Le cycle du carbone dans un climat perturbé !

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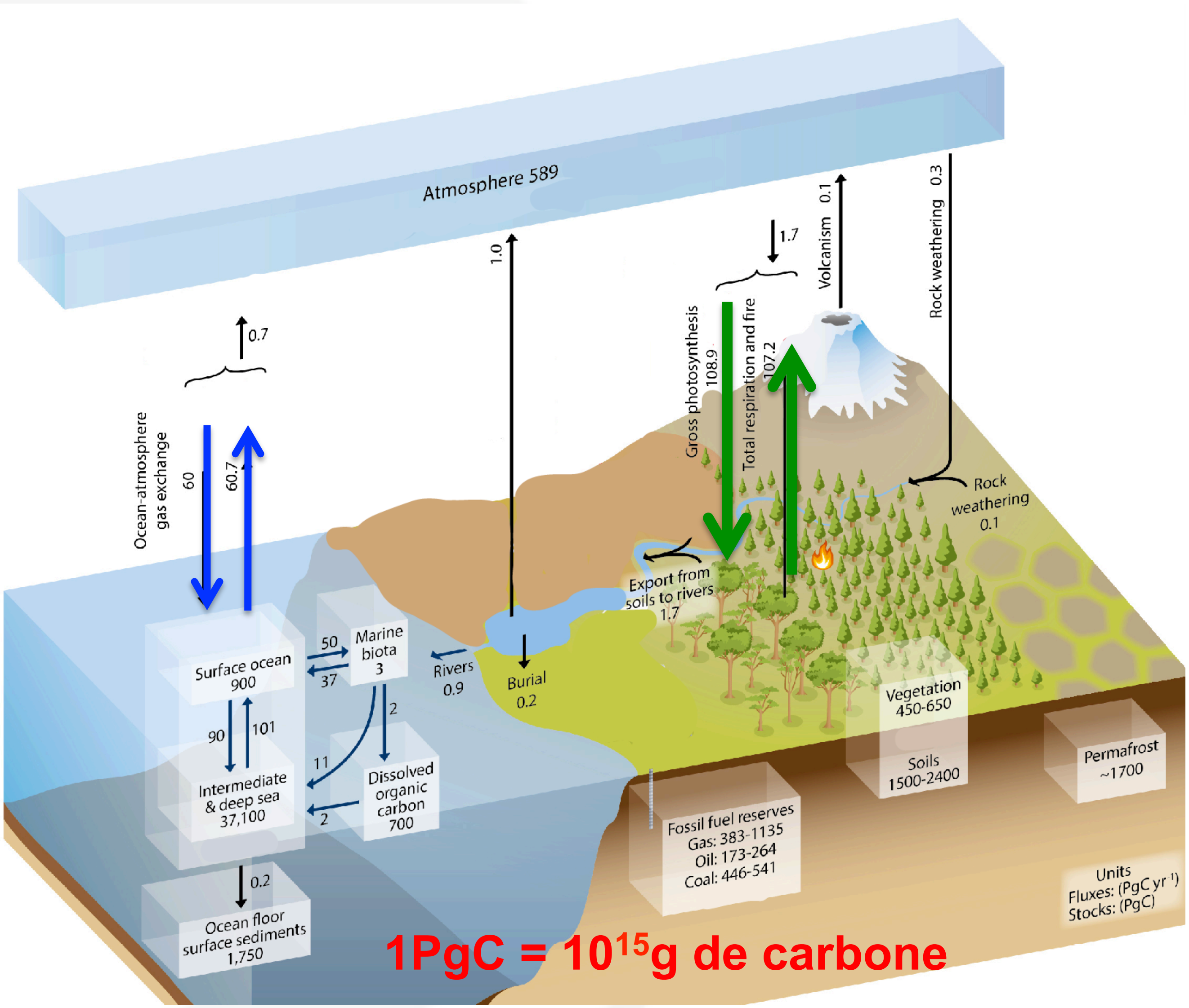
Plan :

- Le cycle du carbone naturel
- La perturbation anthropique
- Réponse des écosystèmes à la perturbation
- Evolution future du cycle du carbone et incertitudes

Cycle naturel pré-industriel du CO_2



1PgC = 10^{15}g de carbone

Photosynthèse brute
108.9 PgC/an

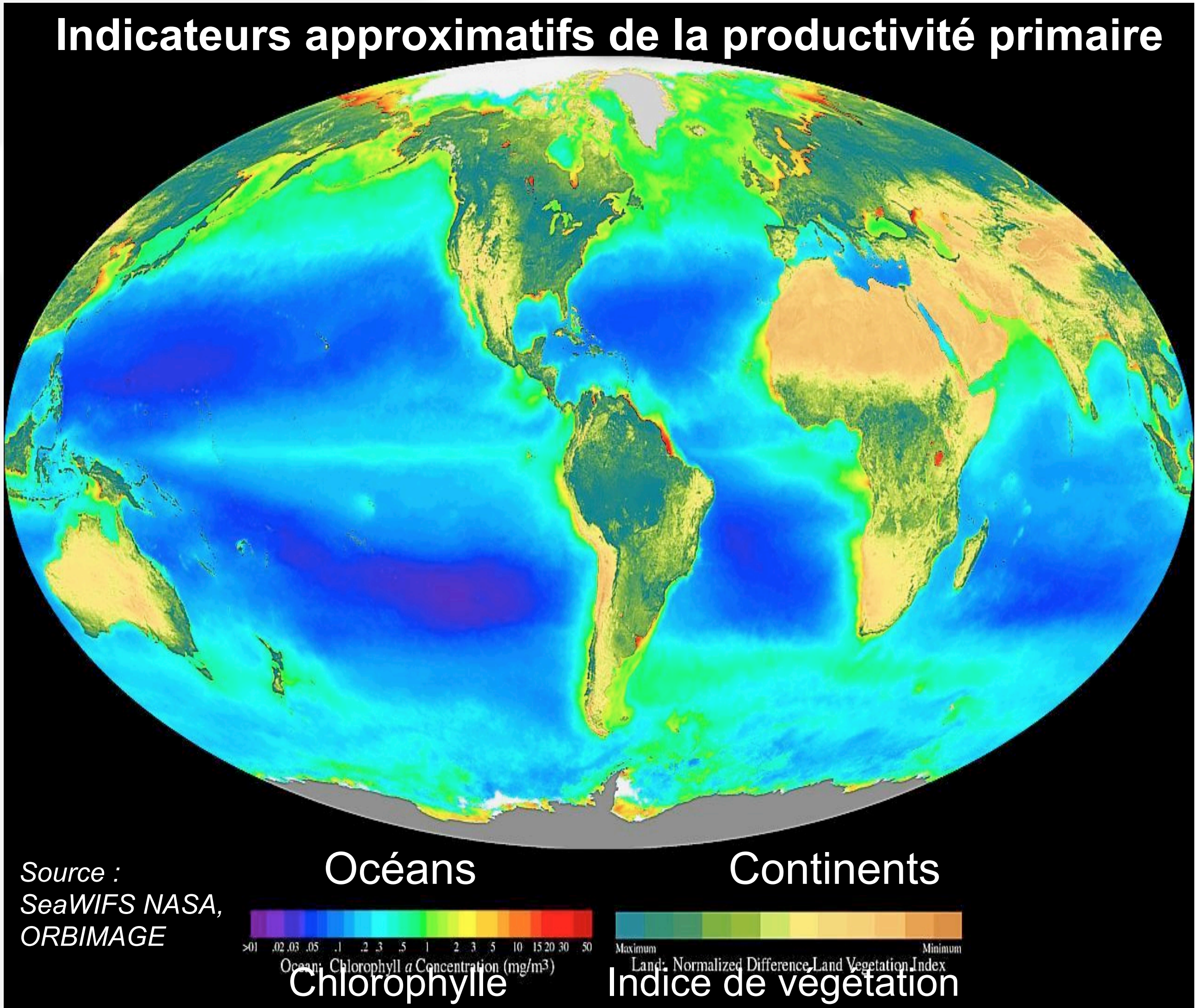
Respiration et feux
107.2 PgC/an

Absorption océans
60 Pg/an

Dégazage océans
60.7 Pg/an

Erosions, rivières, volcans, sédimentation
2 PgC/an

Productivité Primaire continentale et océanique



CONTINENTS

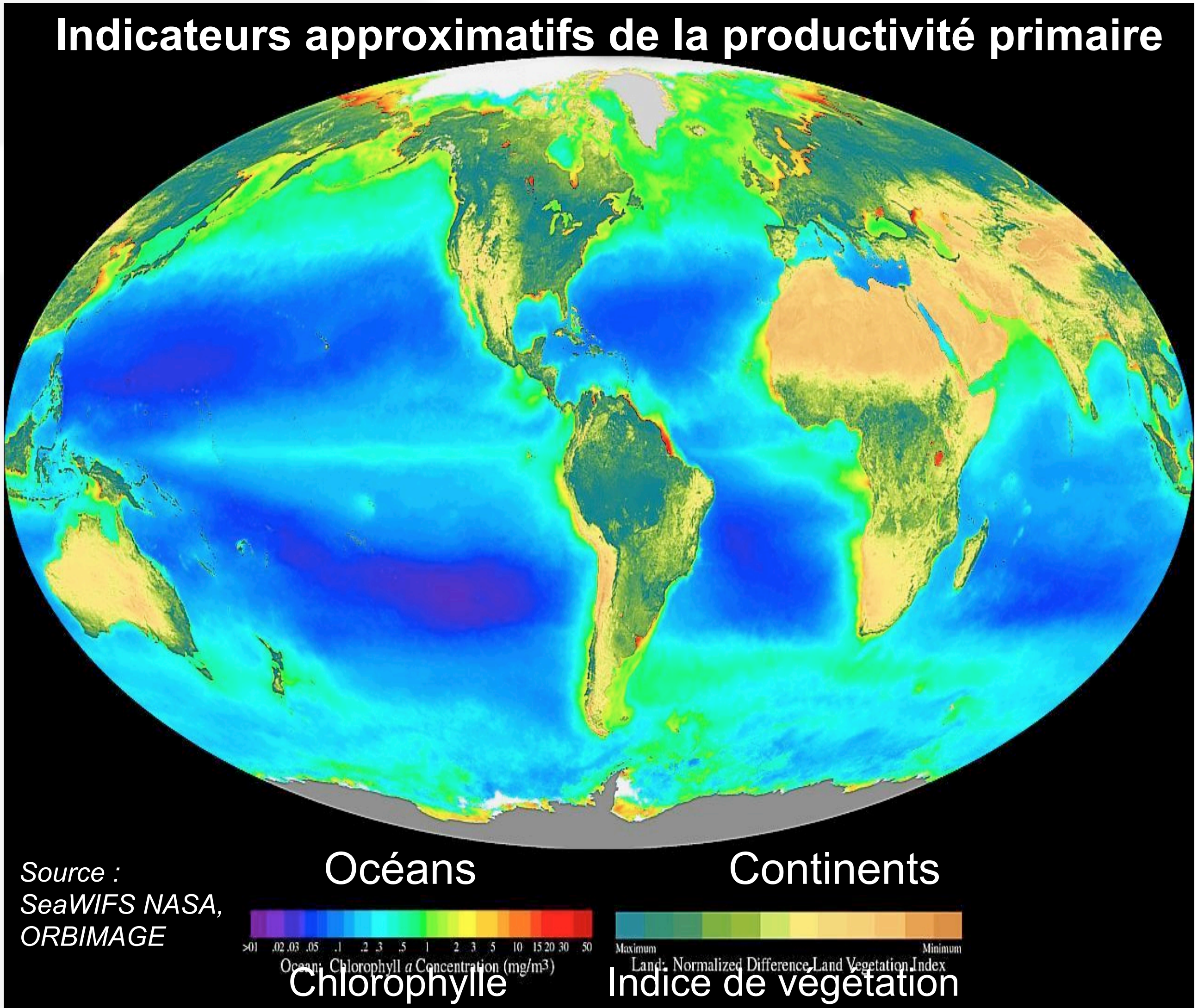
~ 60 PgC/an

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

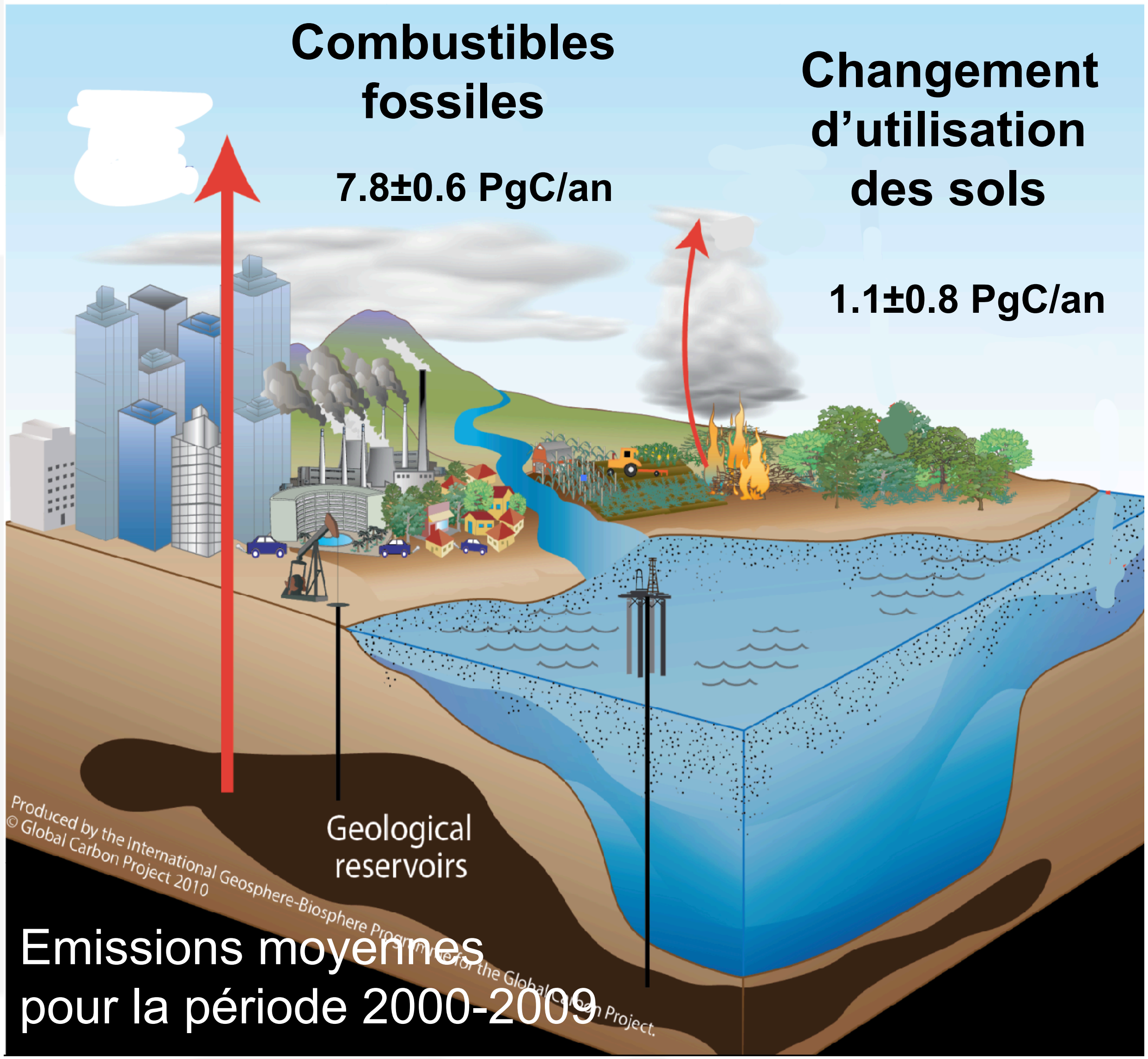
Assurée par le phytoplancton

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

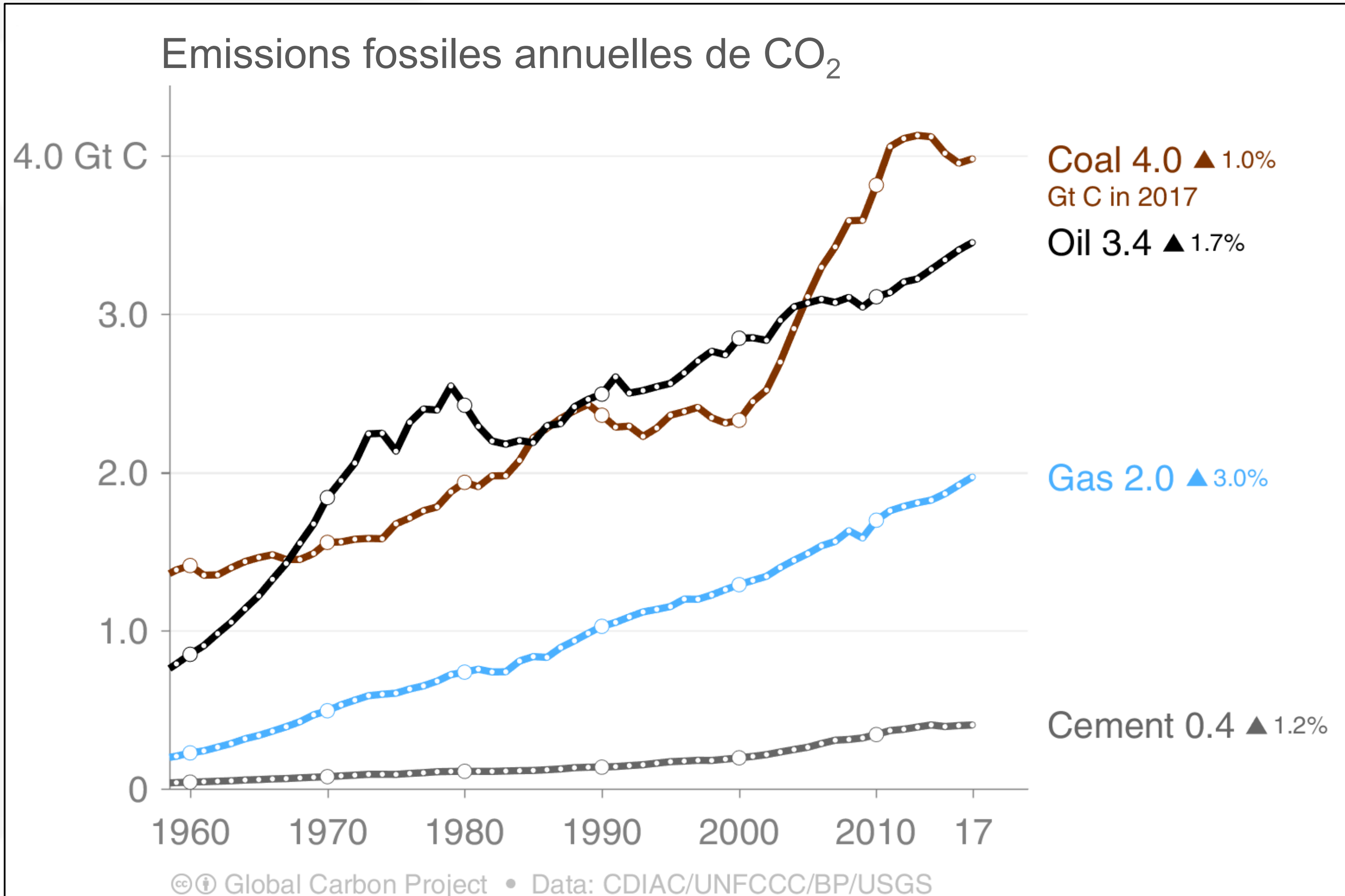
Changement d'utilisation des sols (déforestation incluant les feux de biomasse et de biofuels, conversions de terres)

1.1±0.8 PgC/an

Source : IPCC

Emissions fossile de CO_2 par catégorie

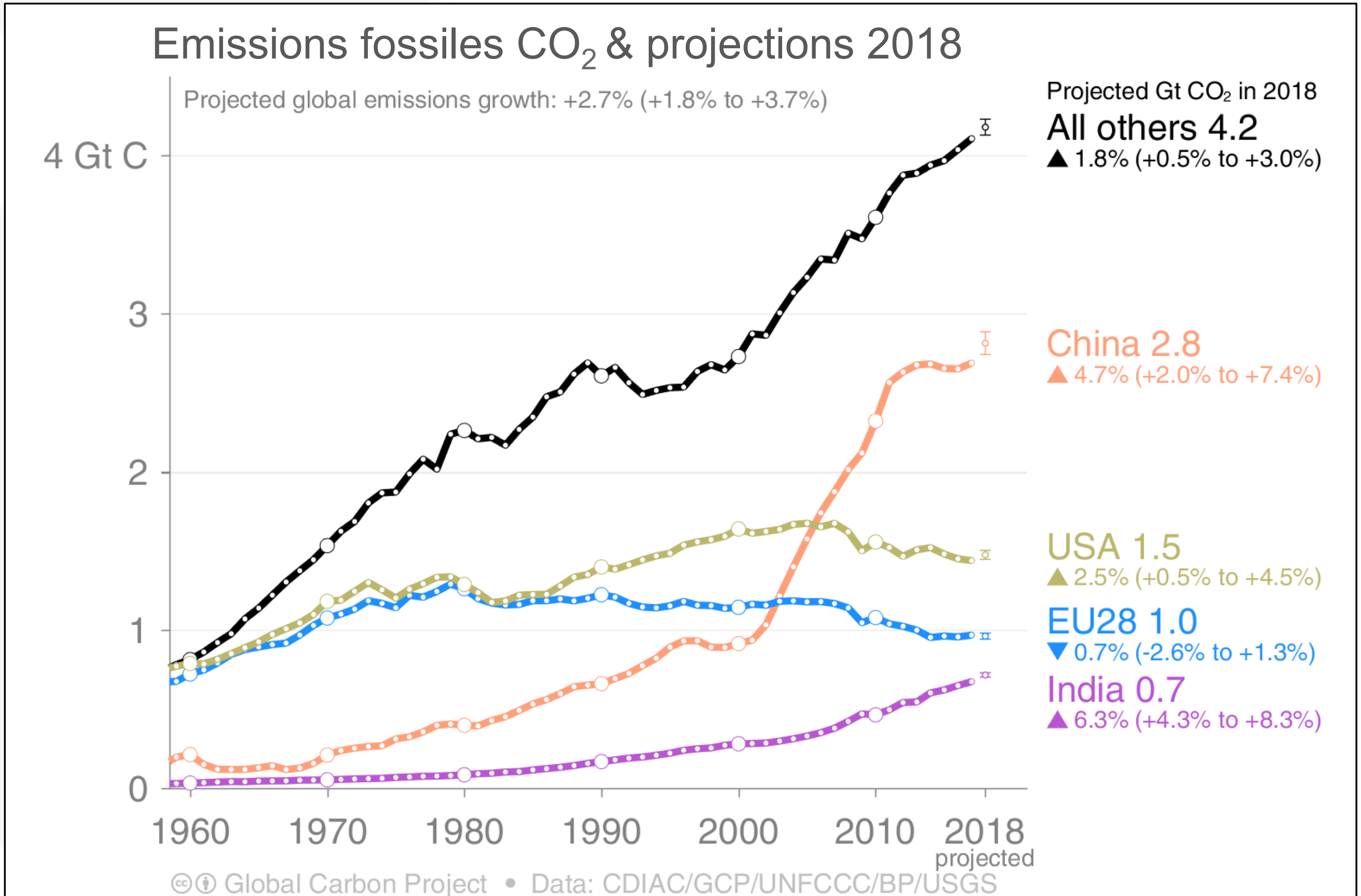
Partage des émissions fossiles de CO_2 en 2017:
Charbon (40%), Pétrole (35%), Gaz (20%), Ciment (4%), Torchère (1%, not shown)



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

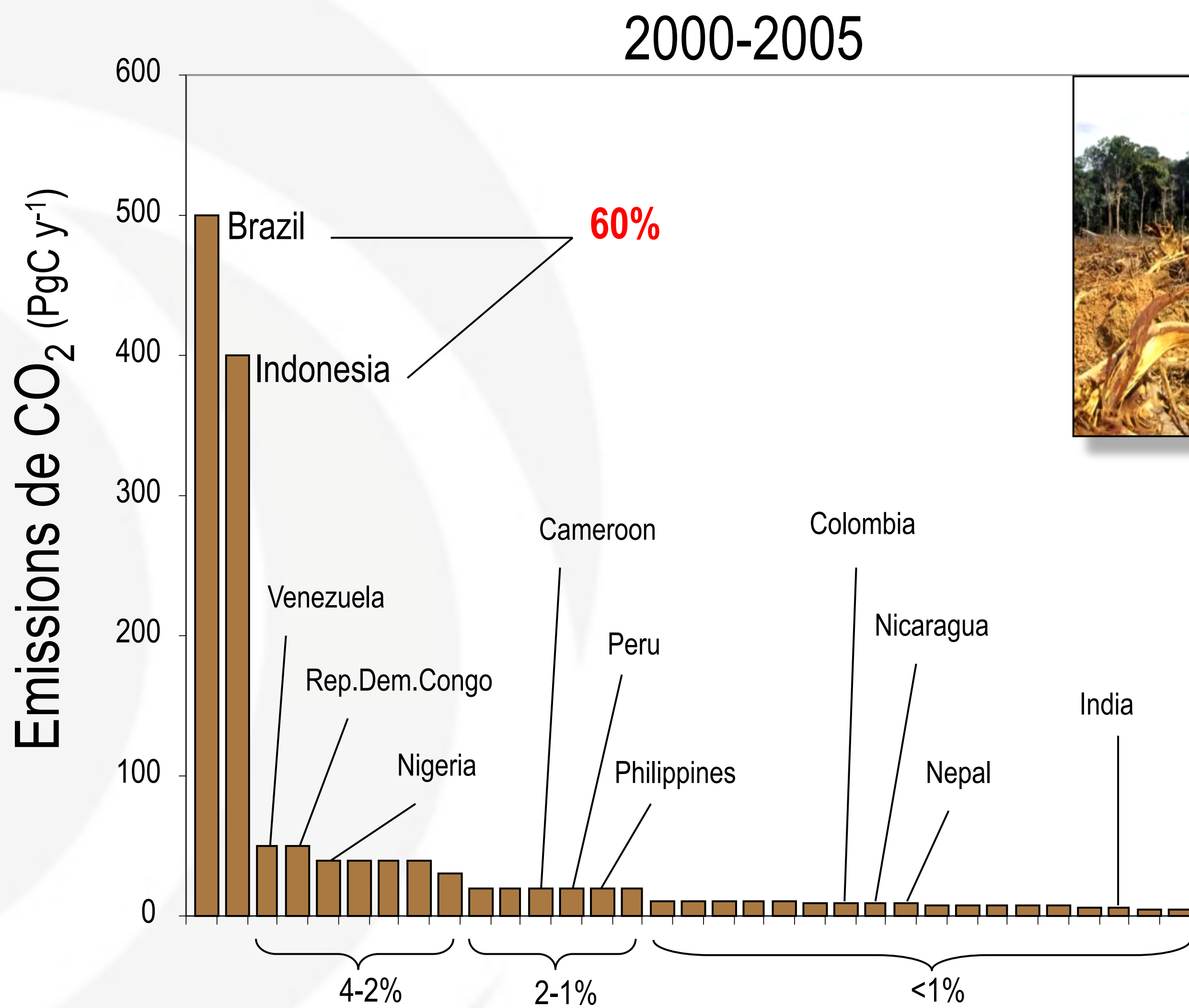
Emissions par "pays" & Projections pour 2018

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

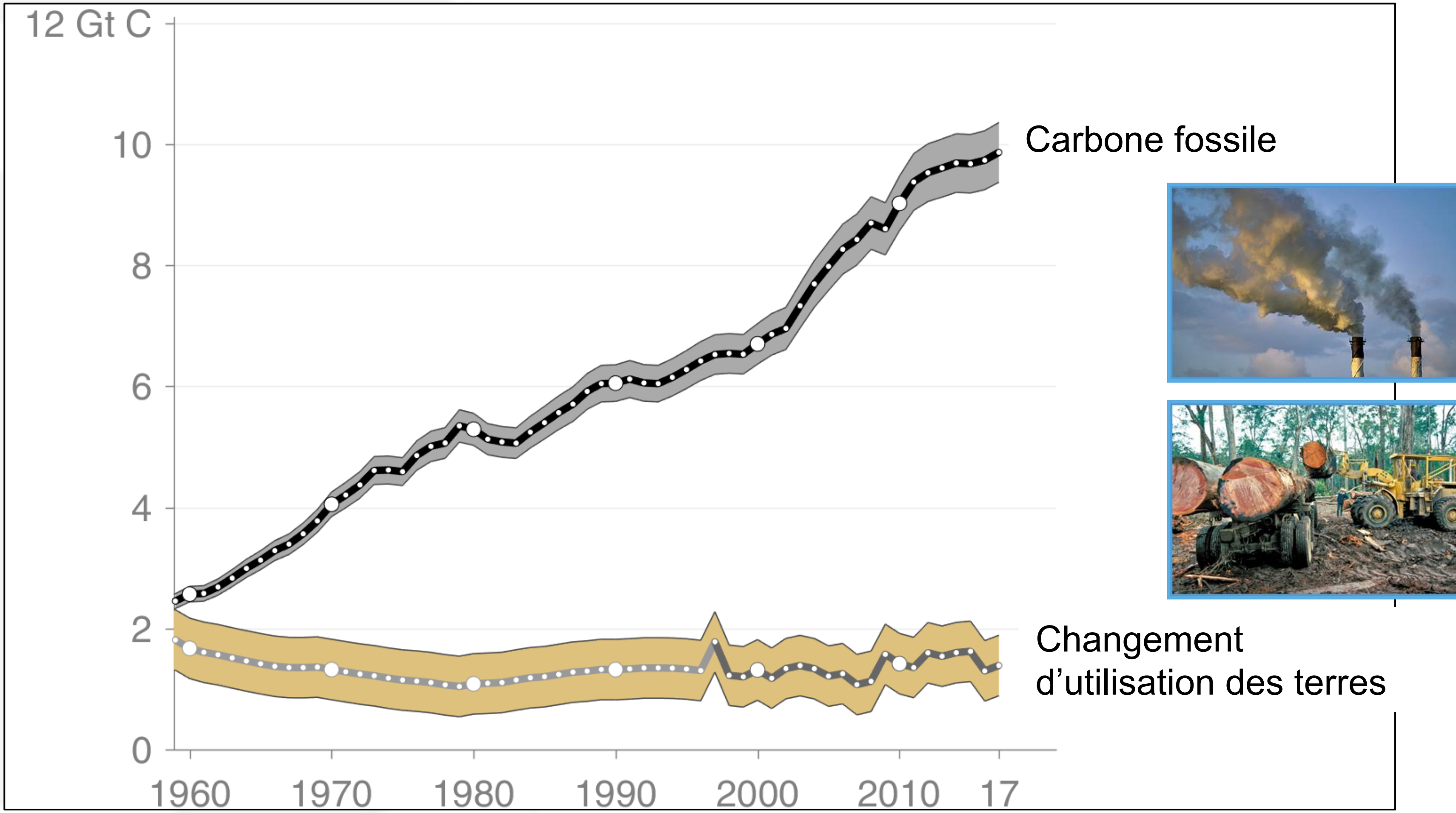


Source : Global Carbon Project

Emissions anthropiques globales

Émissions totales globales : 11.2 ± 0.8 GtC en 2017

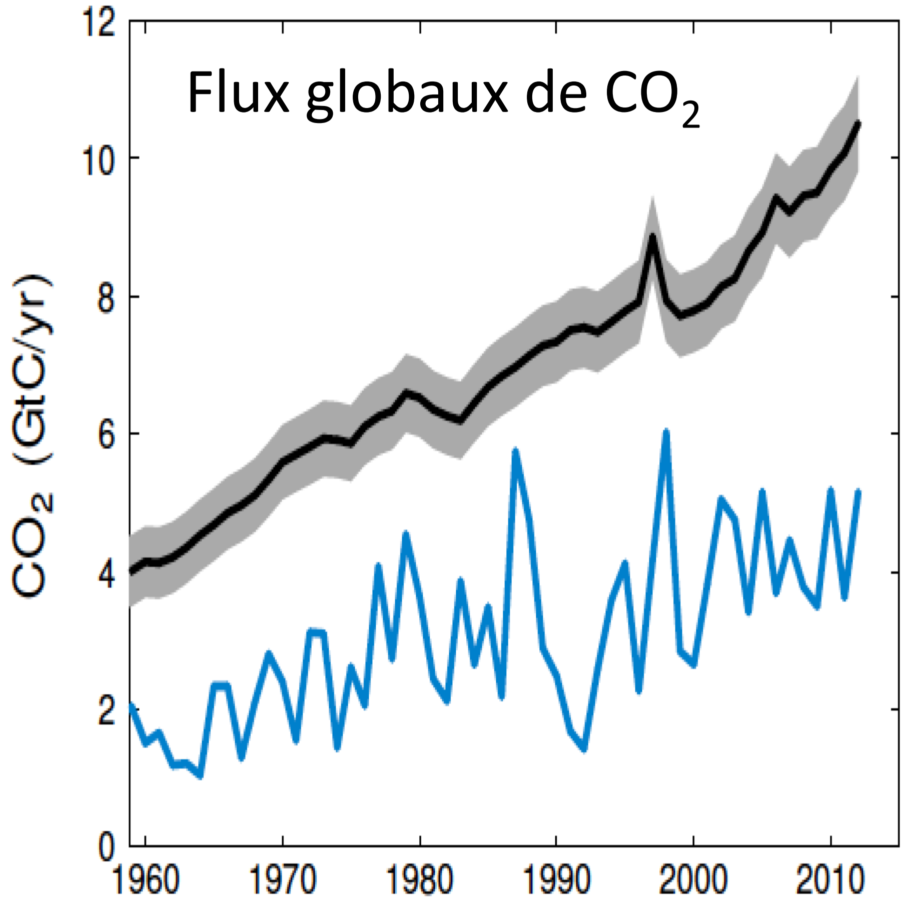
Contribution de utilisation des terres: 43% en1960, 13% en moyenne sur 2008–2017



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

Absorption partielle des émissions de CO_2



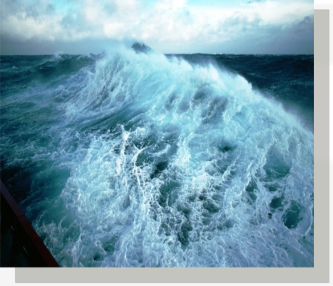
	Moyenne 2008-2017
Emissions totales	10.8 ± 0.6 PgC/an
Taux de Croissance observé	4.7 ± 0.1 PgC/an

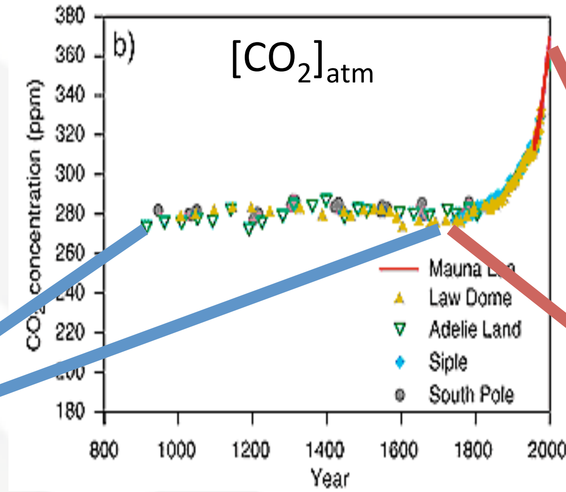
Absorption par les écosystèmes terrestres et océaniques (≈ la moitié)

Source: CDIAC Data; Global Carbon Project 2018

1PgC = 10^{15}g de carbone

Absorption par l'océan: mécanismes



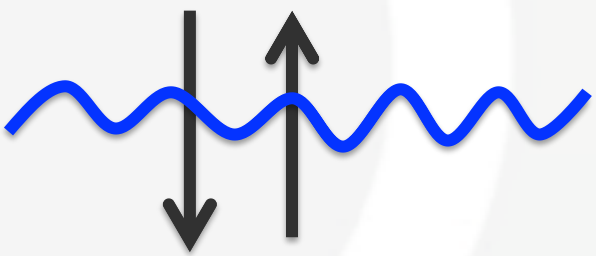


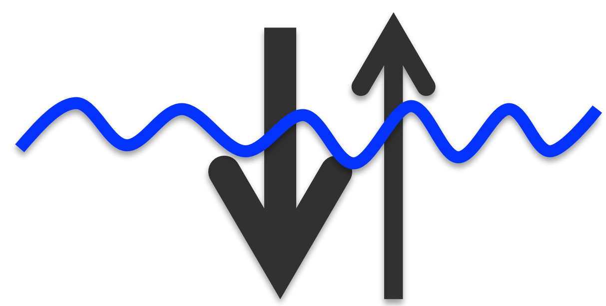
Etat pré-industriel

Perturbation anthropique

CO_2 Atmos.
Stable

CO_2 atmos.
Croissant





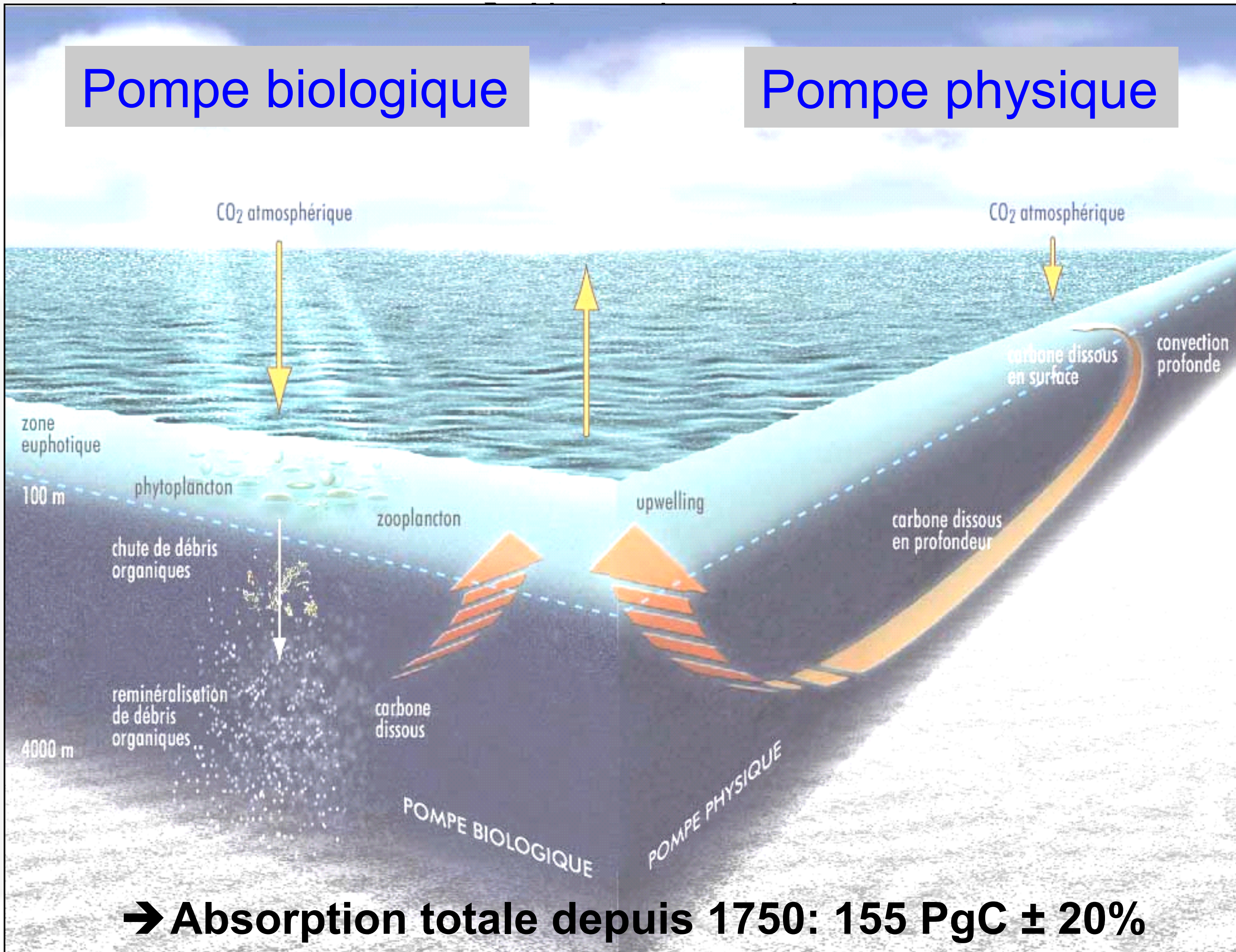
CO_2 dissout
Stable

CO_2 dissout
Croissant

$$CO_2 + H_2O + CO_3^{2-} \leftrightarrow 2\ HCO_3^-$$

Couplage avec: "Pompe biologique" & "Mélange océanique"

Cycle du carbone océanique



➔ **Absorption totale depuis 1750: 155 PgC ± 20%**

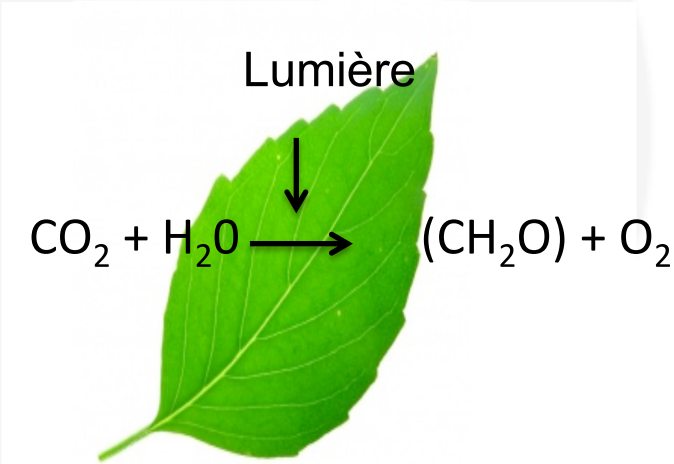
Absorption par la biosphère terrestre

➔ Effet fertilisant du CO_2 atmosphérique

Photosynthèse (principe)

CO_2 atmos : substrat limitant

↗ $[CO_2]_{atm}$ ➡ ↗ Assimilation C



Plante chlorophyllienne

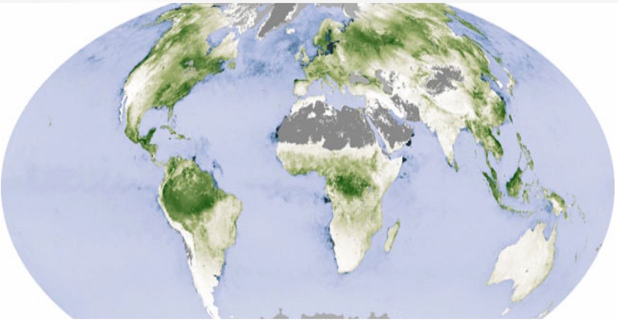
Mise en évidence expérimentale

Expérience FACE (doublement CO_2)

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

Absorption par la biosphère terrestre

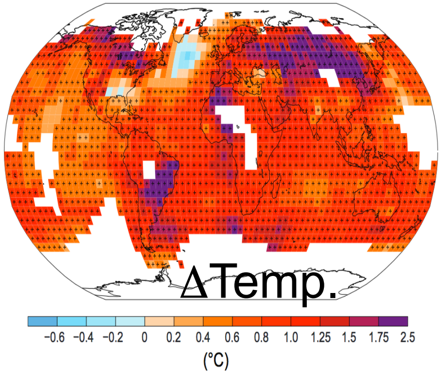
- ➢ Effet fertilisant du CO_2



➔ Lié à la productivité primaire

- ➢ Impact du changement climatique

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

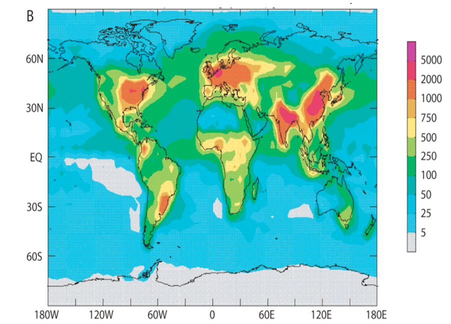


- ➢ Gestion des écosystèmes

Extensif vs Intensif

- ➢ Disponibilité en nutriments (dépots d'azote)

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



?

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

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

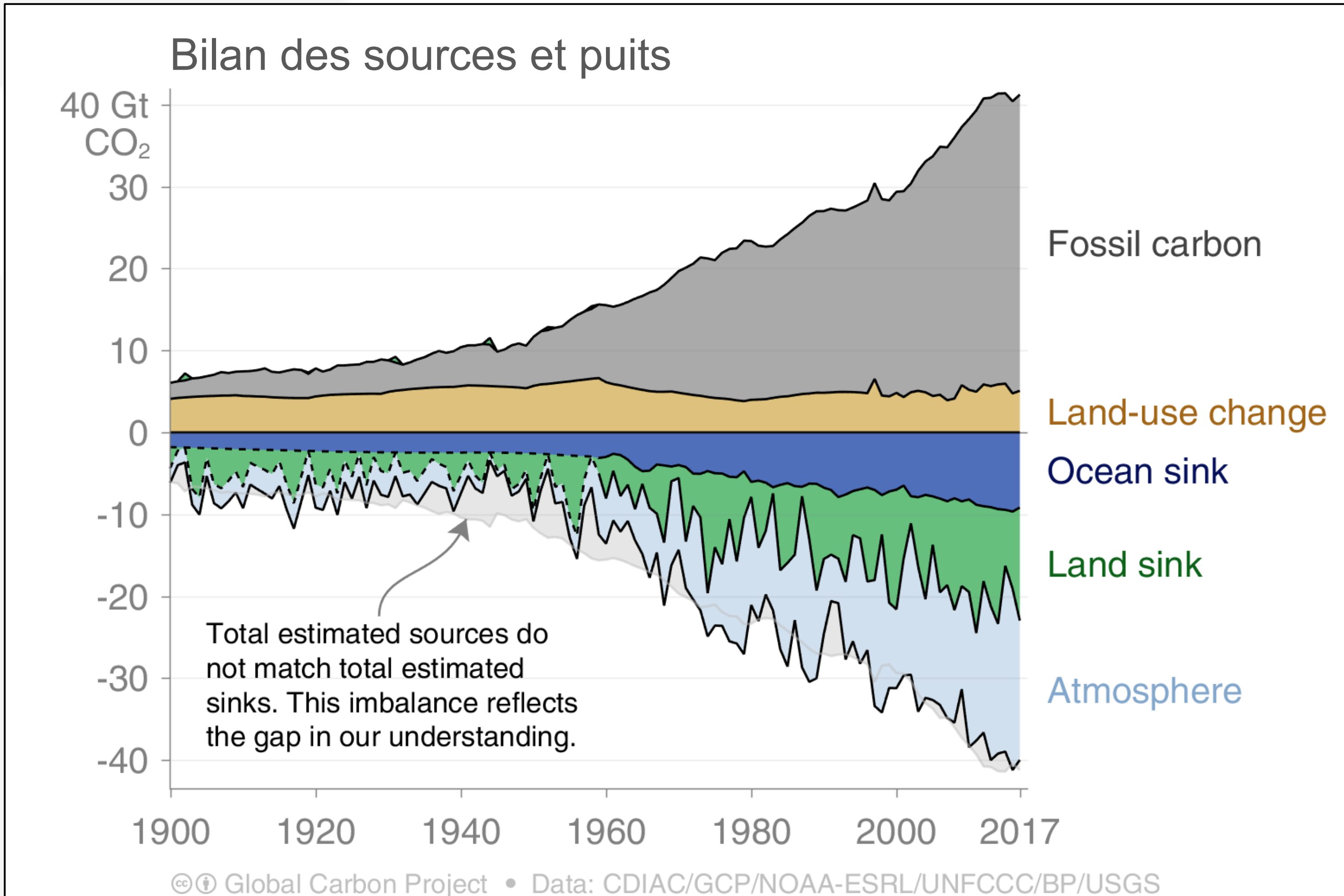
Déséquilibre du budget:
(différence entre les sources et puits estimés)

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)



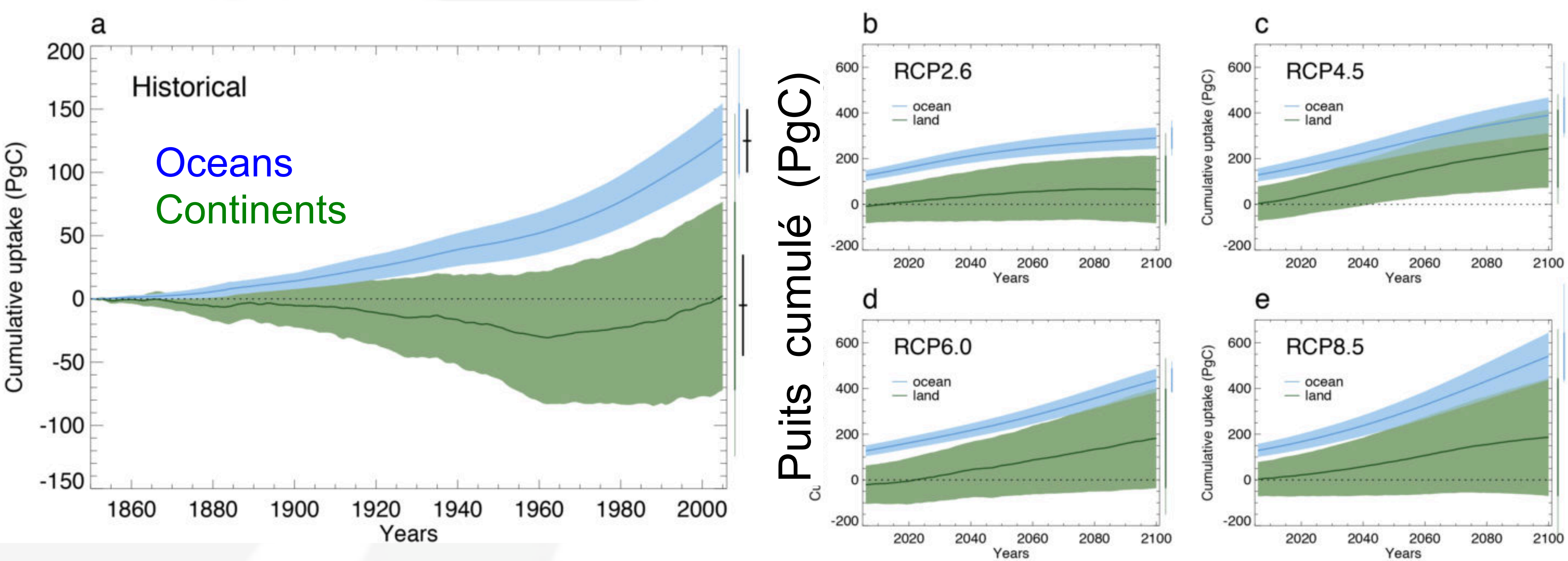
Le terme “déséquilibre” entre émissions et puits totaux révèle notre manque de compréhension!

Source: [CDIAC](); [NOAA-ESRL](); [Global Carbon Budget 2018]()

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

Historique

Futur: trajectoires représentatives de concentration en GhG (RCP)

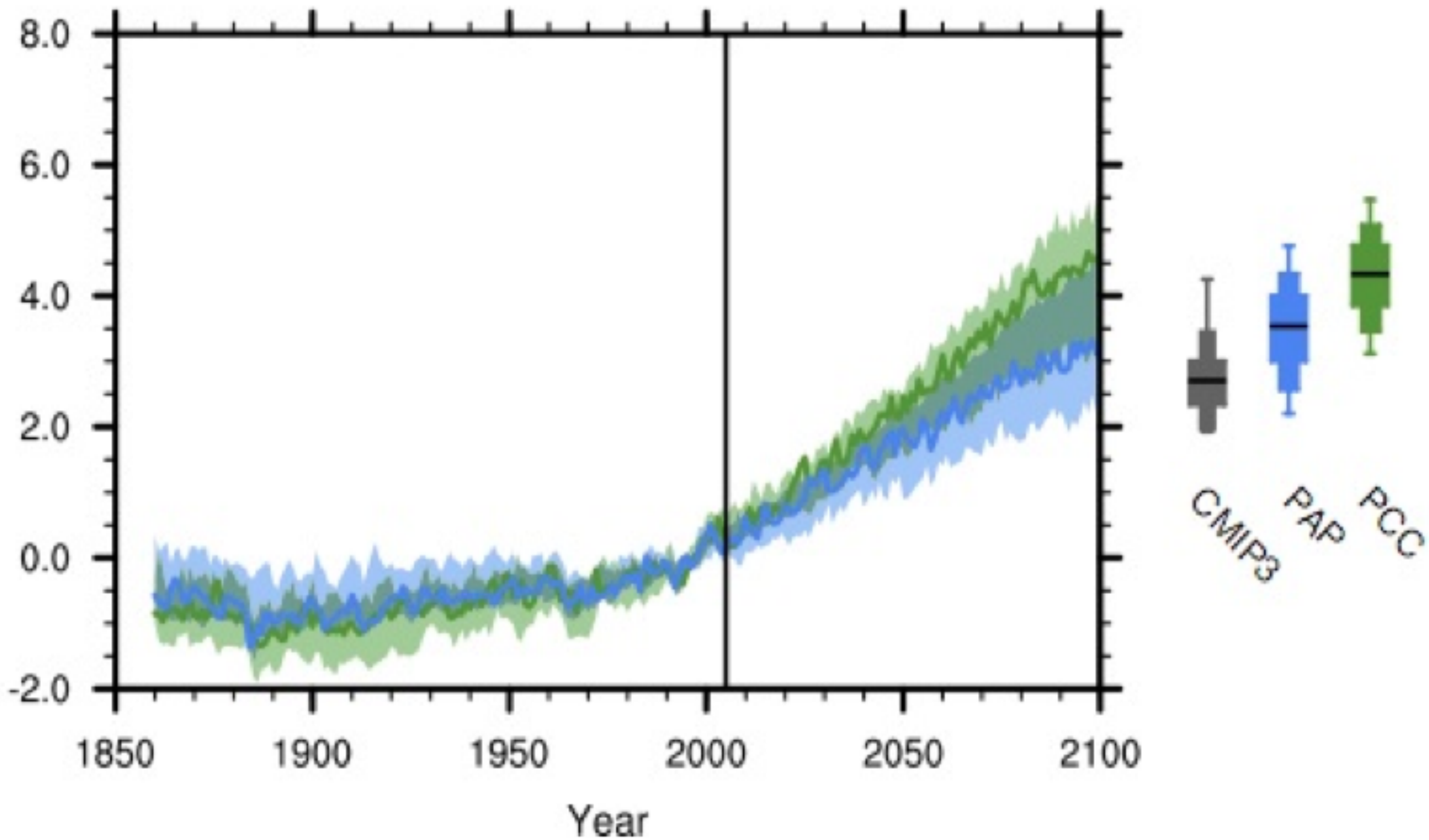


Très forte incertitude associée aux projections du stockage de C sur les continents

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)

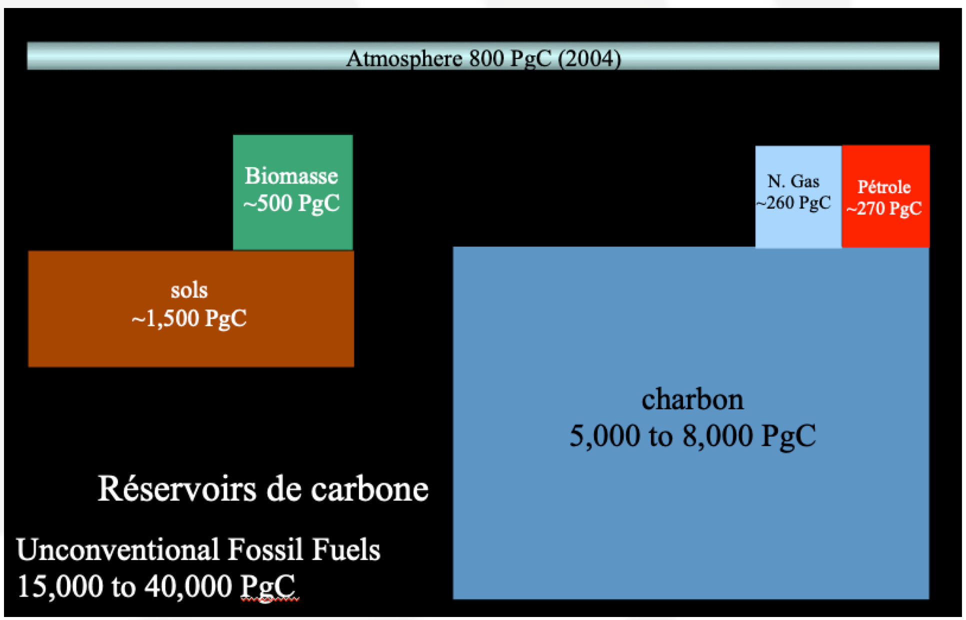


Booth et al. 2012

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

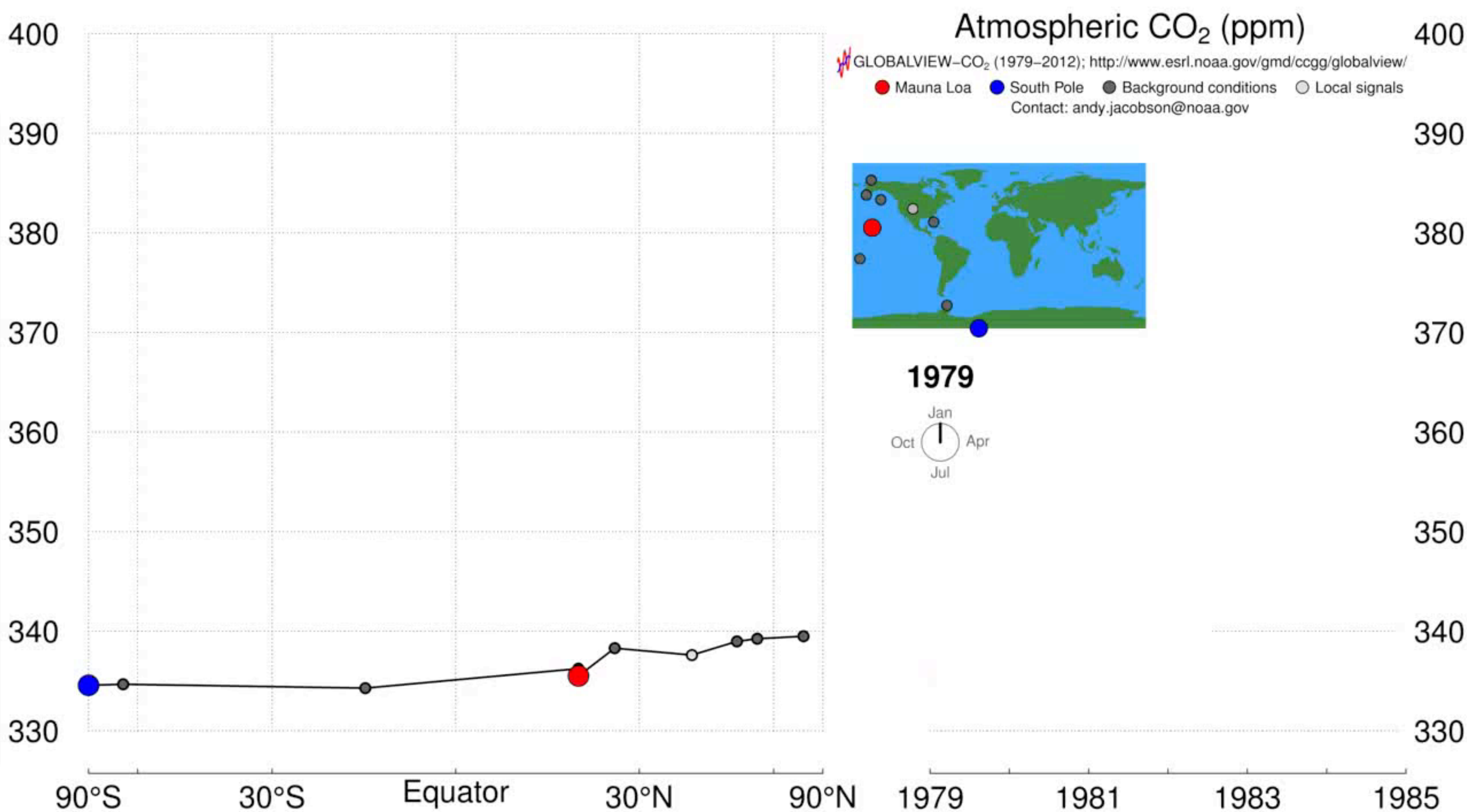
Le cycle du carbone vu de l'atmosphère

The global carbon budget 1959–2011

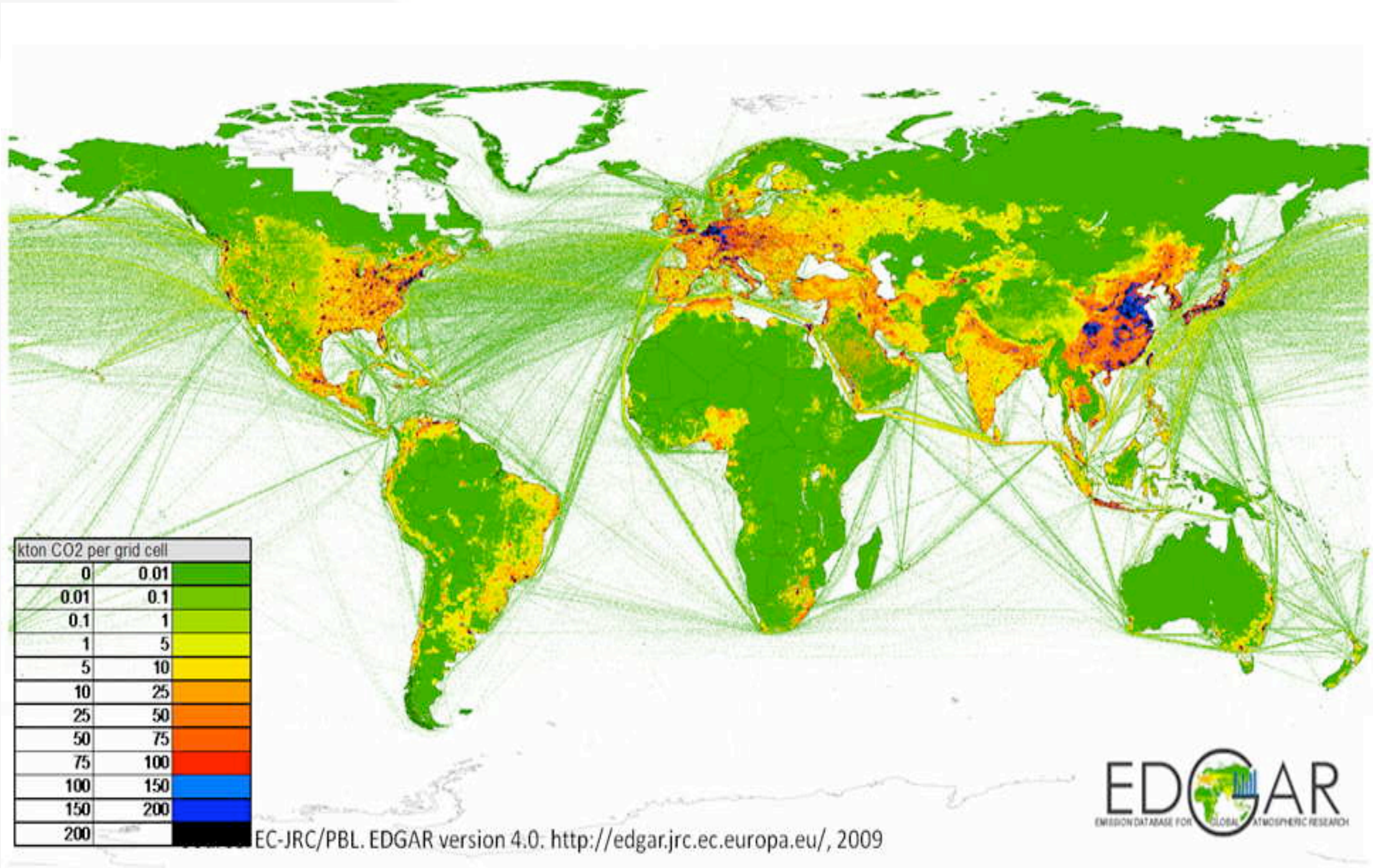
C. Le Quéré[1], R. J. Andres[2], T. Boden[2], T. Conway[3], R. A. Houghton[4], J. I. House[5], G. Marland[6], G. P. Peters[7], G. R. van der Werf[8], A. Ahlström[9], R. M. Andrew[7], L. Bopp[10], J. G. Canadell[11], P. Ciais[10], S. C. Doney[12], C. Enright[1], P. Friedlingstein[13], C. Huntingford[14], A. K. Jain[15], C. Jourdain[1,*], E. Kato[16], R. F. Keeling[17], K. Klein Goldewijk[18,19,20], S. Levis[21], P. Levy[14], M. Lomas[22], B. Poulter[10], M. R. Raupach[11], J. Schwinger[23,24], S. Sitch[25], B. D. Stocker[26,27], N. Viovy[10], S. Zaehle[28], and N. Zeng[29]

1 PPM ≈ 2.12 Gt de C

(1 Gigatone (Gt) = 1×10^{15}g
= 1 Petagram (Pg))

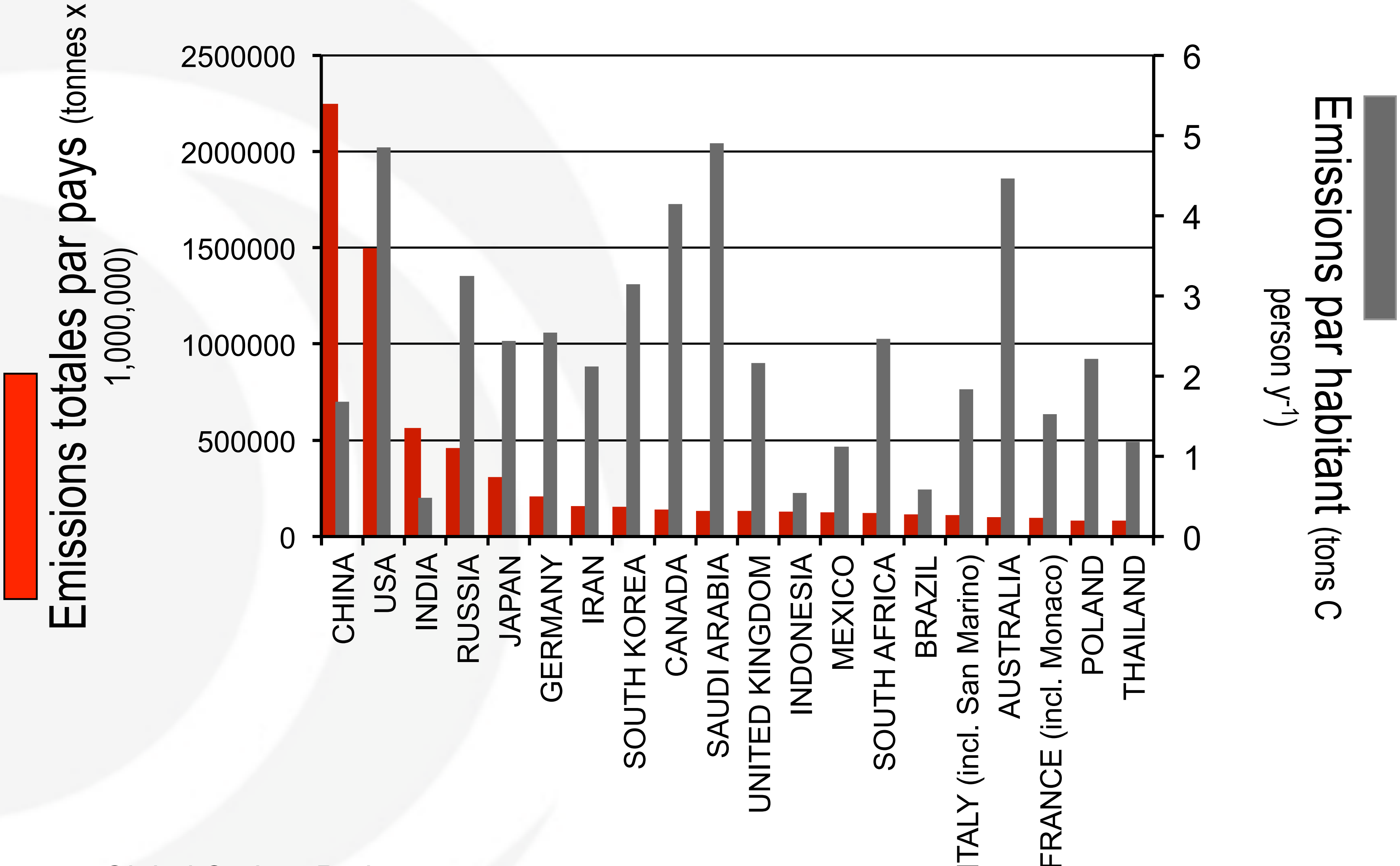


Carte et évolution des émissions de CO_2



Source : EDGAR4.0

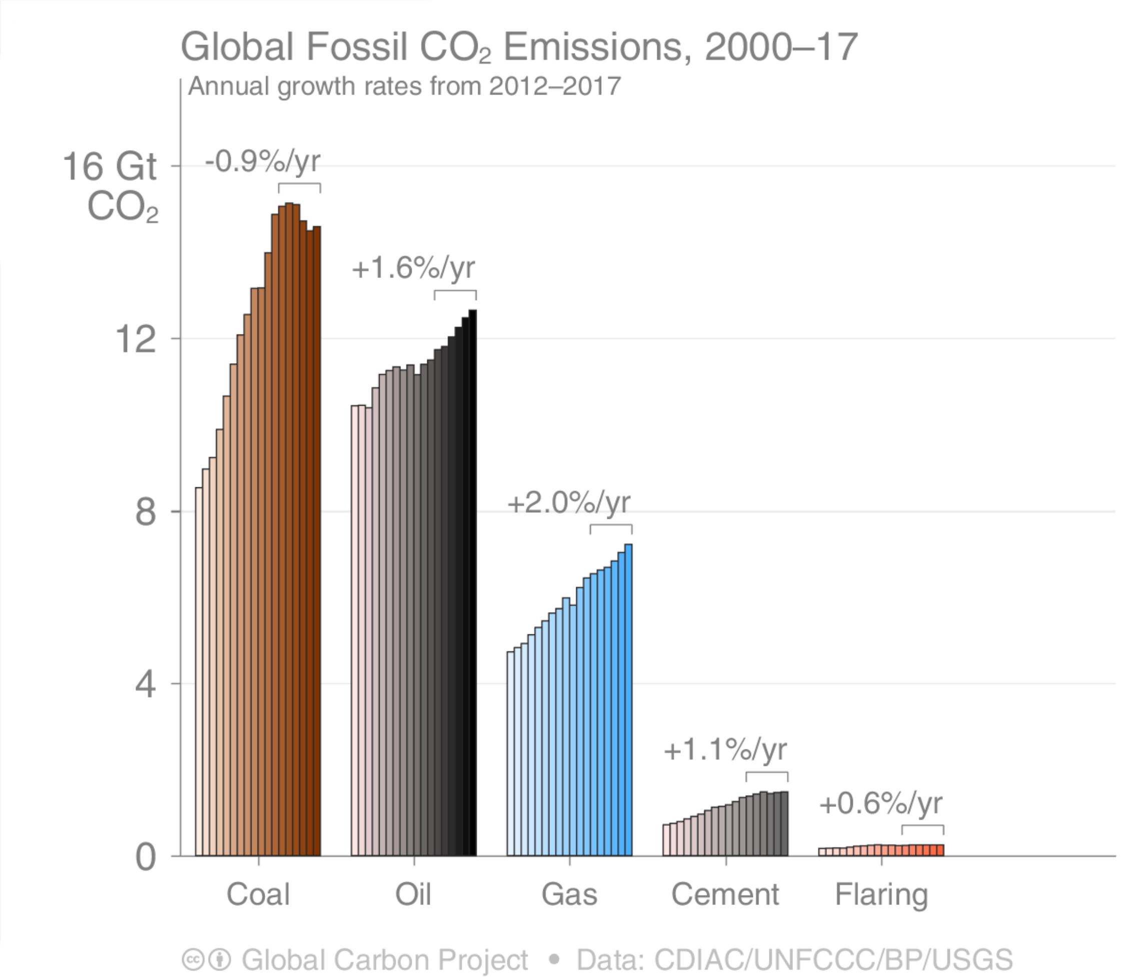
Emissions de CO_2 fossile par pays et par habitant



Source : Global Carbon Project

Fossil CO_2 Emissions by source

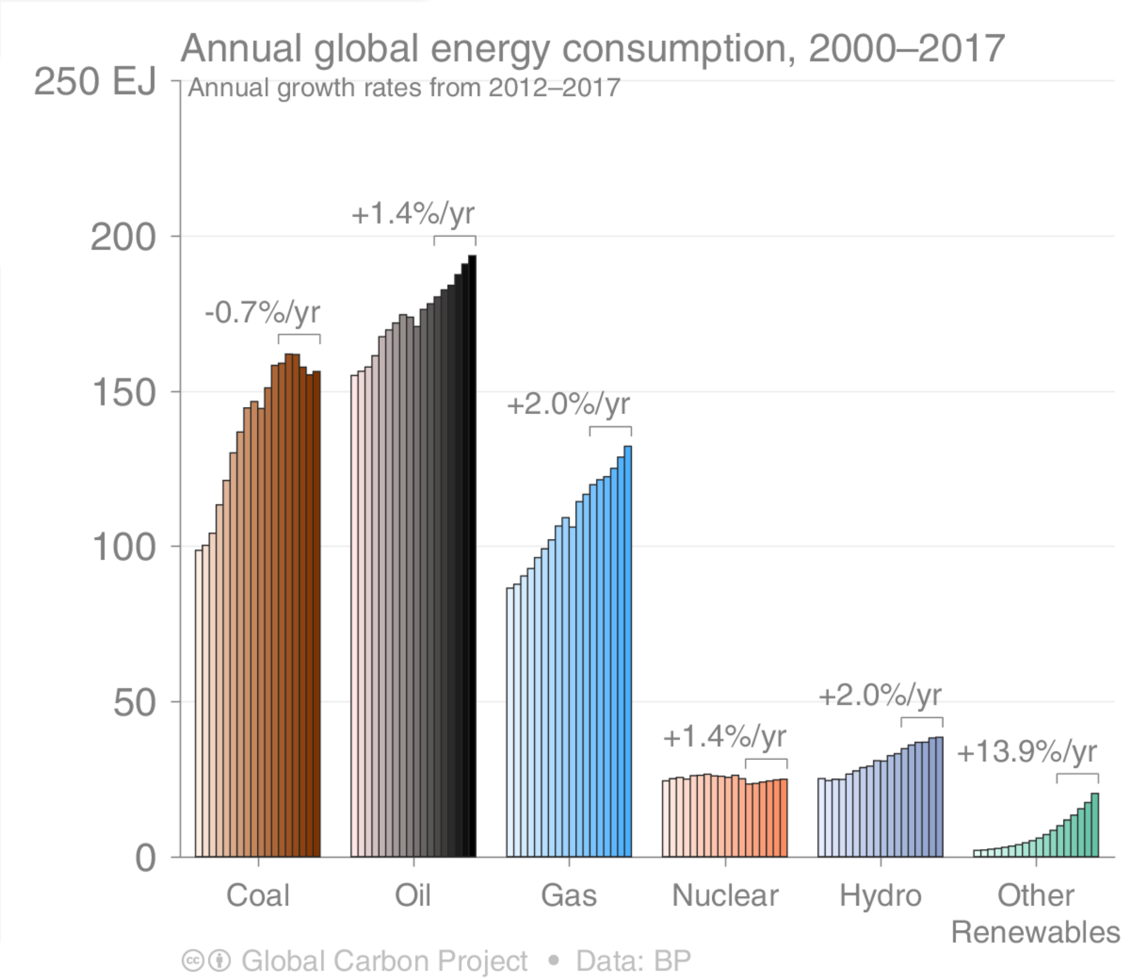
Emissions by category from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017



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

Energy use by source

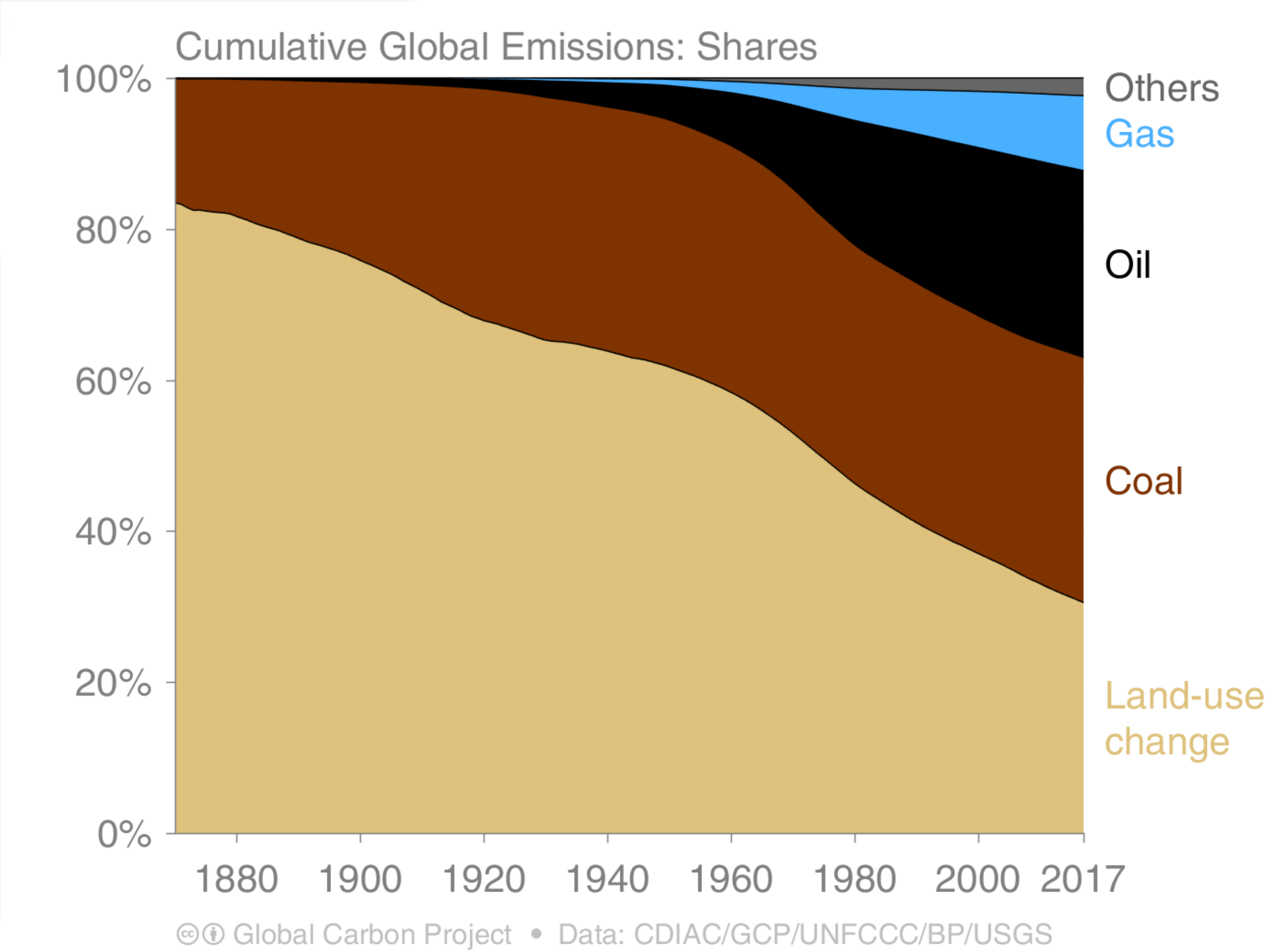
Energy consumption by fuel source from 2000 to 2017, with growth rates indicated for the more recent period of 2012 to 2017



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

Historical cumulative emissions by source

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

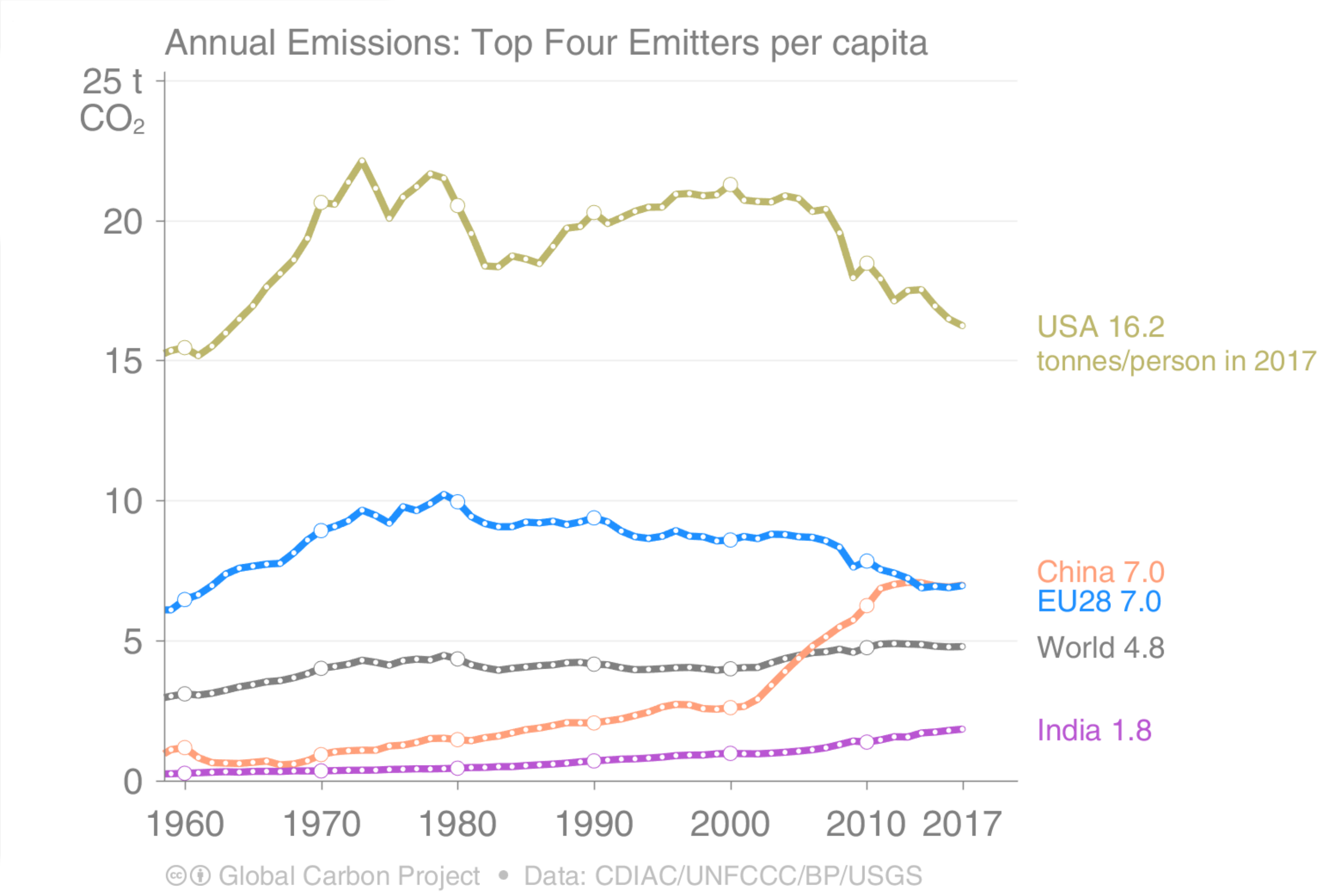


Others: Emissions from cement production and gas flaring

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

Top emitters: Fossil CO_2 Emissions per capita

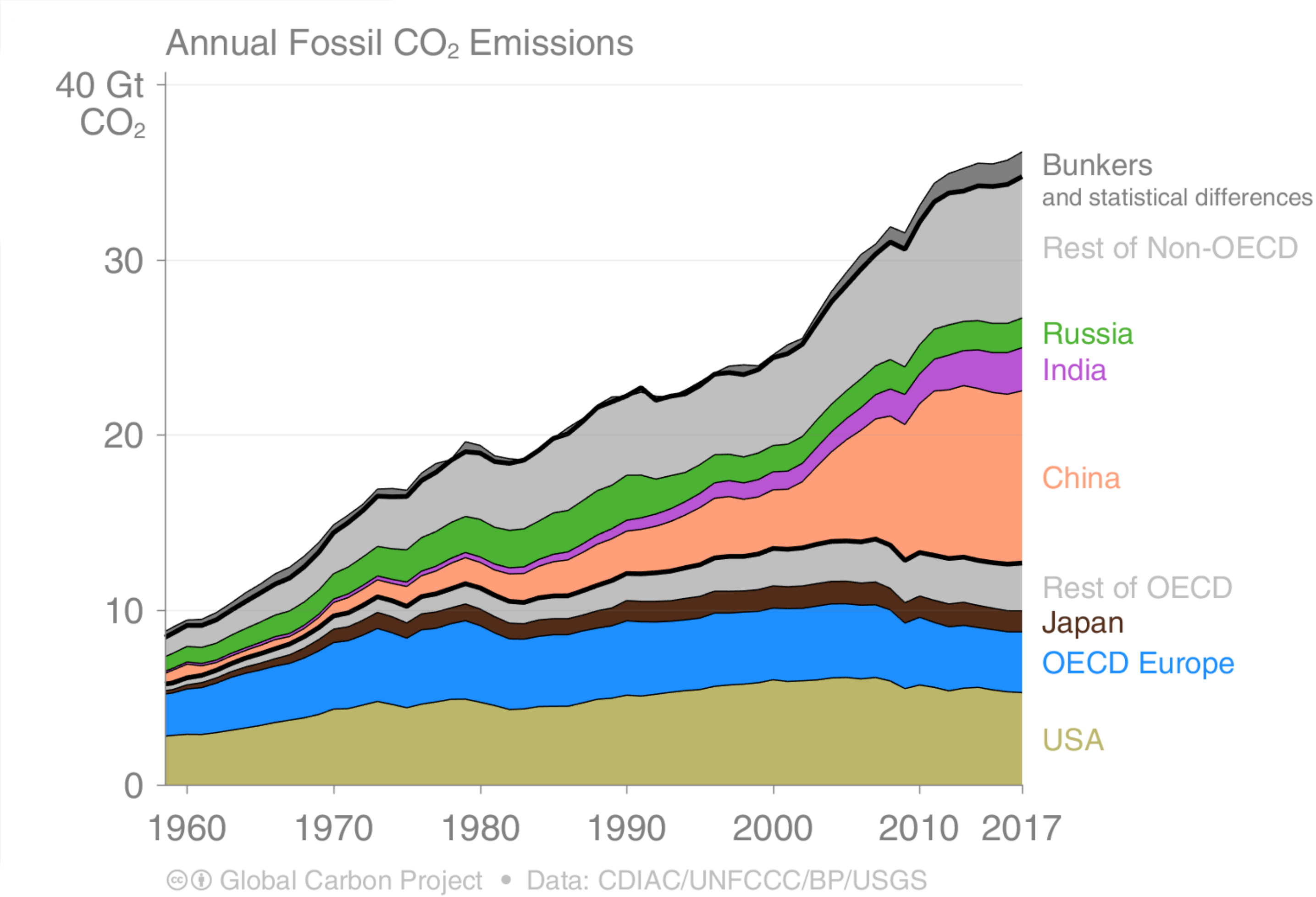
Countries have a broad range of per capita emissions reflecting their national circumstances



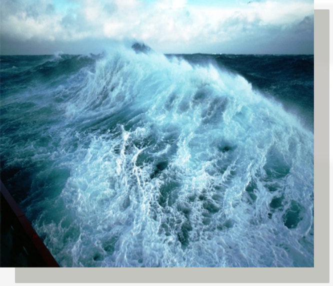
Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018

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

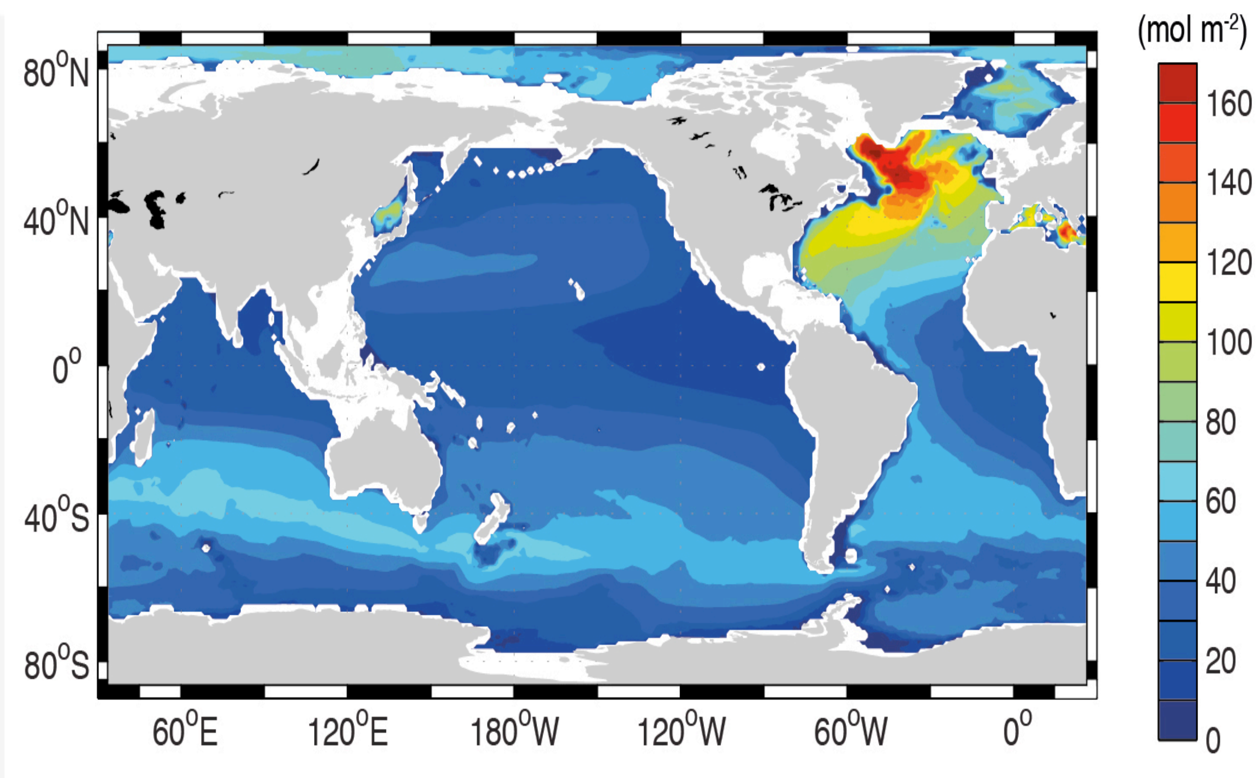


Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018



Absorption par l’océan: distribution spatiale

Absorption totale du CO_2 anthropique intégrée verticalement (2010)



➔ Absorption totale depuis 1750: **155 PgC ± 20%**

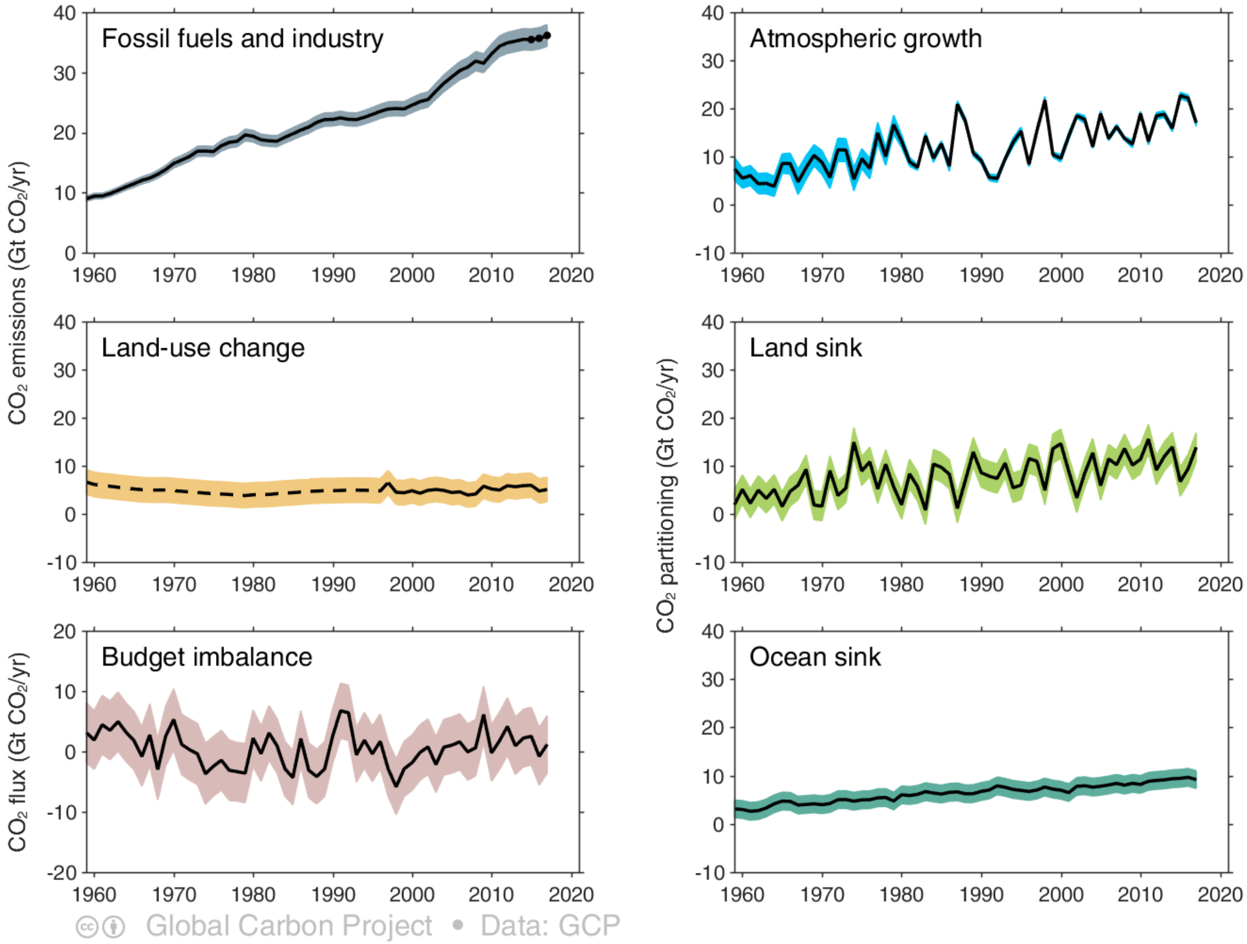
➔ Importance des zones de plongée d’eau profonde (i.e. Atlantique nord)

➔ Augmentation du puits entre années 1990 et 2010

Source : IPCC; Khatiwala et al. 2013

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.

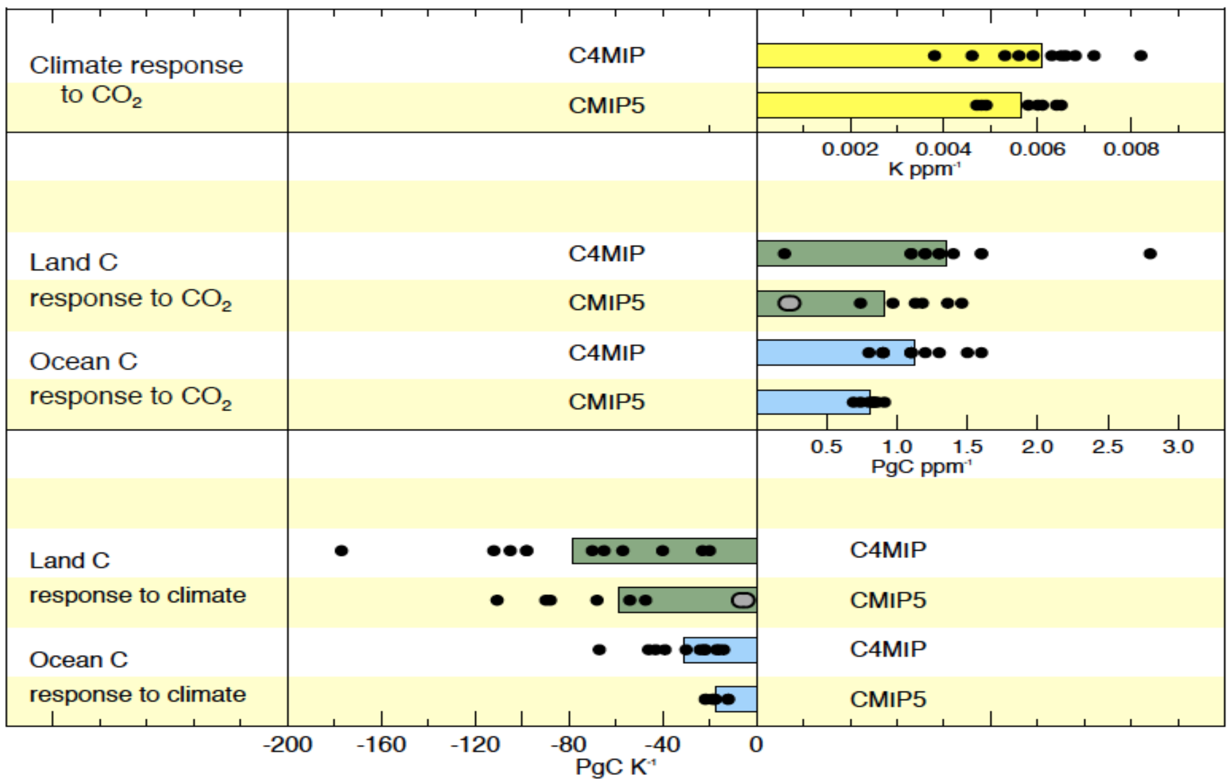
Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Positive carbon climate feedbacks confirmed in AR5

Climate response to CO_2 (K / ppm)

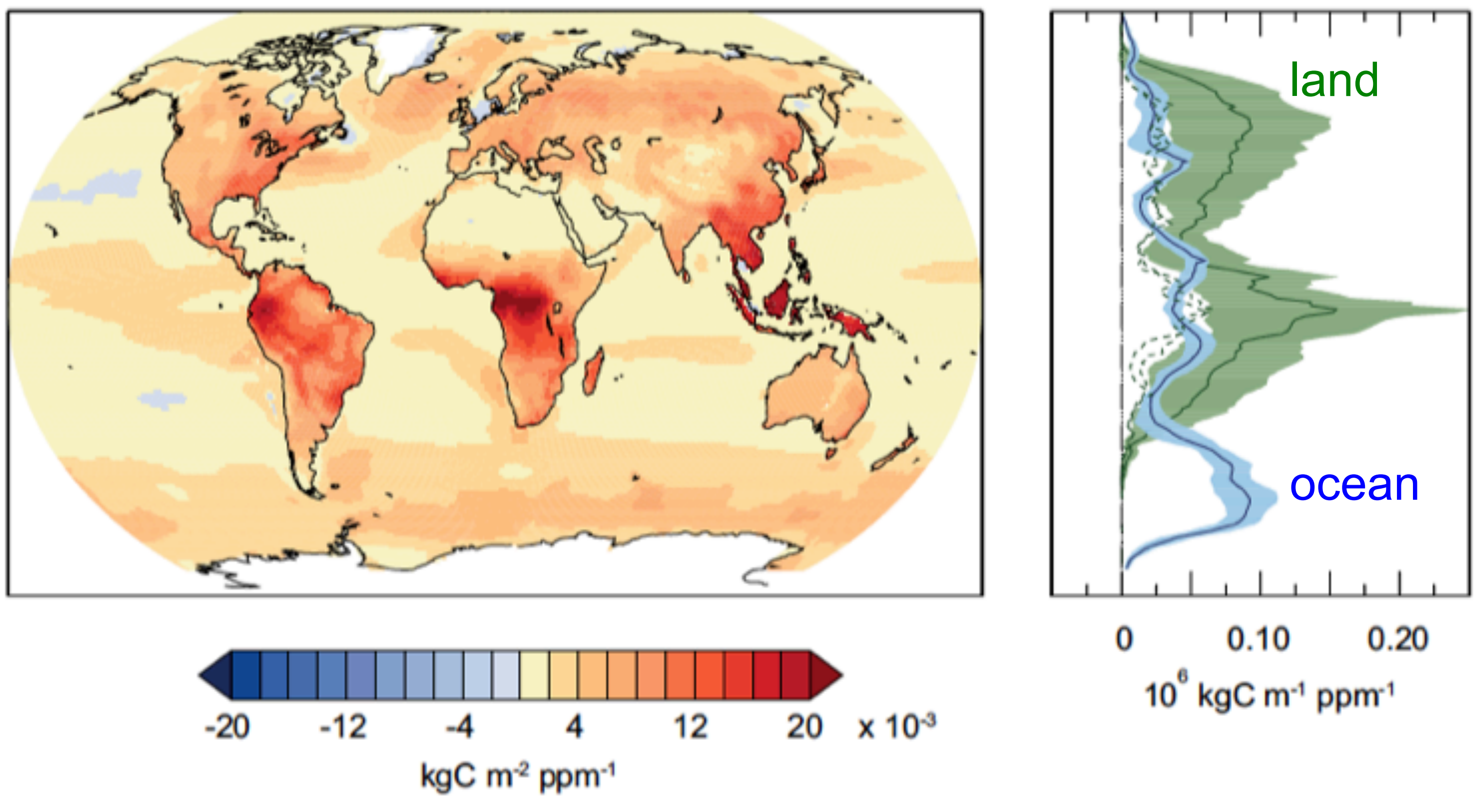
Sinks response to CO_2 (PgC / ppm)

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*)

Response to atmospheric CO_2 only

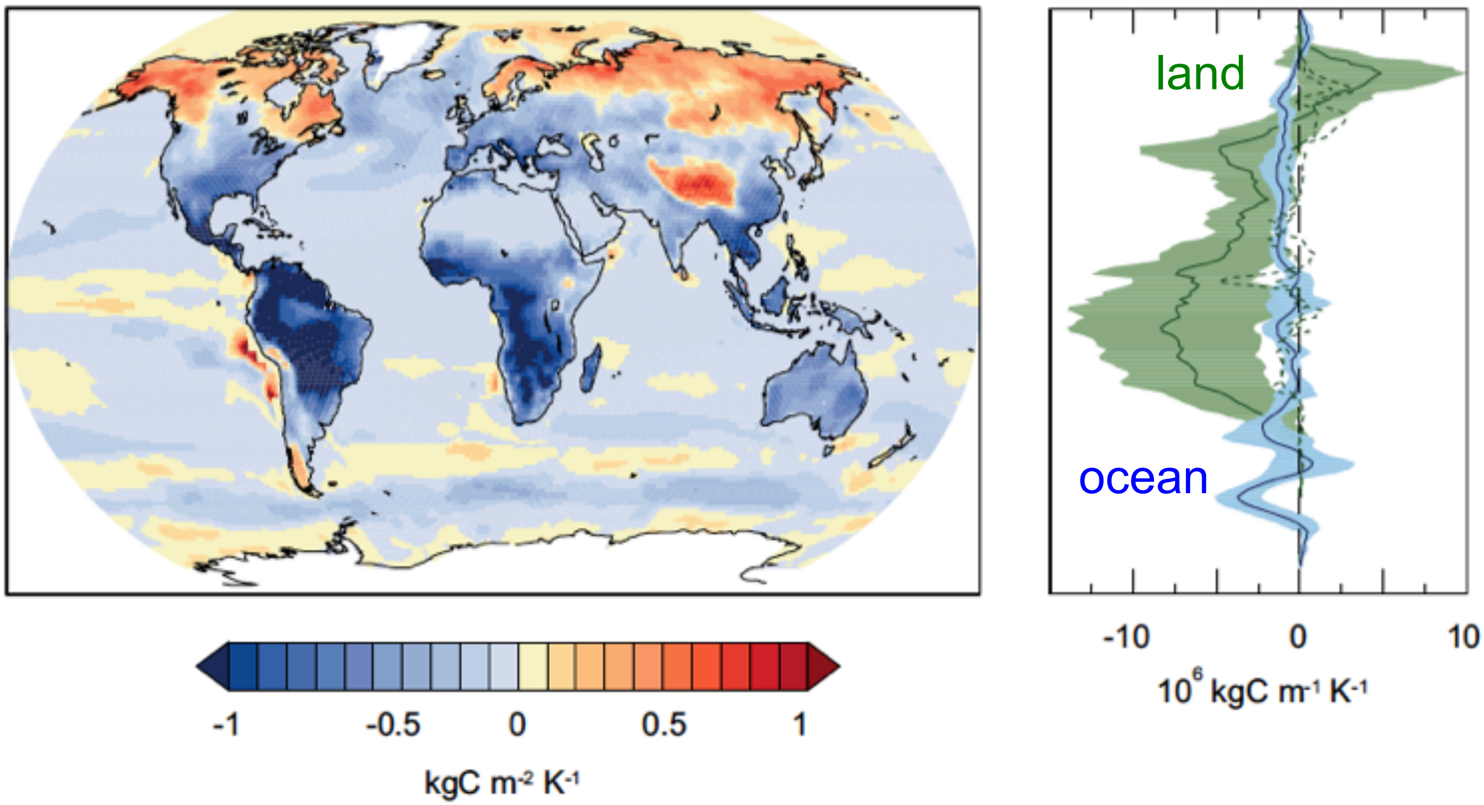


decreasing sink

increasing sink

source: Ciais et al. 2013 IPCC AR5

Response to climate change only



decreasing sink

increasing sink

models do not include the release of permafrost C

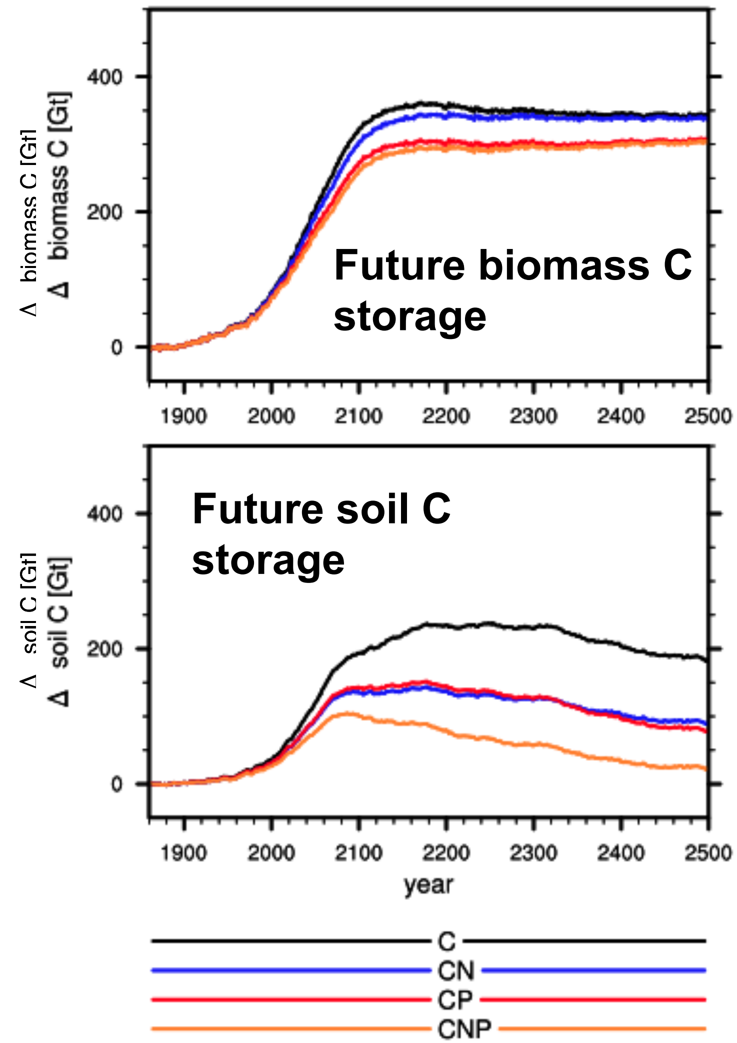
source: Ciais et al. 2013 IPCC AR5

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

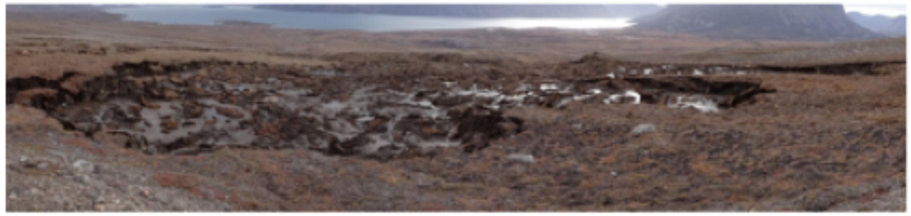


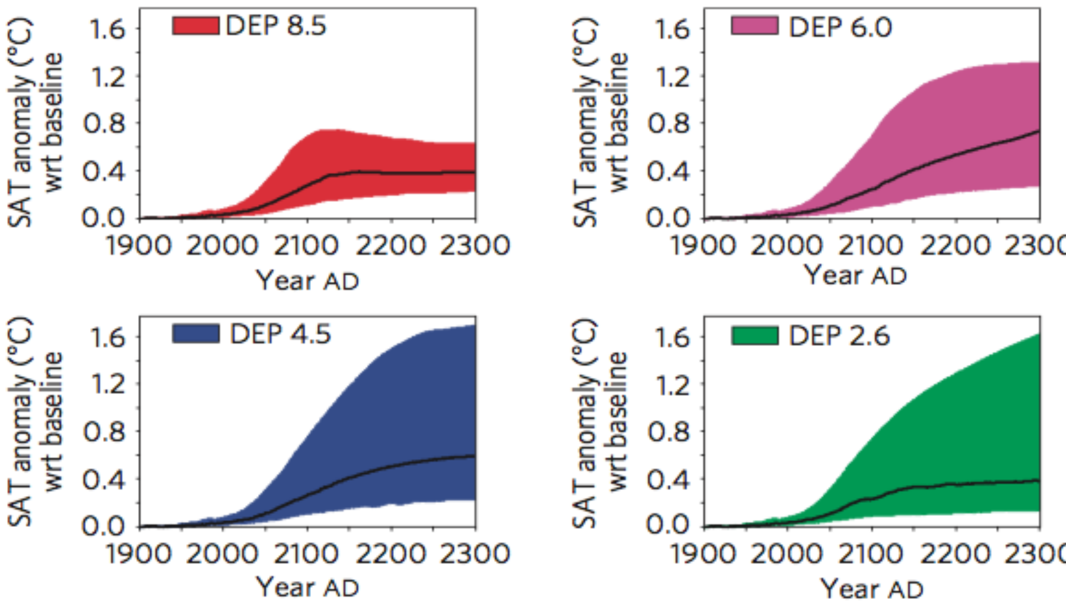
Goll et al. 2012

Future of the assessment :

‘cold’ carbon processes, permafrost C

1670 Pg C
In permafrost





Mc Dougall et al. 2013

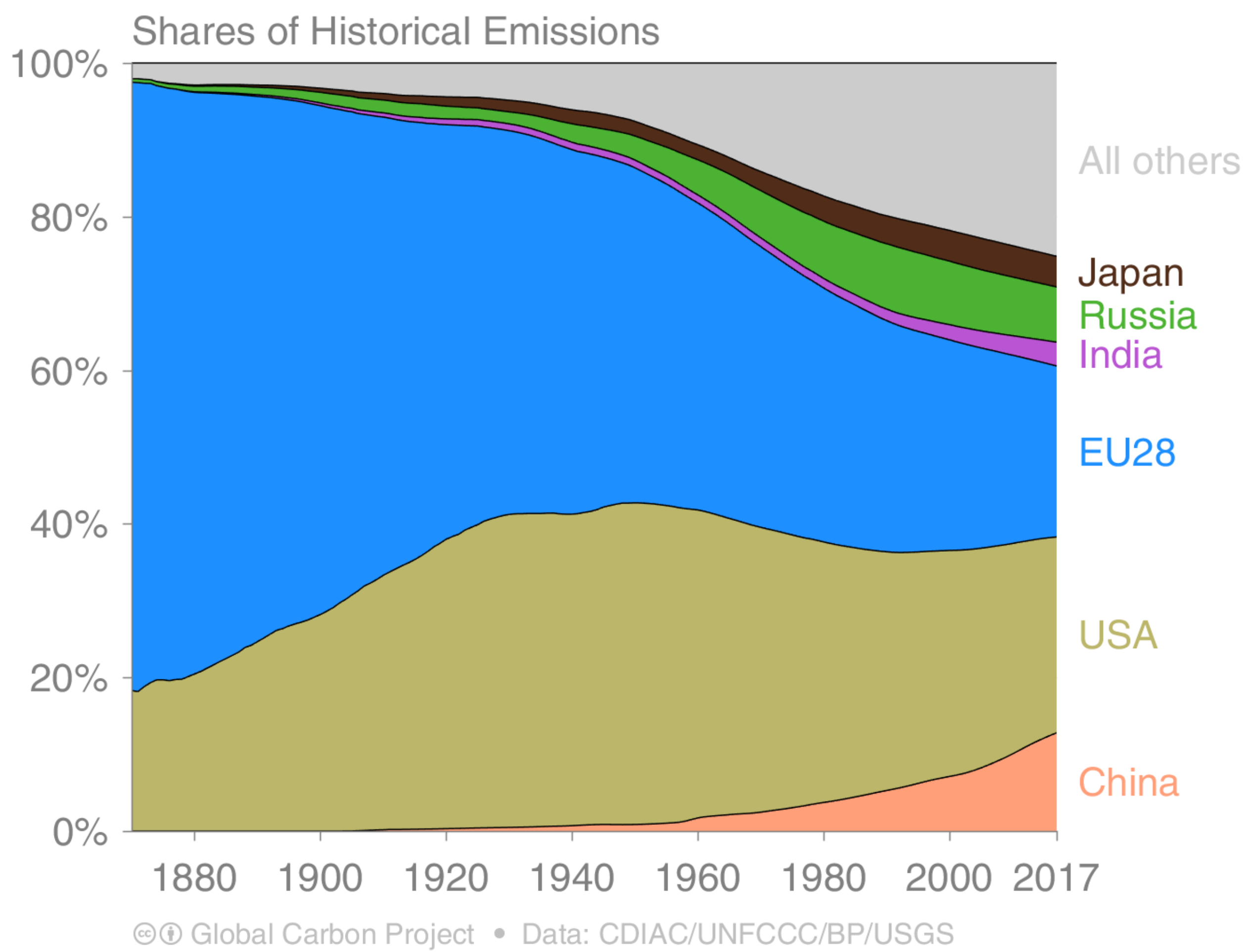
An Earth System Model with permafrost carbon processes was driven by RCP emissions

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