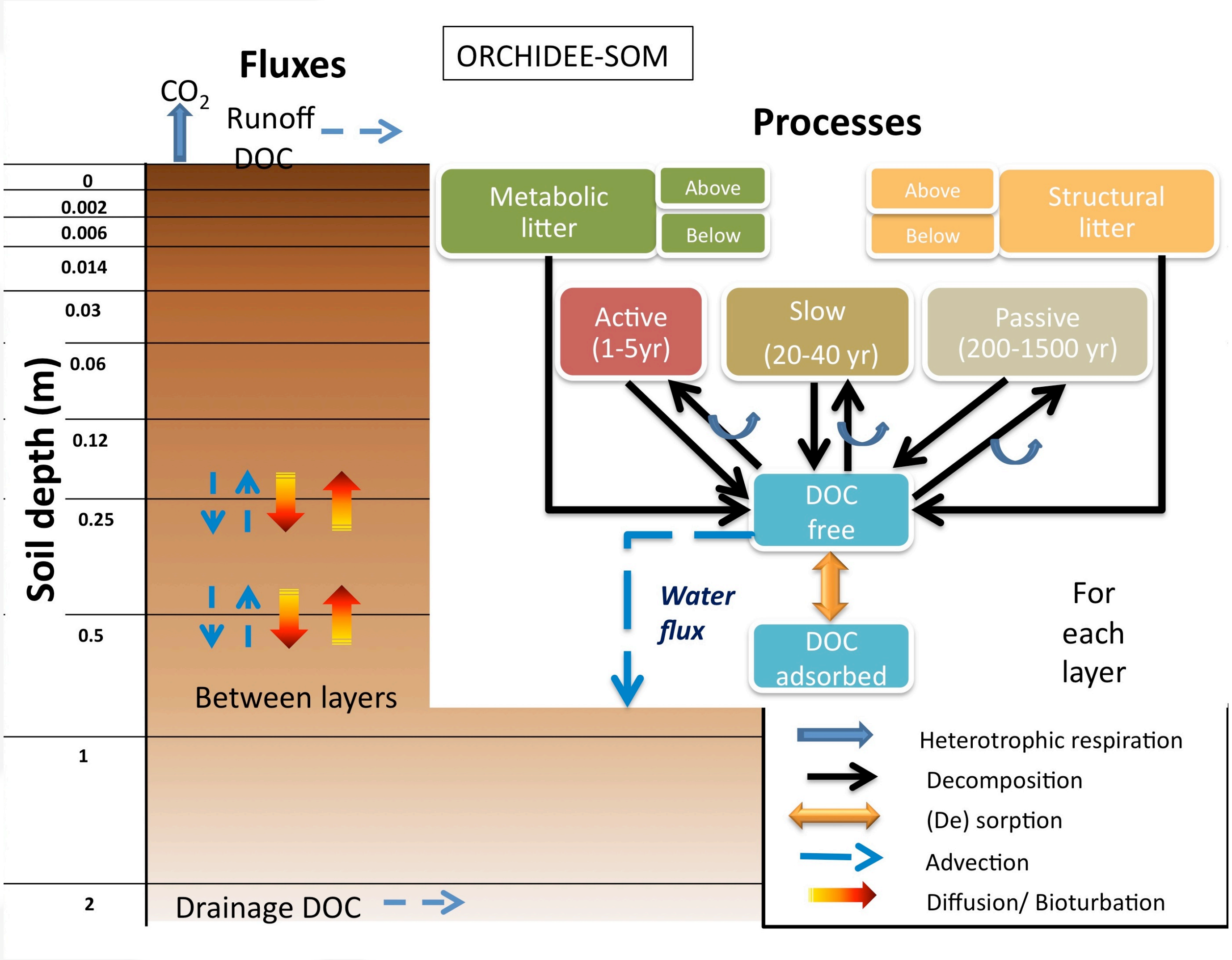
- Soil representation mainly based on CENTURY (Parton et al., 1987) or on RothC (Coleman and Jenkinson, 1999)

$$\frac{\partial SOC}{\partial t} = I - k \times SOC \times \theta \times \tau$$



Représentation du carbone des sols (ORCHIDEE modèle)

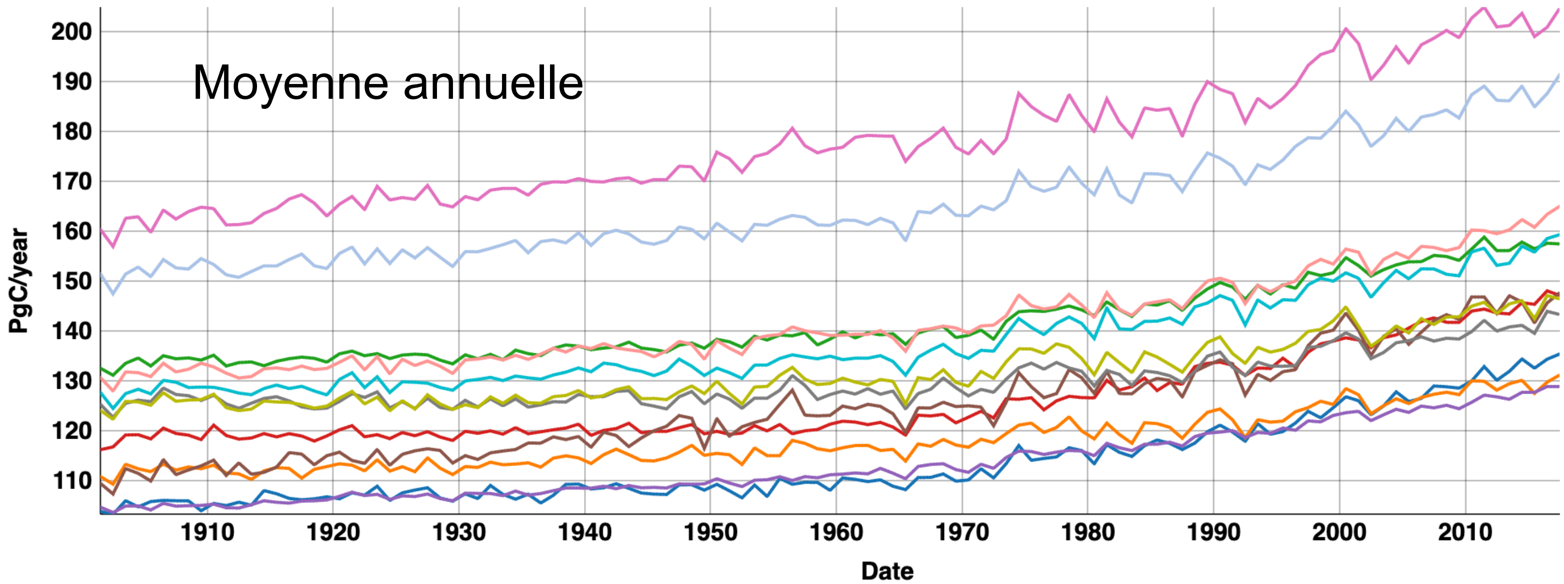
- Soil C discretized using the same layers than hydrology scheme (11 layers). A new pool introduced (DOC)

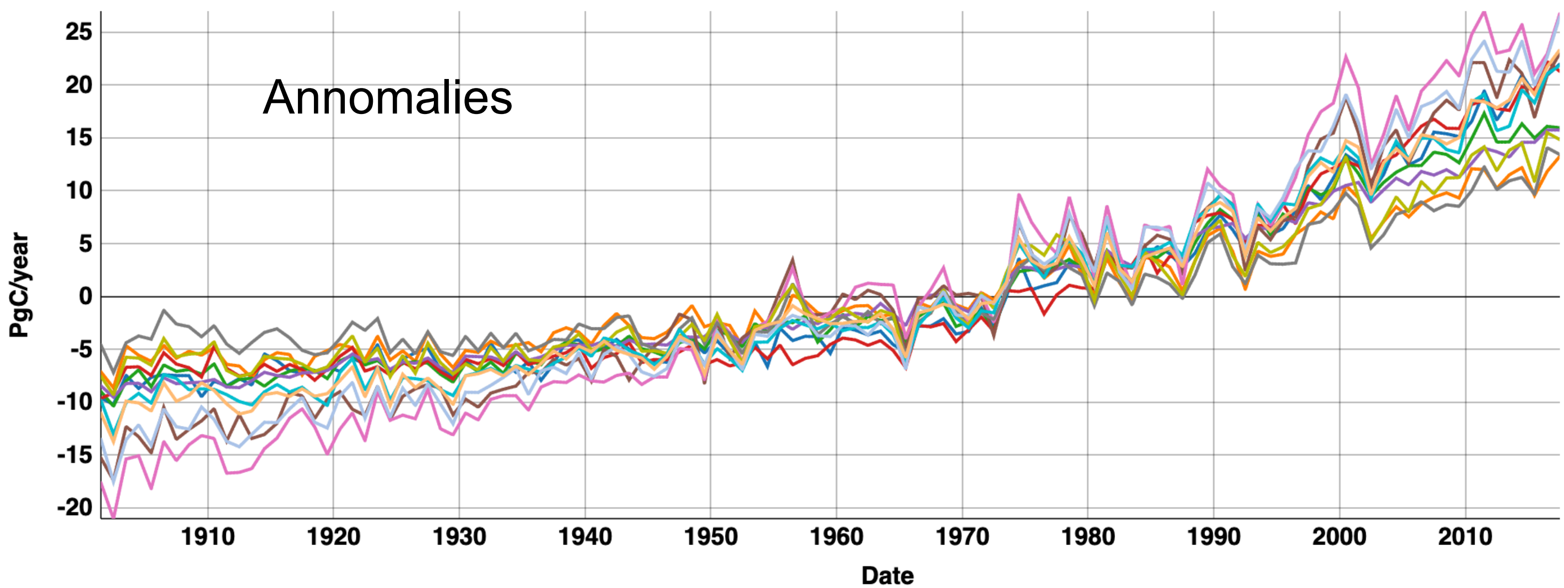


Quelles incertitudes associées aux modèles de biosphère actuels ?

Flux de Photosynthèse: Modèle globaux

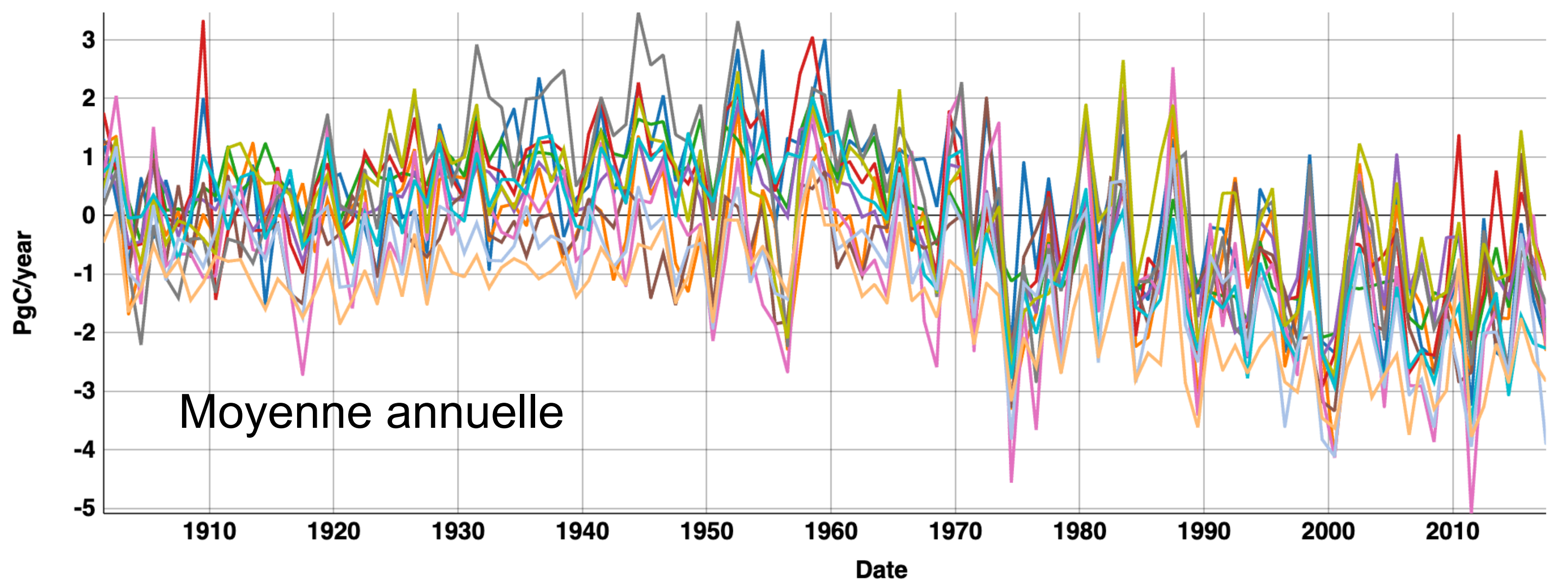
TRENDY Inter-comparaison

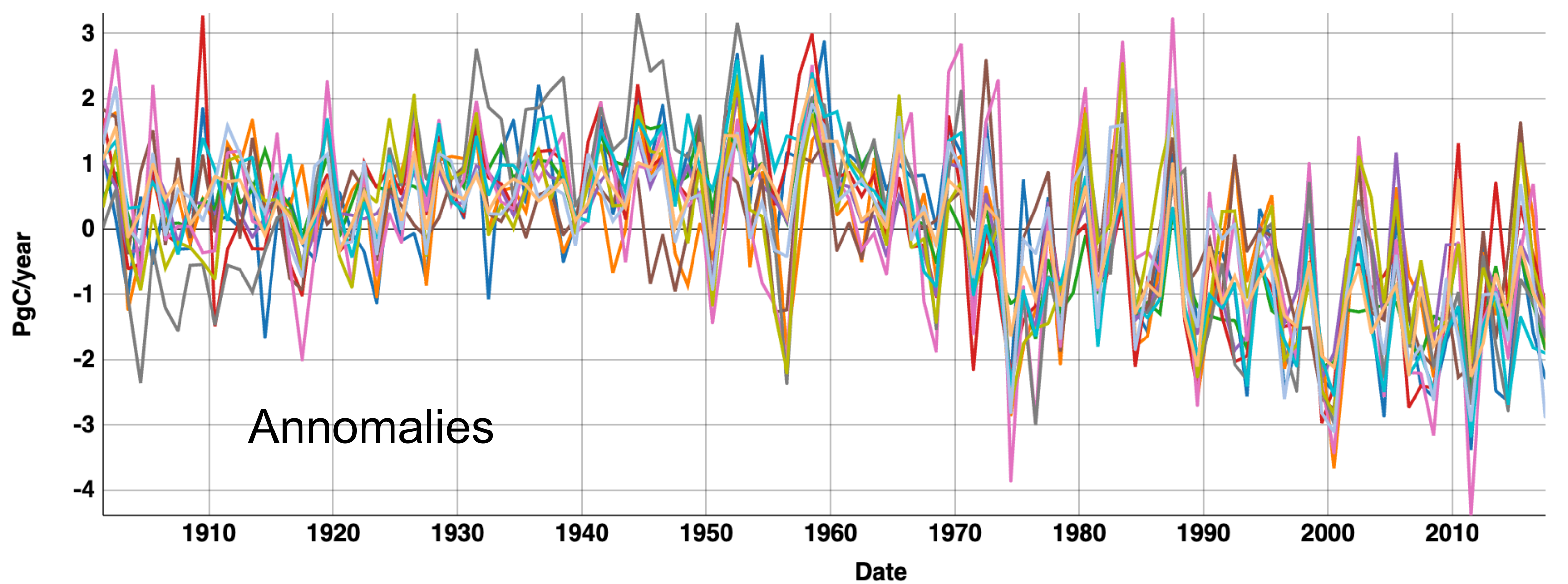




Flux de net de de carbone (végétation – atmopshère)

TRENDY Inter-comparaison



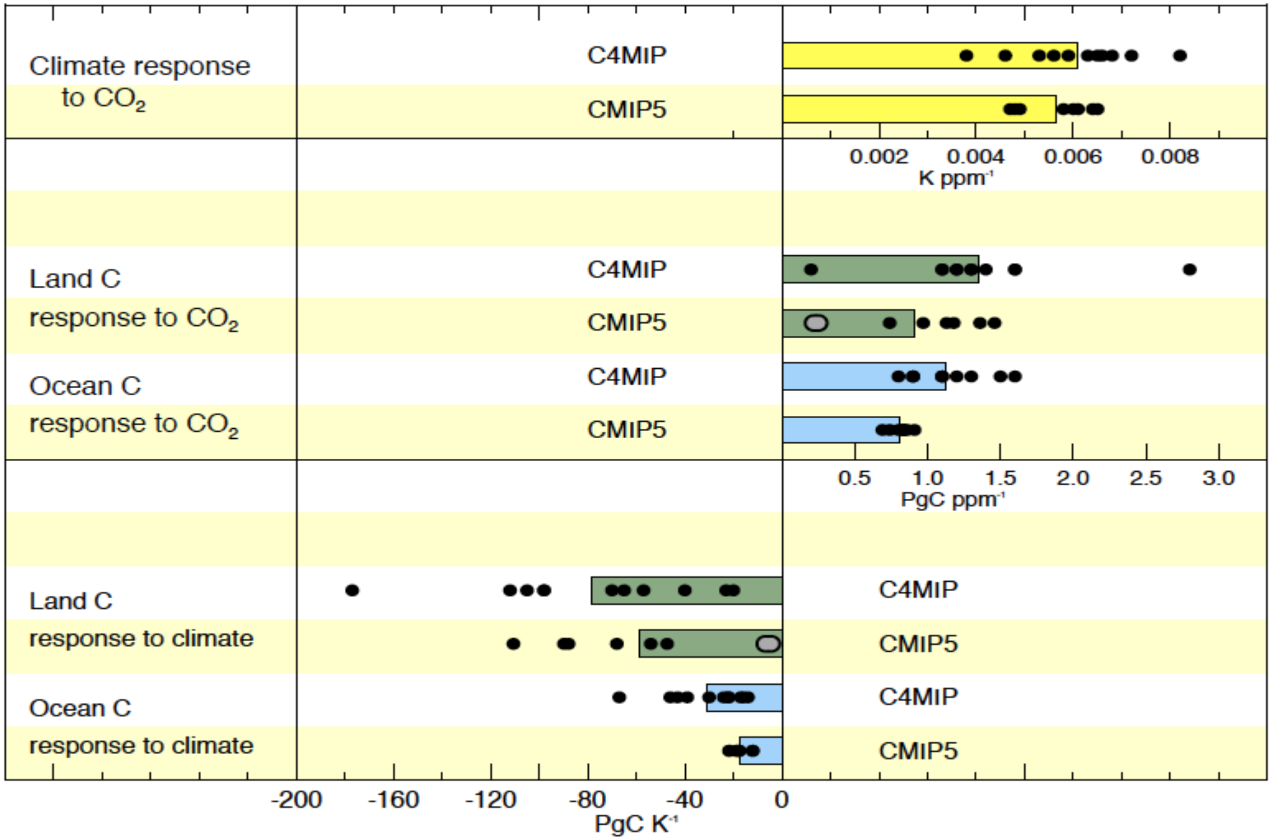


Rétroactions positives Climat - Carbone

Climate response to CO_2 (K / ppm)

Sinks response to CO_2 (PgC / ppm)

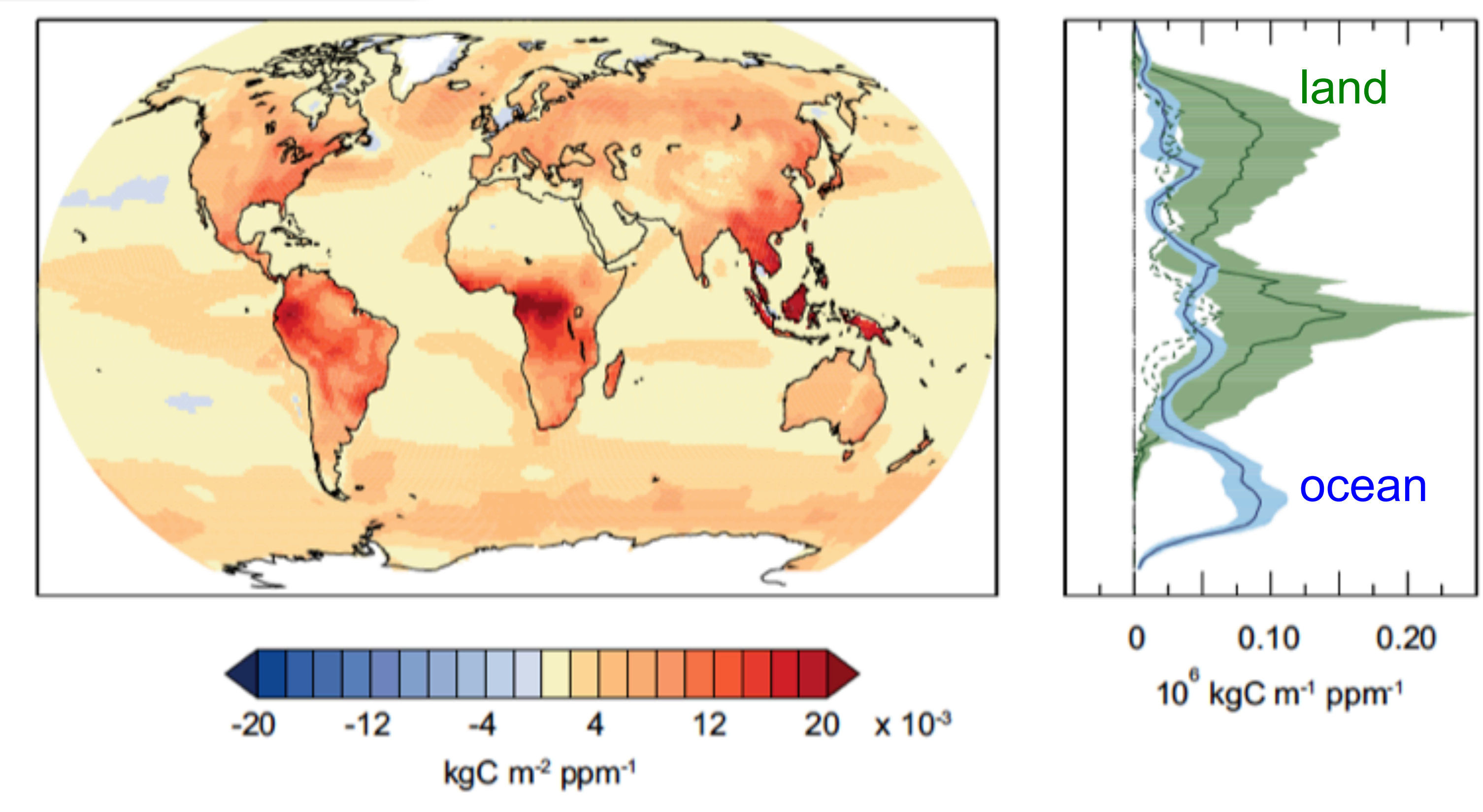
Sinks response to climate (PgC / K)



Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere (*high confidence*)

source: Ciais et al. 2013 IPCC AR5

Réponse au CO_2 atmosphérique seul

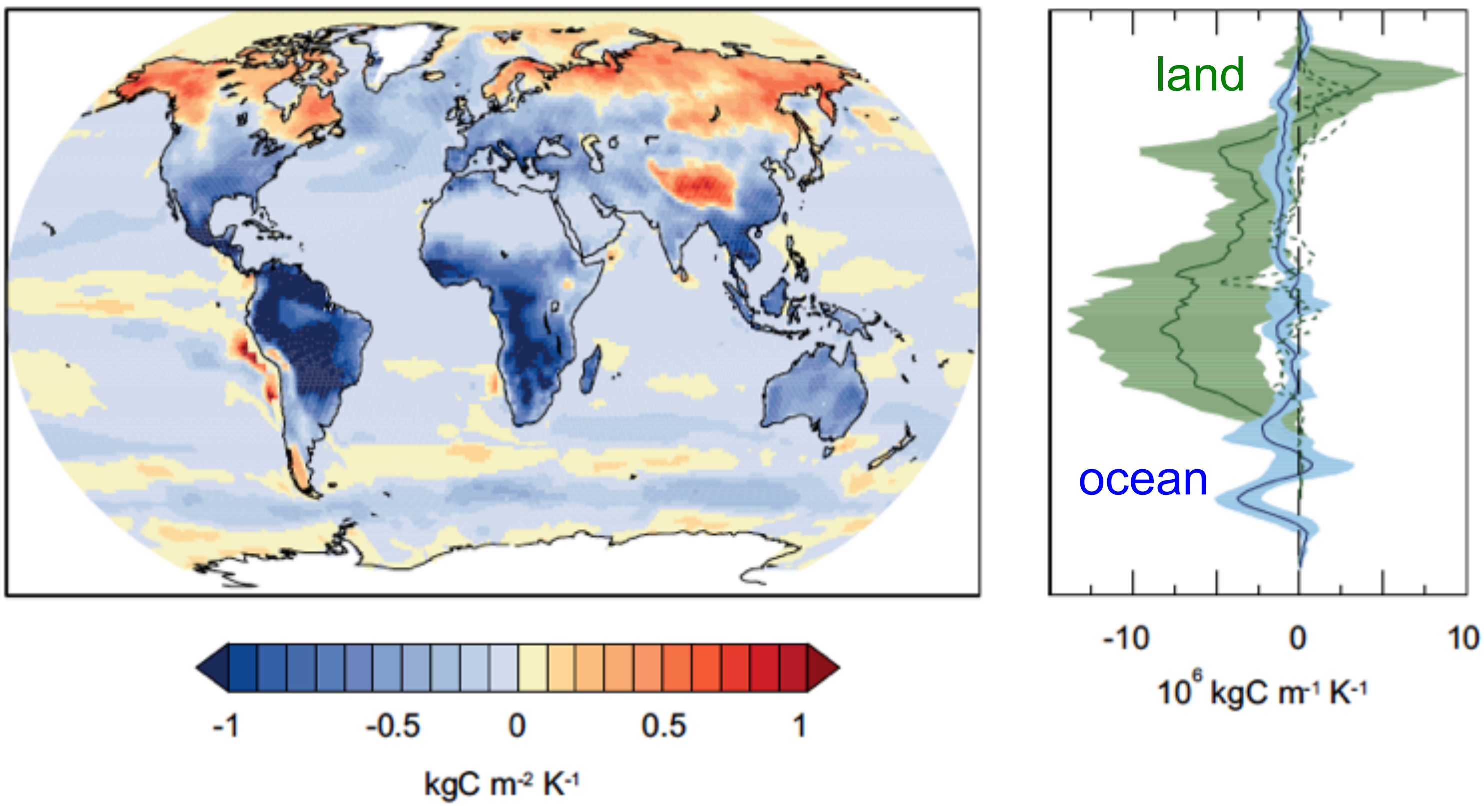


decreasing sink

increasing sink

source: Ciais et al. 2013 IPCC AR5

Réponse au changement du climat seul



decreasing sink

increasing sink

models do not include the release of permafrost C

source: Ciais et al. 2013 IPCC AR5

Productivité limitée par les nutriments

nature geoscience LETTERS
PUBLISHED ONLINE: 20 APRIL 2015 | DOI: 10.1038/NGEO2413

Future productivity and carbon storage limited by terrestrial nutrient availability

William R. Wieder[1,2]*, Cory C. Cleveland[3], W. Kolby Smith[3,4] and Katherine Todd-Brown[5,6]

Wieder et al., Nature 2015

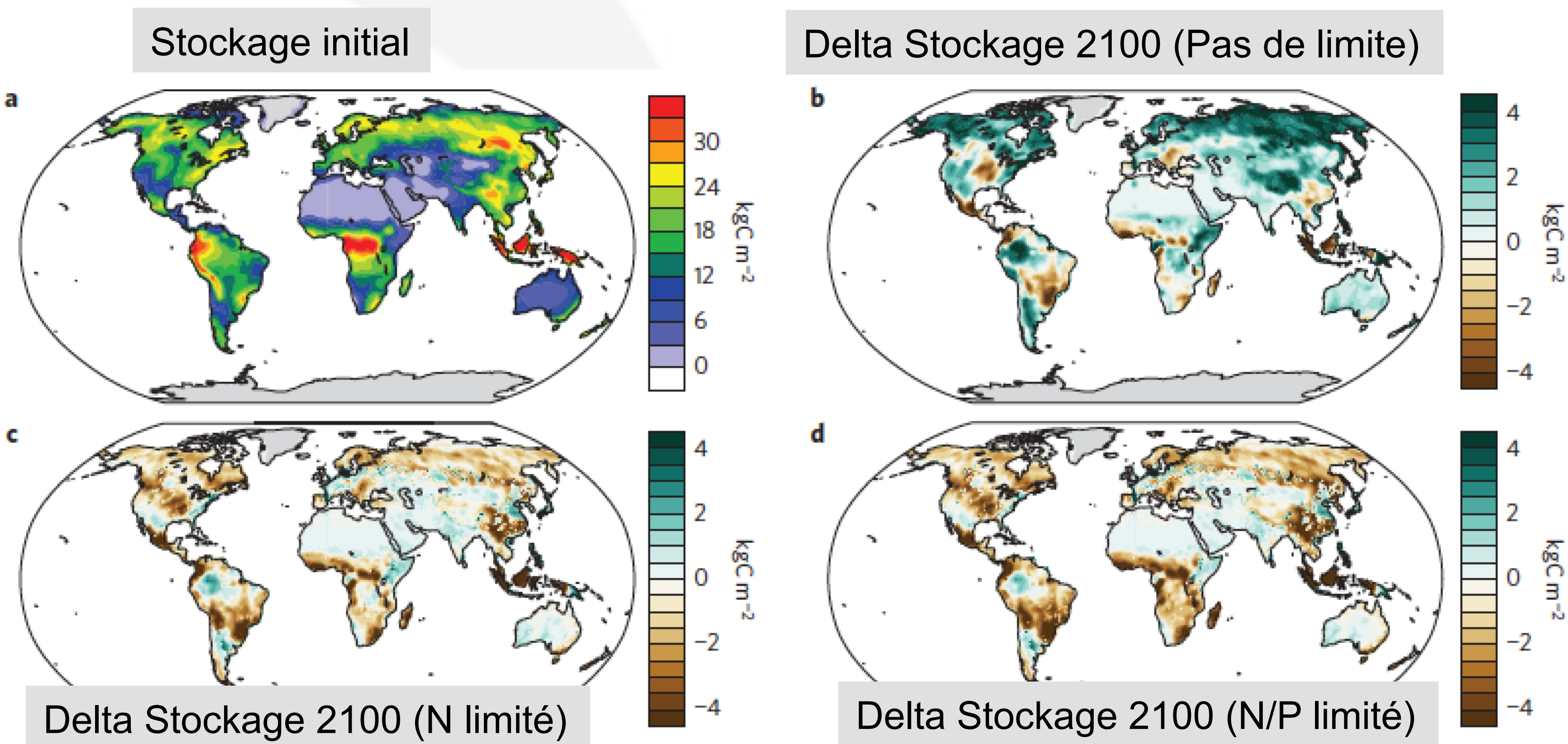


Figure 2 | Multi-model mean terrestrial C storage and changes in C storage with different assumptions about nutrient limitation. a, Mean initial terrestrial C storage for all CMIP5 models (1860–1869). **b–d**, Multi-model mean changes in terrestrial C storage at the end of the twenty-first century under RCP 8.5 assuming that increases in NPP are limited by nothing (as in the CMIP5 archive; **b**), new N inputs (**c**), and new N and P (**d**). Individual model results for data summarized are shown in Supplementary Figs 8–10.

Effet combiné climat - carbone

Combined climate and carbon-cycle effects of large-scale deforestation

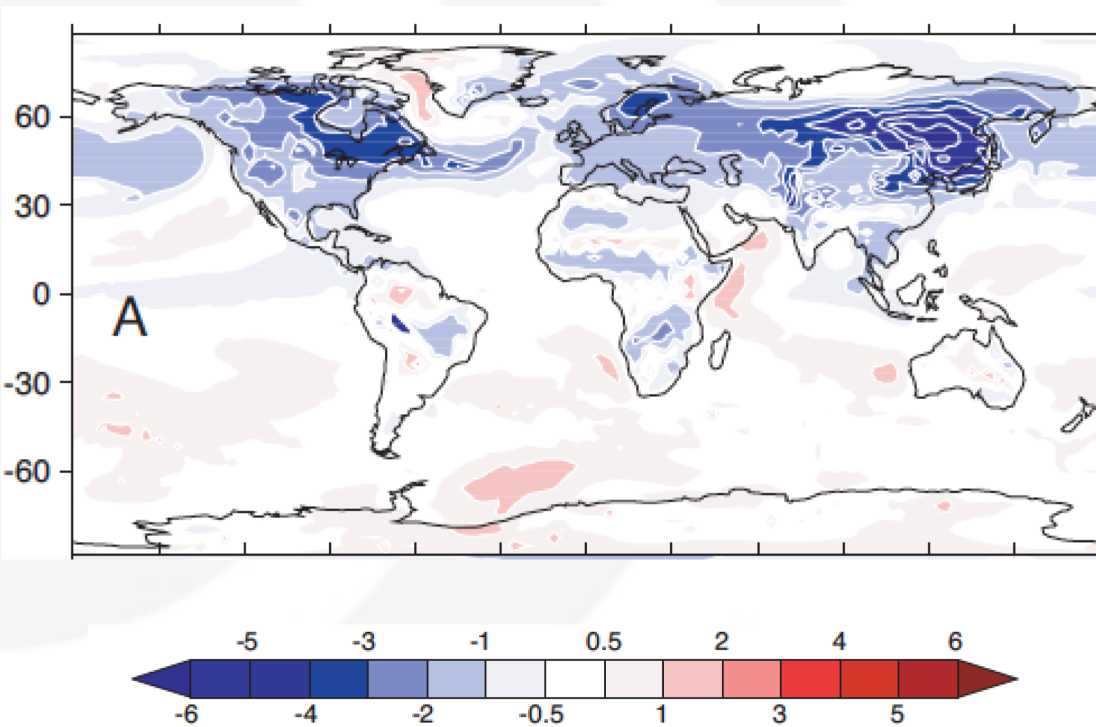
G. Bala*[†], K. Caldeira[‡], M. Wickett*, T. J. Phillips*, D. B. Lobell*, C. Delire[§], and A. Mirin*

*Energy and Environment Directorate, Lawrence Livermore National Laboratory, Livermore, CA 94550; [‡]Department of Global Ecology, Carnegie Institution, Stanford, CA 94305; and [§]Université Montpellier II, 34095 Montpellier cedex 5, France

Edited by Peter Vitousek, Stanford University, Stanford, CA, and approved February 24, 2007 (received for review October 11, 2006)

Bala et al., PNAS, 2007

Simulation du Delta Température en 2100:
Avec déforestation – Reference (sans déforestation)



➔ Effet biophysique refroidissant sur-compense effet réchauffant du CO_2

Qqs enjeux dans la modélisation du bilan de C terrestre

- **Soil processes (carbon dynamic)**

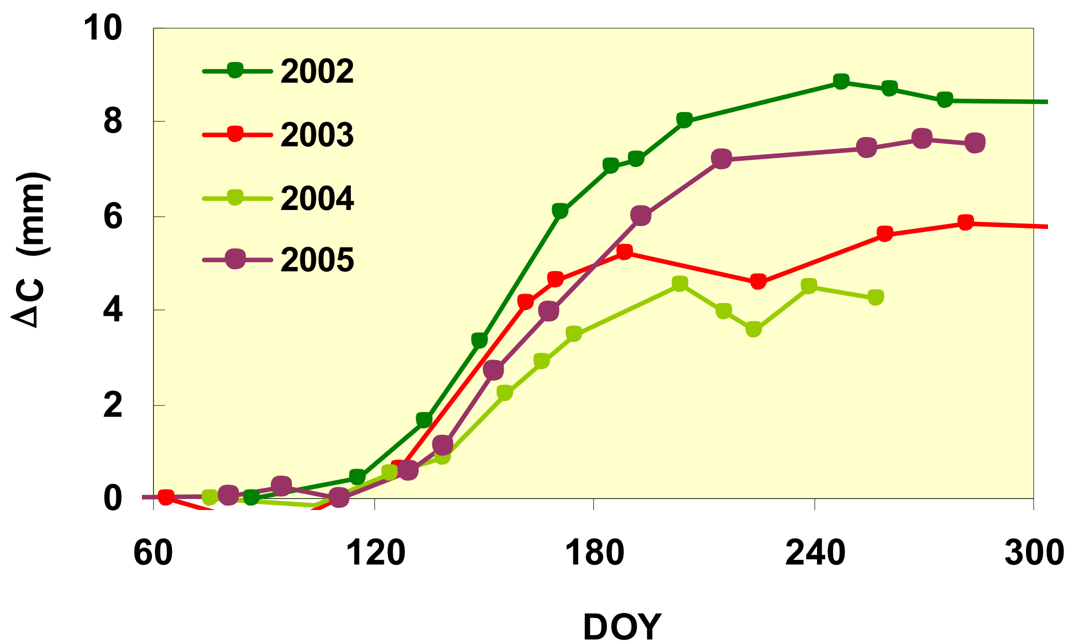
- **Better account for Land management history**

- **Species competitions & Adaptation to climate changes**

- **Biotic effects on forests (i.e. insect damage)**

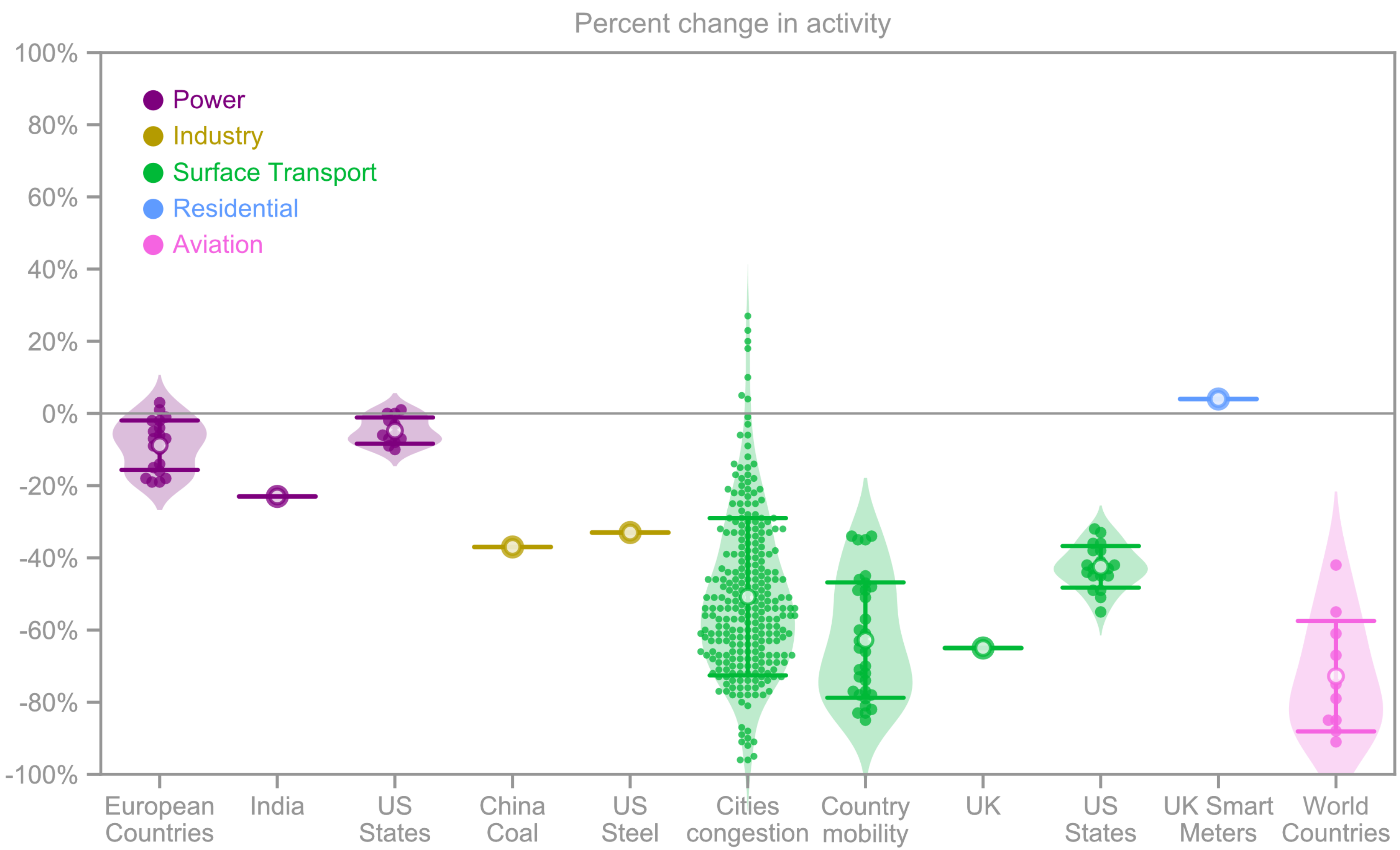
- **Lag effects of climate extreme**

Tree size increment (Beach forest)



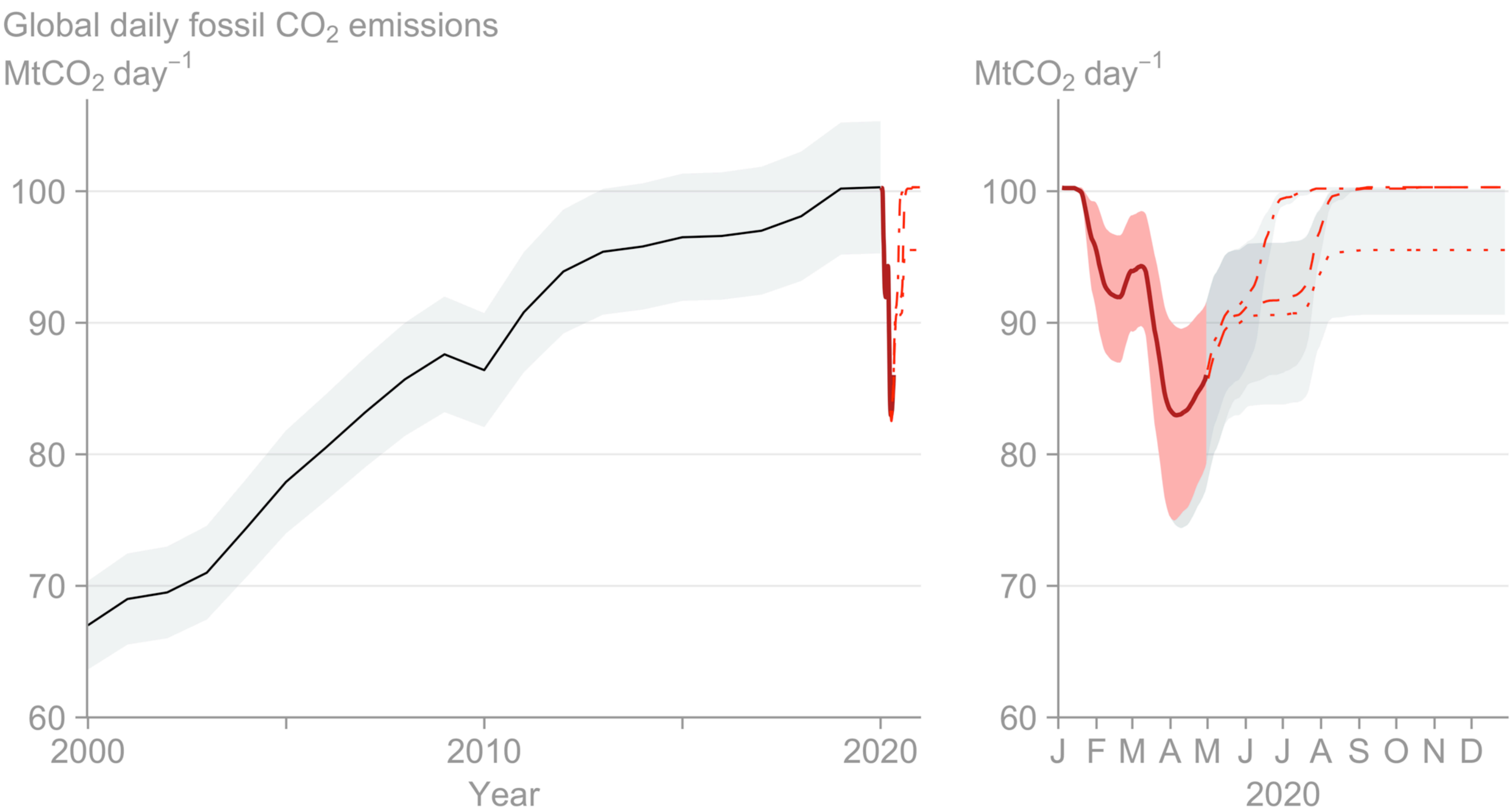
Covid-19 : impact sur les emissions de CO_2

Covid-19 pandemic impact on C fluxes



Source: Le Quéré et al. Nature Climate Change (2020); Global Carbon Project

Covid-19 pandemic impact on C fluxes

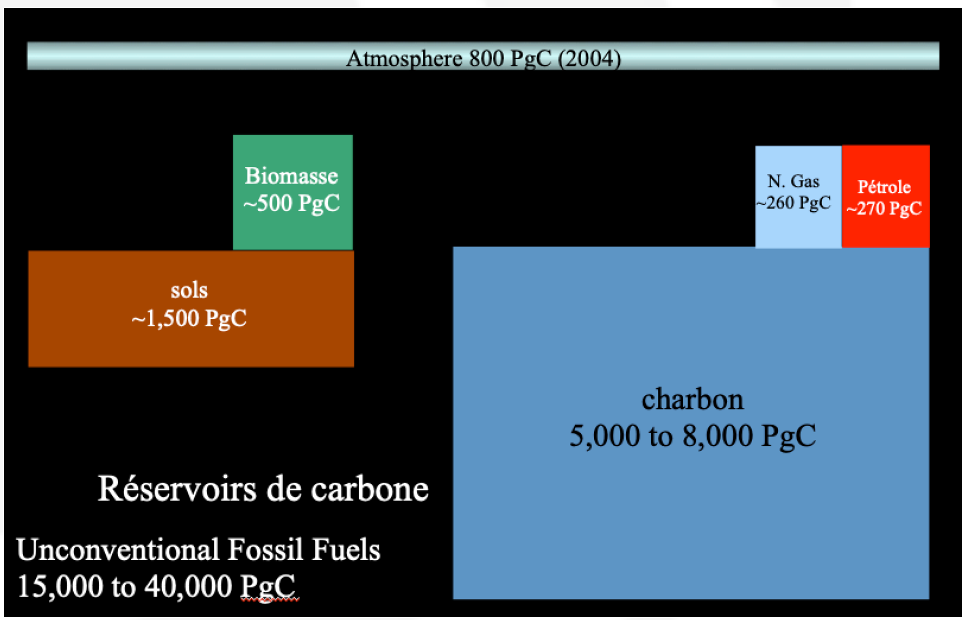


Source: Le Quéré et al. Nature Climate Change (2020); Global Carbon Project

Merci pour votre attention !

Quelques enjeux…

Comment ne pas utiliser tout le C fossile restant ?



Besoin de prendre en compte tous les services écosystémiques !

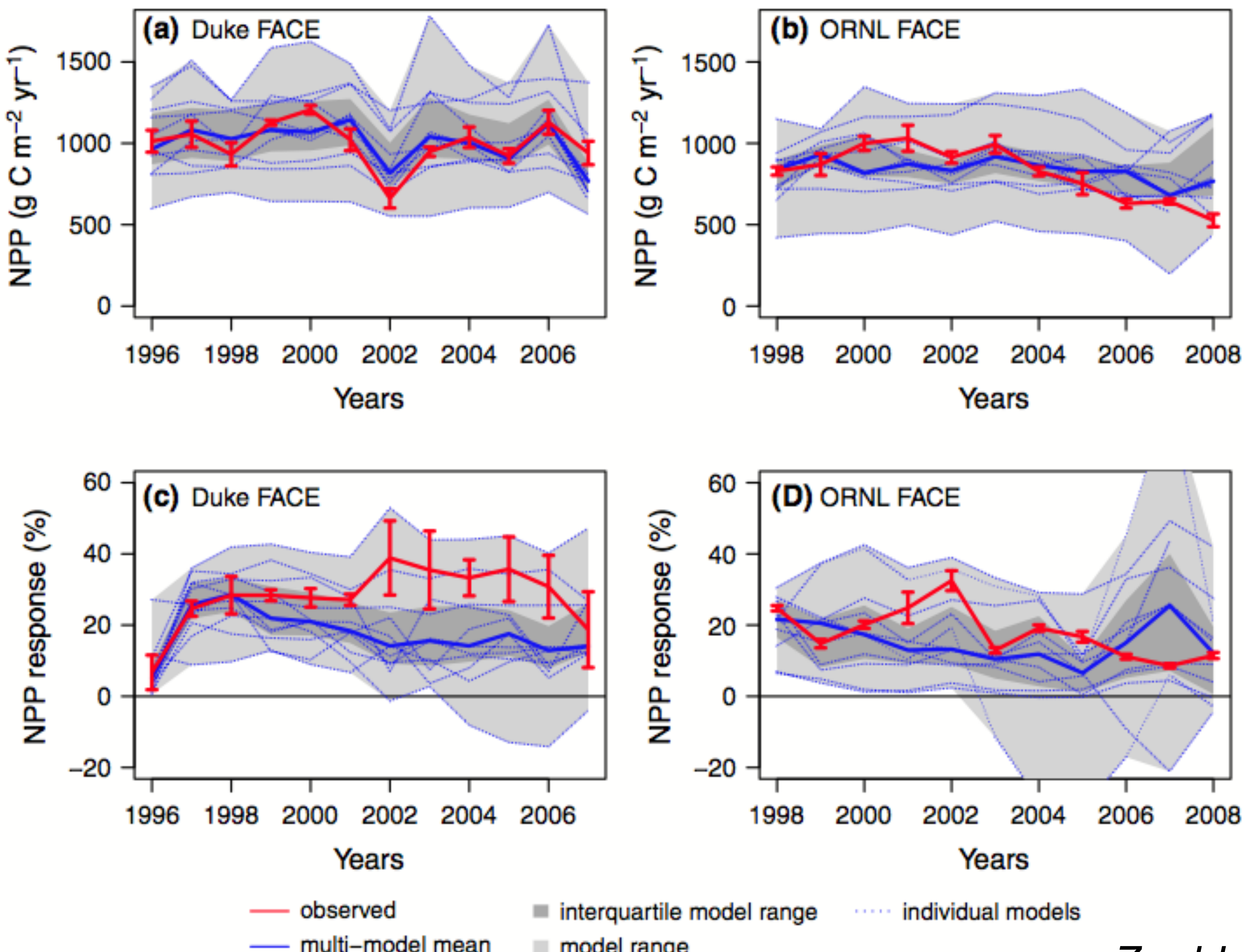
Additional slides

Evaluation de la réponse des modèles au CO2

Expérience d'enrichissement en CO2 : réponse simulée de la Productivité Primaire Nette (NPP) de modèle incluant cycles C/N

NPP (control CO2)

NPP (double CO2)



Observed

Models

Zaehle et al. 2014

Forêts boréales et climat..

Offset of the potential carbon sink from boreal forestation by decreases in surface albedo

Richard A. Betts

Hadley Centre for Climate Prediction and Research, The Met Office, Bracknell, Berkshire RG12 2SY, UK

Betts et al., Nature, 2000

→ Augmentation des forêts boréales compense en partie l'effet de stockage du CO_2 sur le climat (température)
Via
une diminution de l'albédo

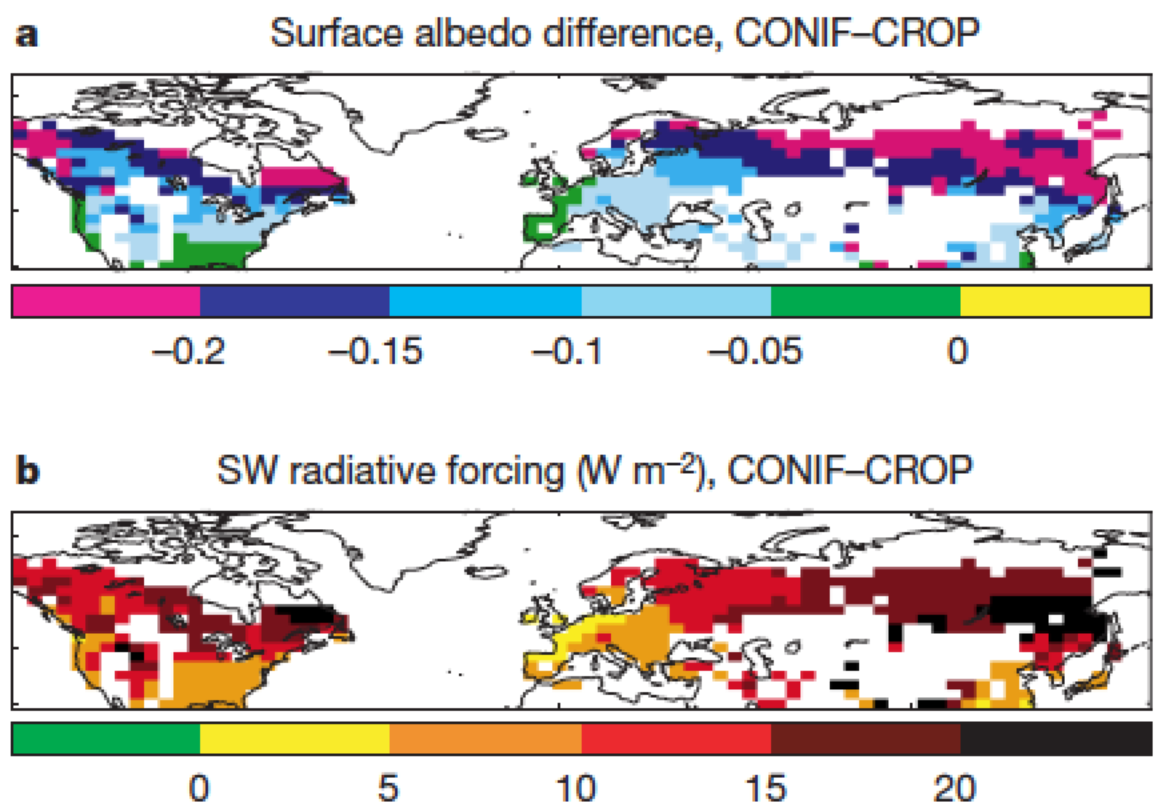
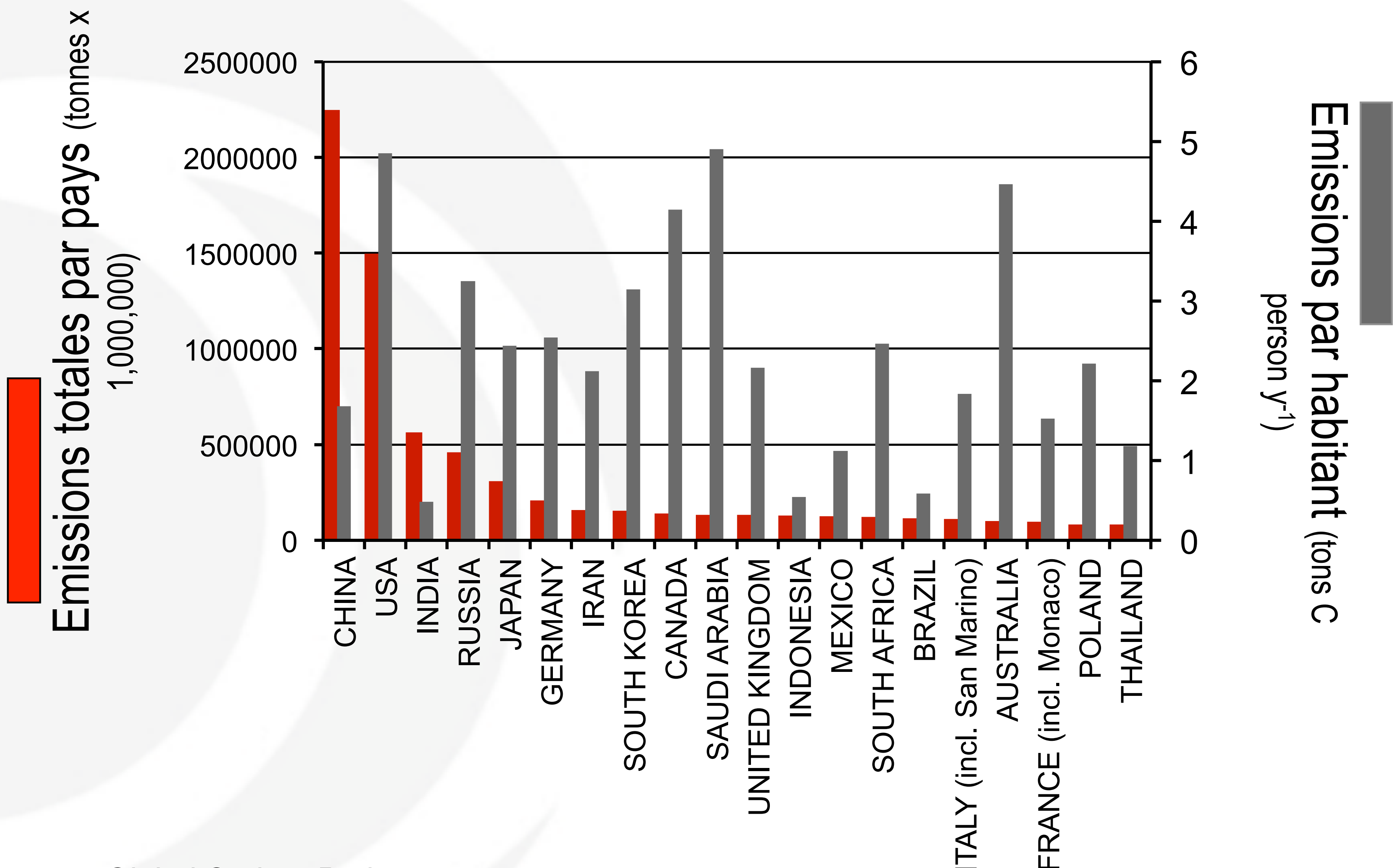


Figure 1 Effects of forestation on the solar radiation budget. **a**, Difference in annual-mean surface albedo α simulated by CONIF and CROP. **b**, Local instantaneous shortwave (SW) radiative forcing at the tropopause due to surface albedo change. At uncoloured gridpoints, vegetation was identical in CONIF and CROP.

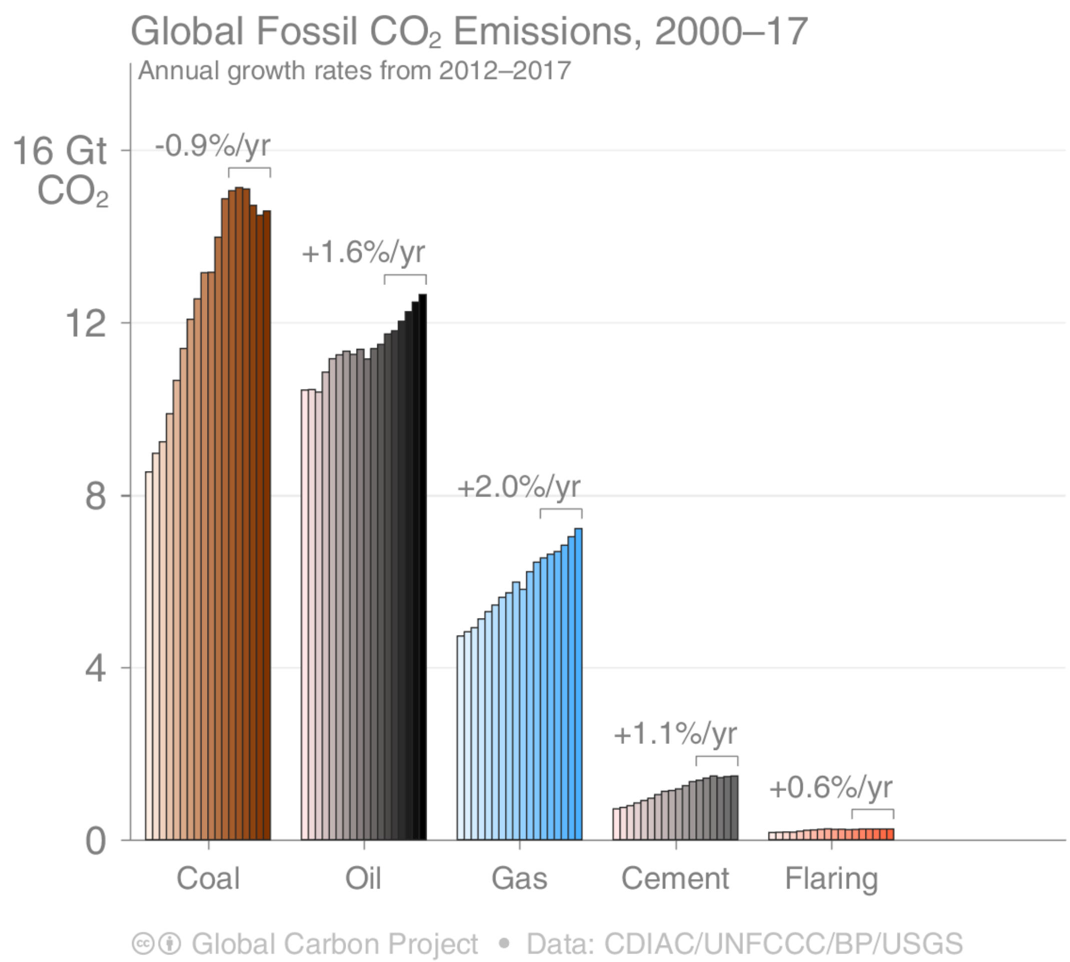
Emissions de CO_2 fossile par pays et par habitant



Source : Global Carbon Project

Fossil CO_2 Emissions by source

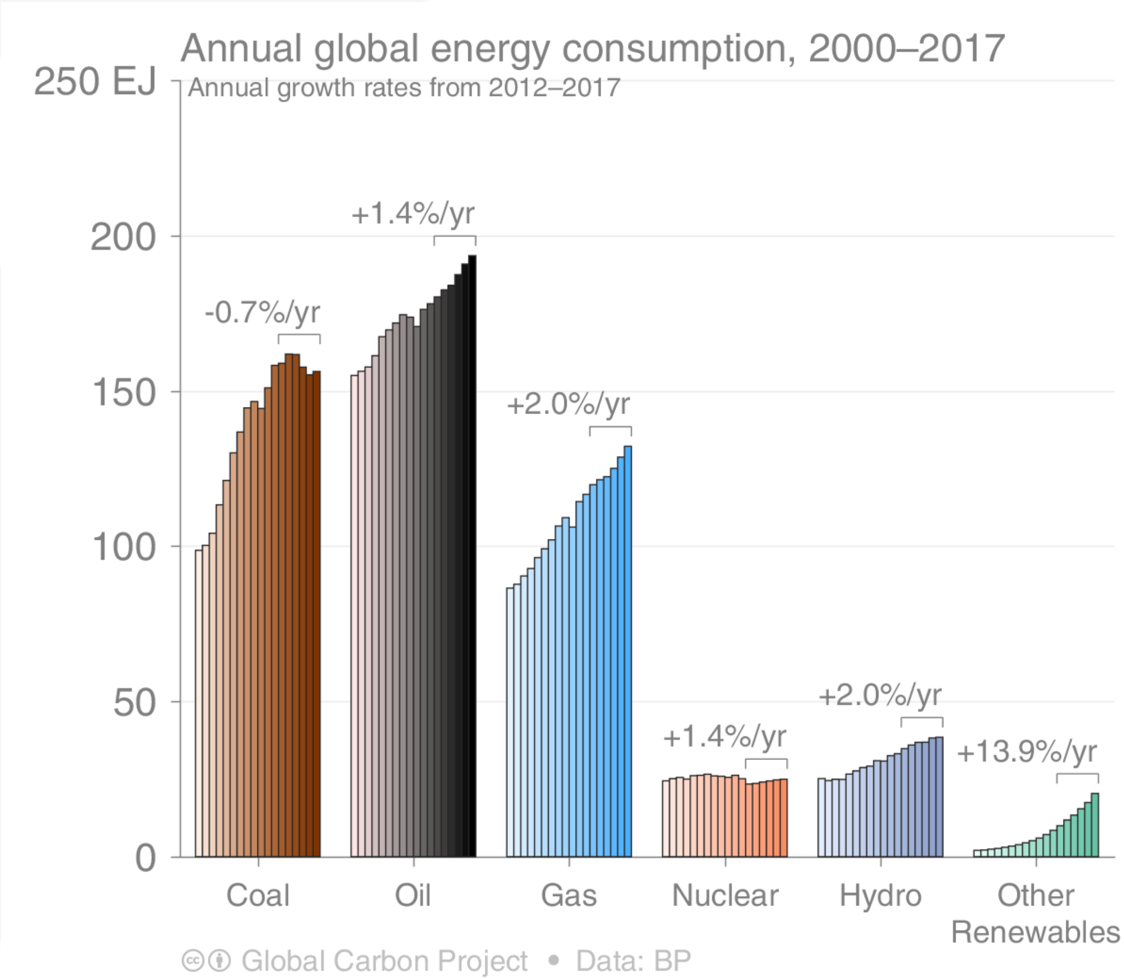
Emissions by category from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017



Source: [CDIAC](); [Jackson et al 2018](); [Global Carbon Budget 2017]()

Energy use by source

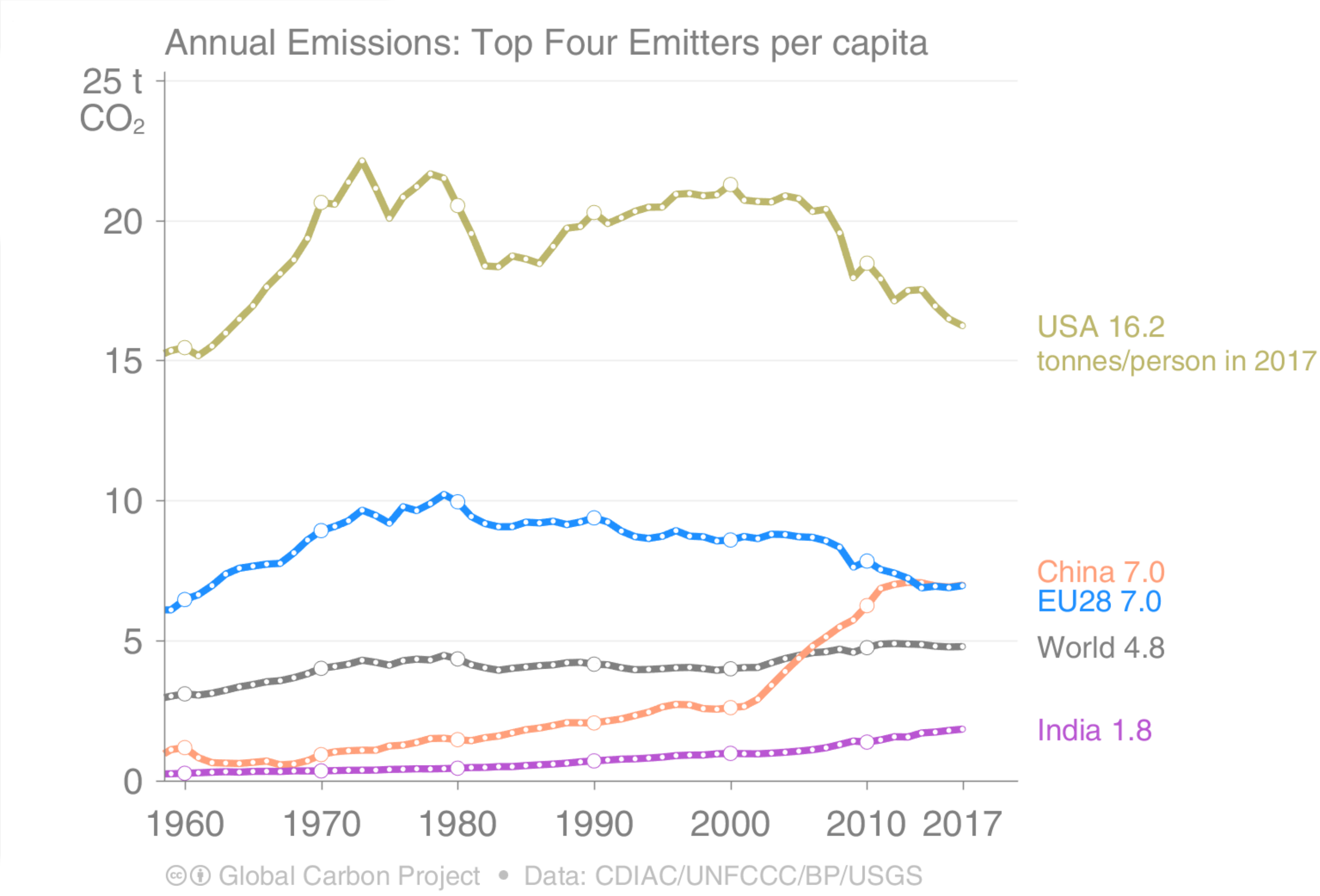
Energy consumption by fuel source from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017



This figure shows "primary energy" using the BP "substitution method" (non-fossil sources are scaled up by an assumed fossil efficiency of 0.38)
Source: BP 2018; Jackson et al 2018; Global Carbon Budget 2018

Top emitters: Fossil CO_2 Emissions per capita

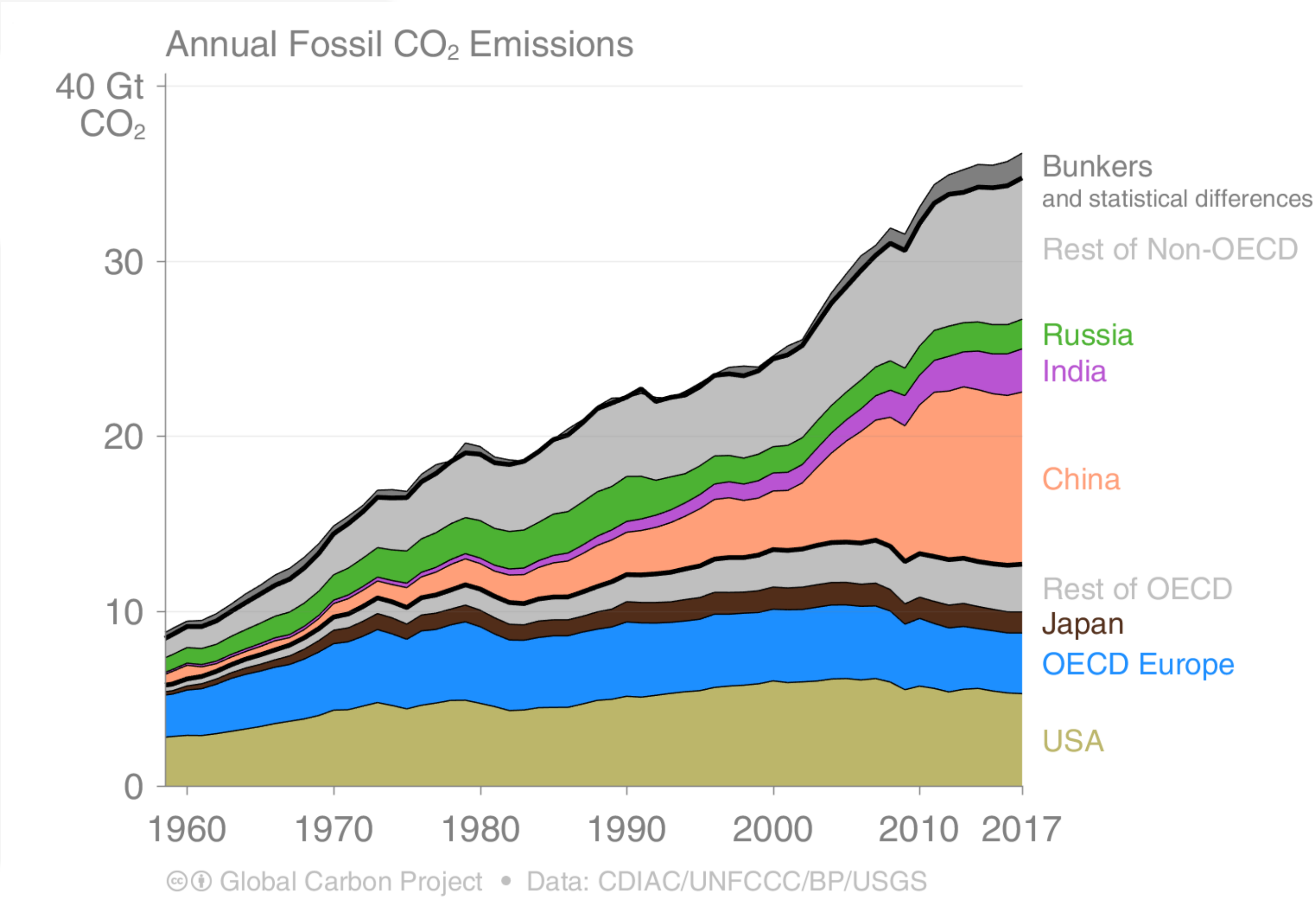
Countries have a broad range of per capita emissions reflecting their national circumstances



Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Breakdown of global fossil CO_2 emissions by country

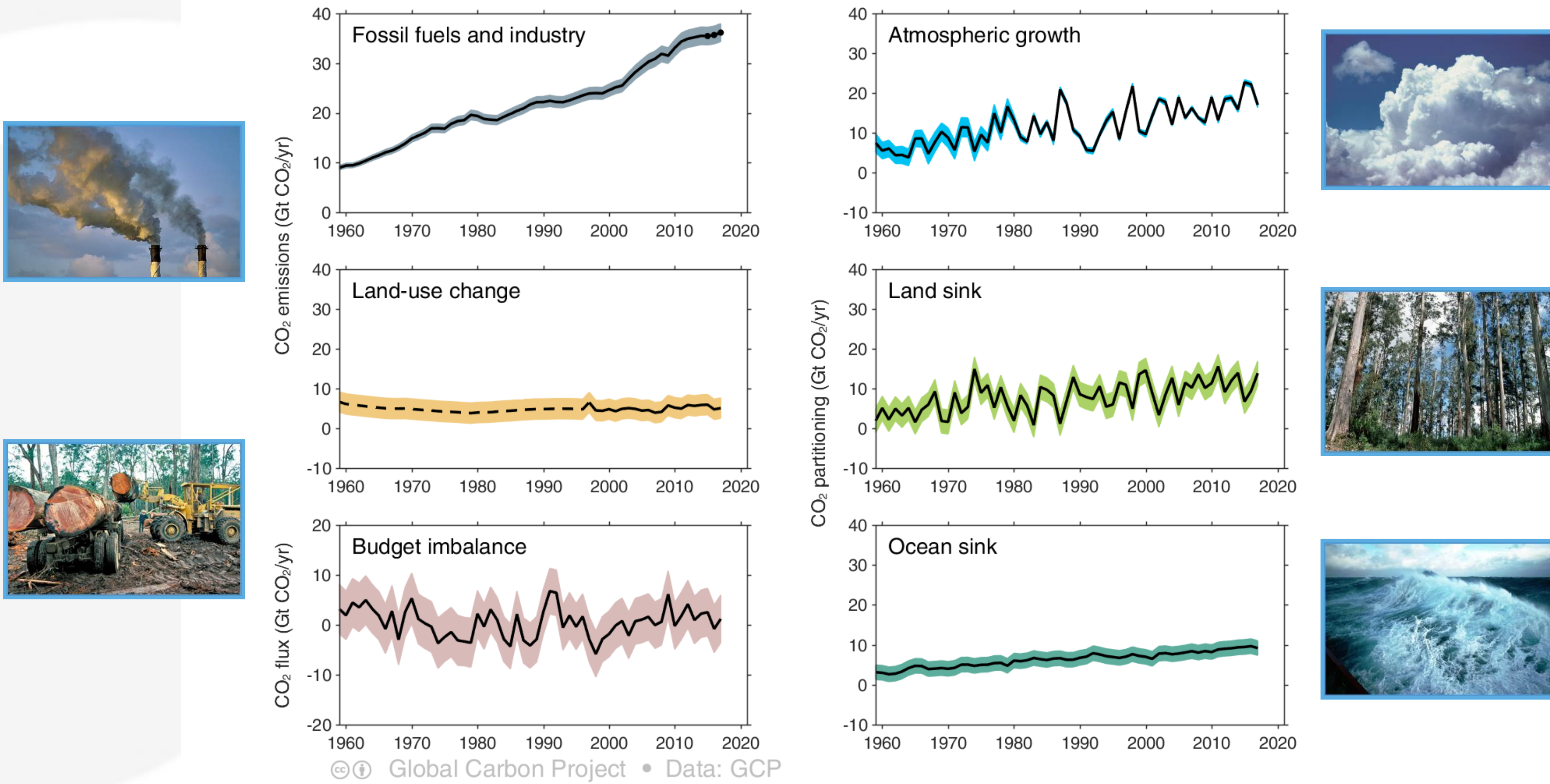
Emissions in OECD countries have increased by 5% since 1990,
while those in non-OECD countries have more than doubled



Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

Changes in the budget over time

The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean. It reflects the limits of our understanding of the carbon cycle.

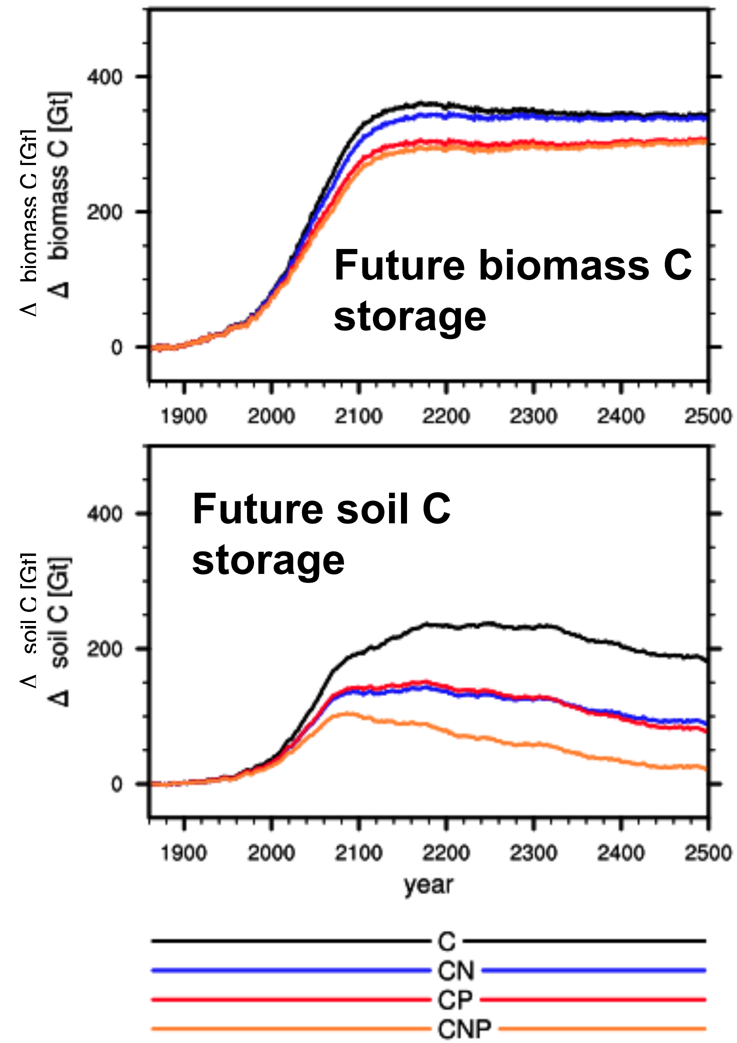
Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Future of the assessment :

Nutrient limitation on terrestrial C storage

Only 1-2 Earth System Models included N-limitations in CMIP5 and found a smaller sink response to CO_2 and climate

Offline model with N & P limitations

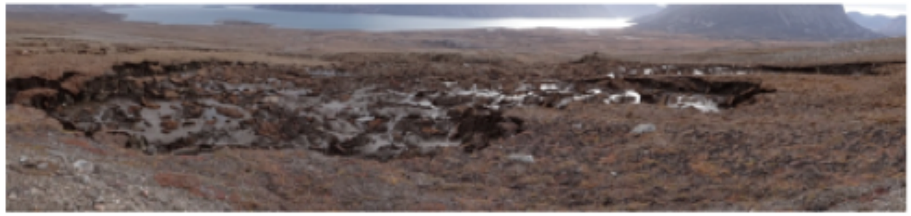


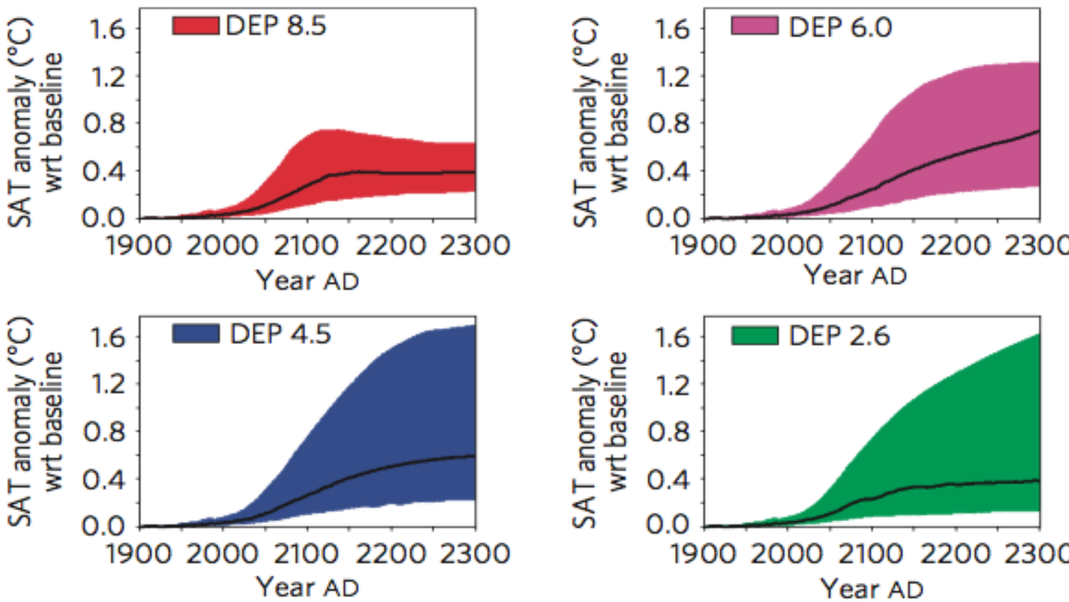
Goll et al. 2012

Future of the assessment :

‘cold’ carbon processes, permafrost C

1670 Pg C
In permafrost





Mc Dougall et al. 2013

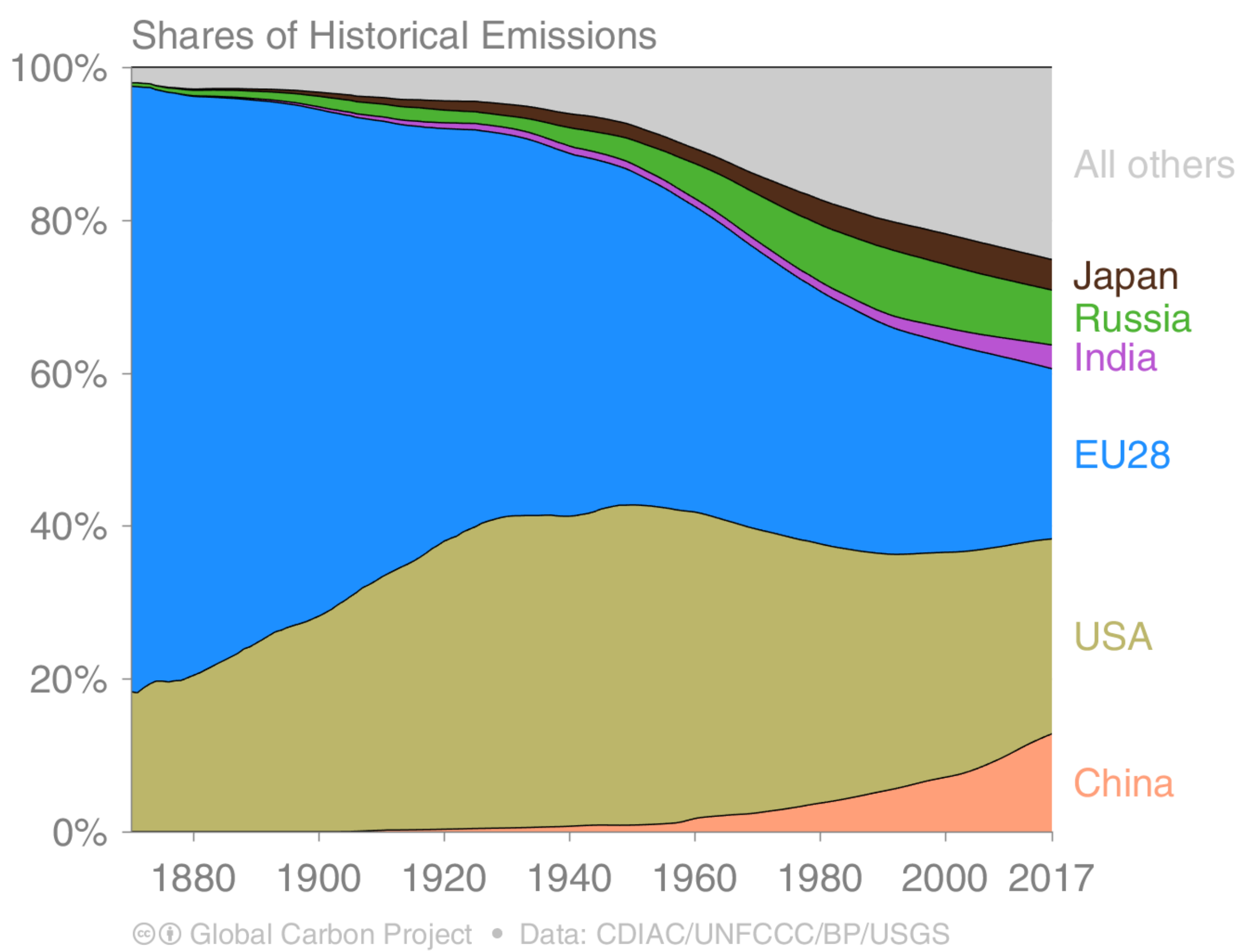
An Earth System Model with permafrost carbon processes was driven by RCP emissions

Result: higher projected warming (0.13 to 1.7°C) and CO_2 release (70 to 500 PgC)

Key « missing » processes : soil ice, soil C vertical distribution, soil C pools decomposition rates [C:N], fire & thermokarst

Historical cumulative fossil CO_2 emissions by country

Cumulative fossil CO_2 emissions were distributed (1870–2017):
USA 25%, EU28 22%, China 13%, Russia 7%, Japan 4% and India 3%



Cumulative emissions (1990–2017) were distributed China 20%, USA 20%, EU28 14%, Russia 6%, India 5%, Japan 4%
'All others' includes all other countries along with bunker fuels and statistical differences
Source: [CDIAC]; [Le Quéré et al 2018]; [Global Carbon Budget 2018]