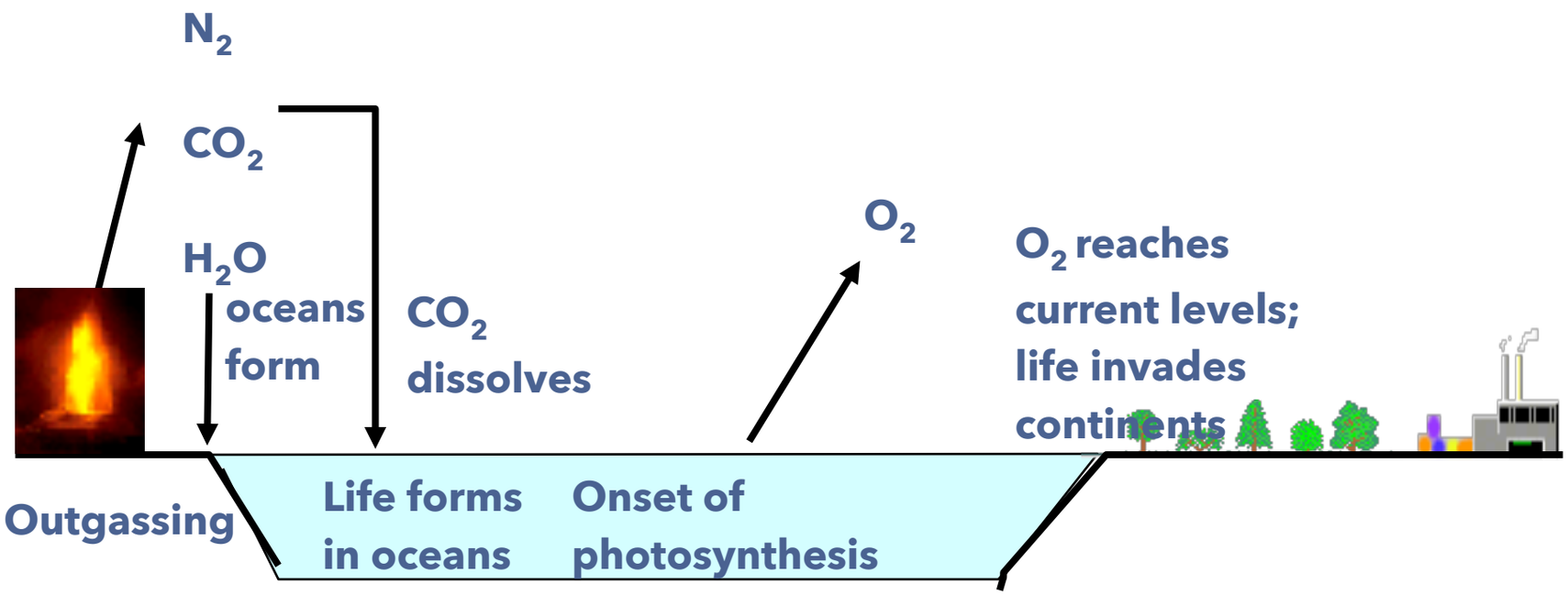
Introduction to the Biosphere-Atmosphere system

Lecture Autumn 2025

Part IV

Steffen M. Noe

How can we model this?



4.5 billion yrs. B.P

4 billion yrs. B.P.

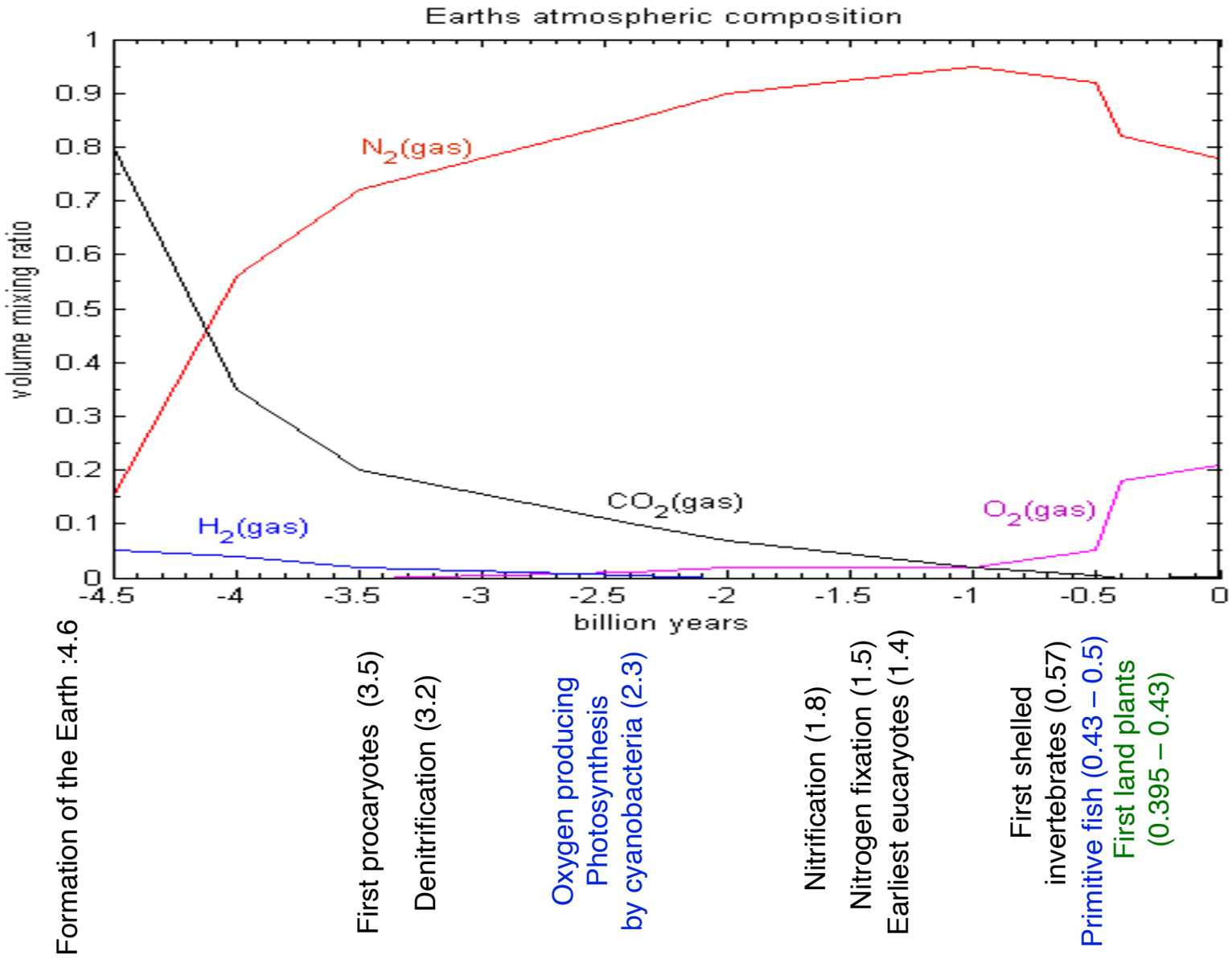
3.5 billion yrs. B.P.

0.4 billion yrs. B.P.

present

D.J. Jacob

History of Earths atmospheric composition

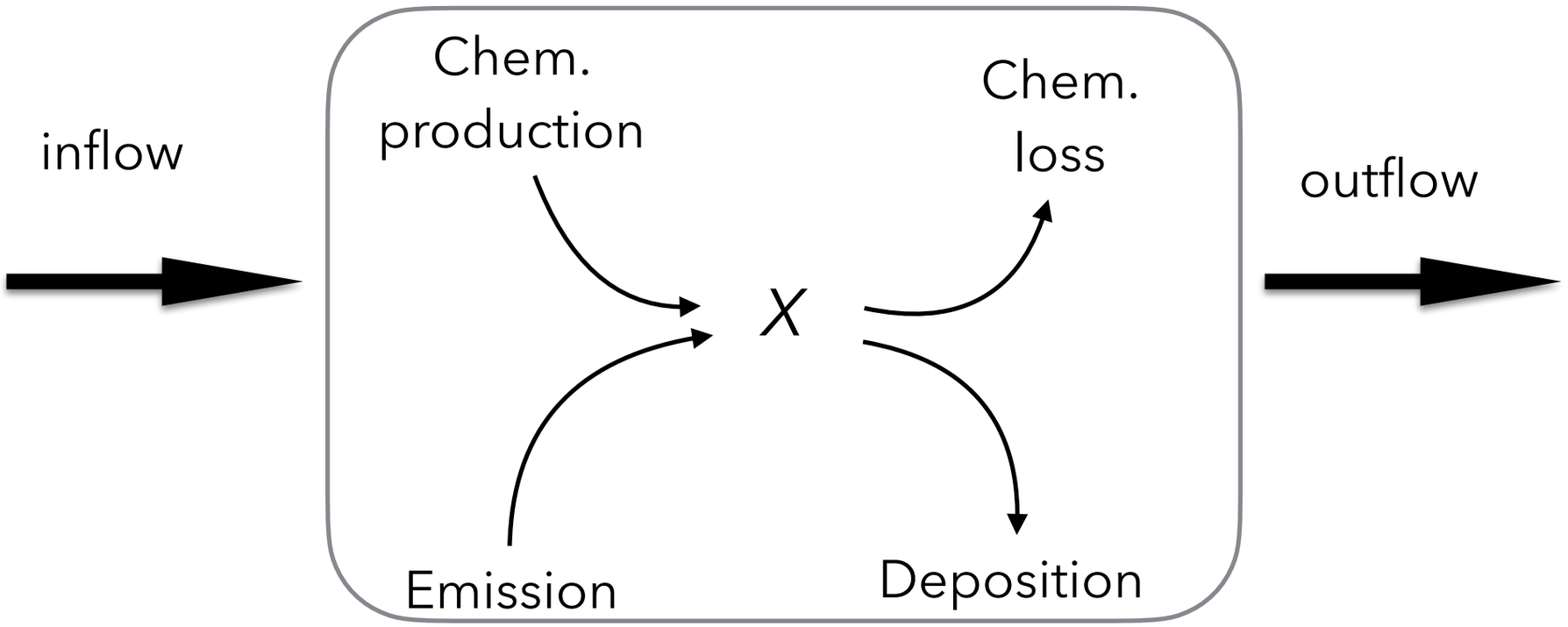


Jacobson, 2002

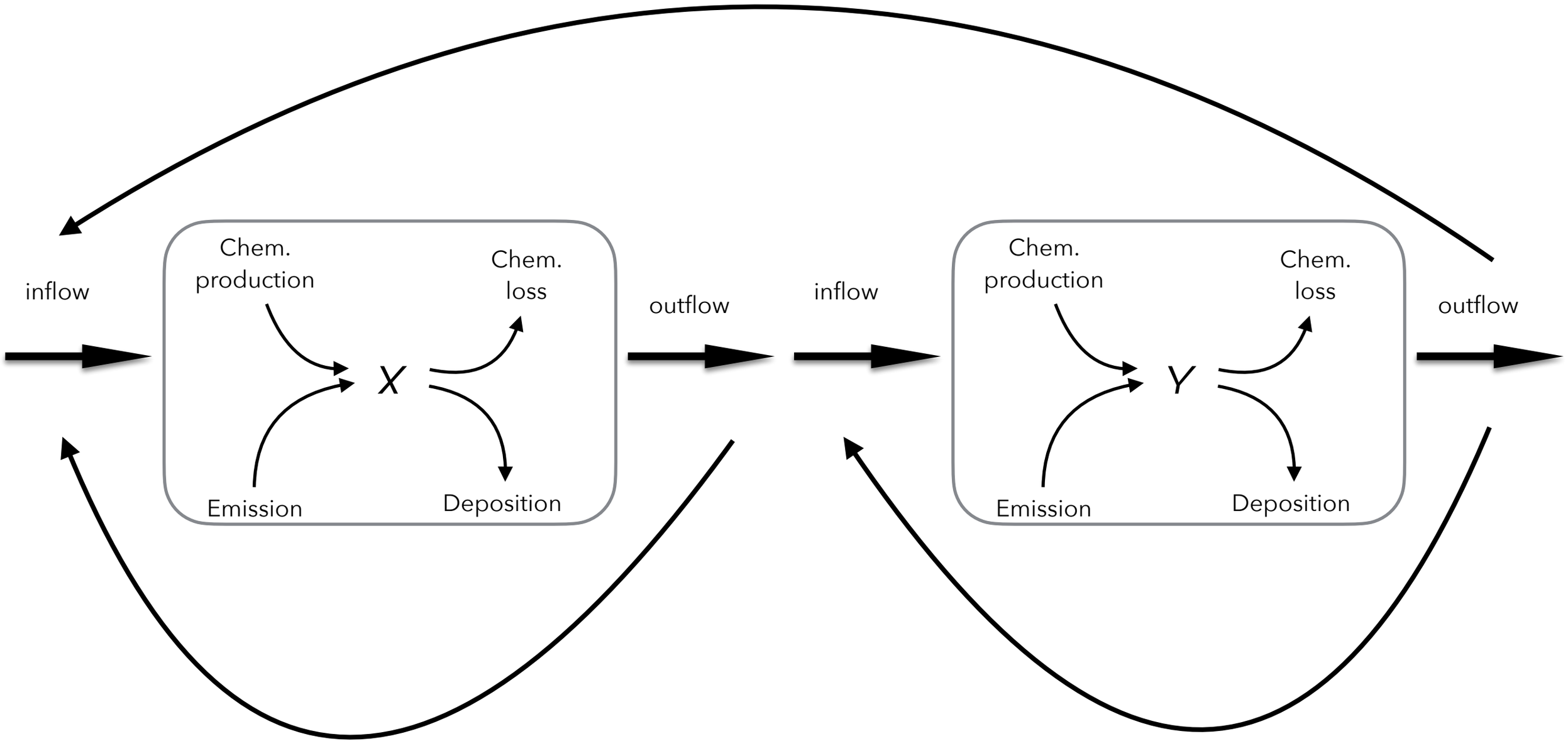
How to describe the Earth system?

- The standard approach is to use **box models**!
- Individual reservoirs are seen as individual boxes!
- Each box has it’s own certain mass (or **inventory**) of elements of interest!
- The migration of those elements is described by **flows** between the boxes!

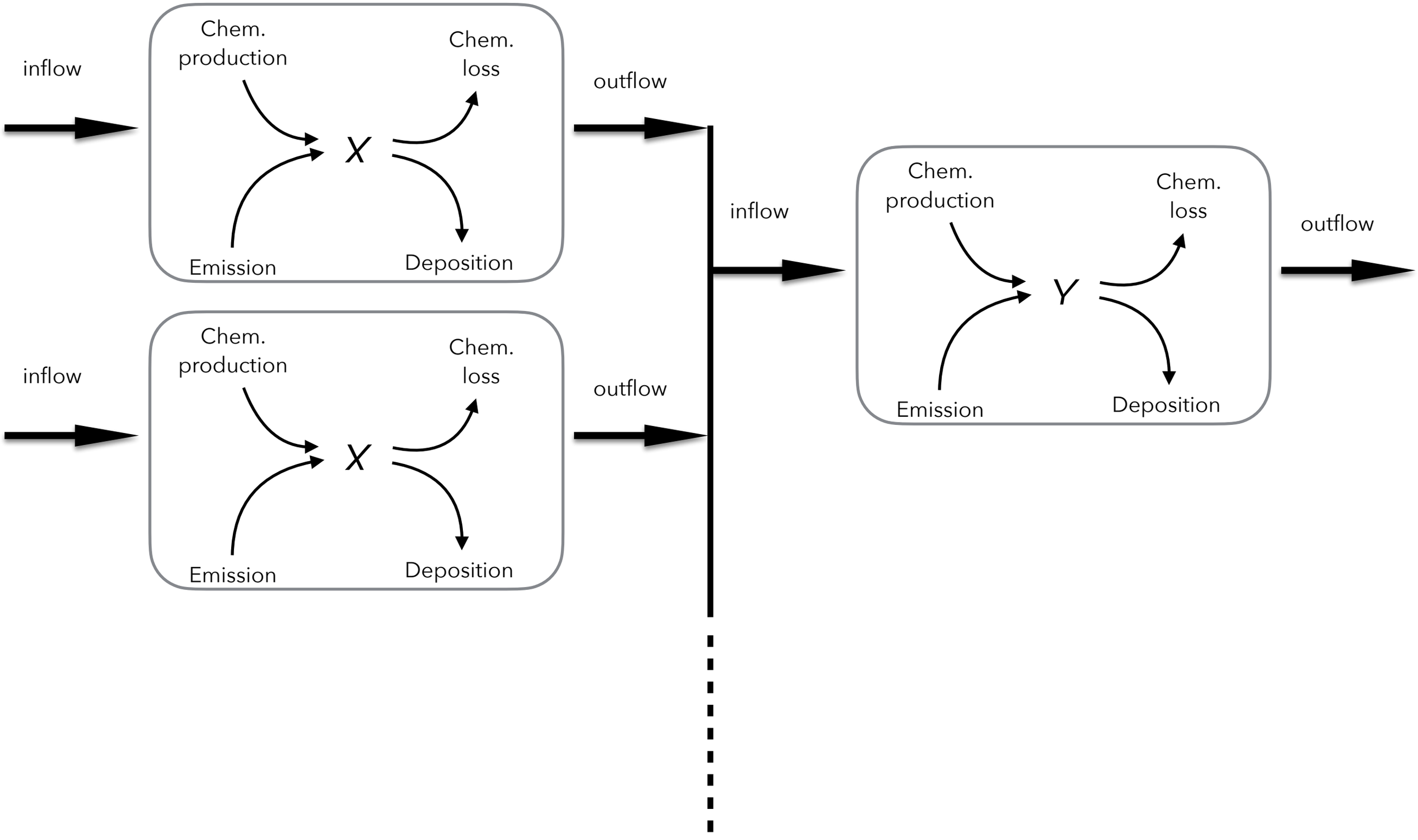
One box model: the building block



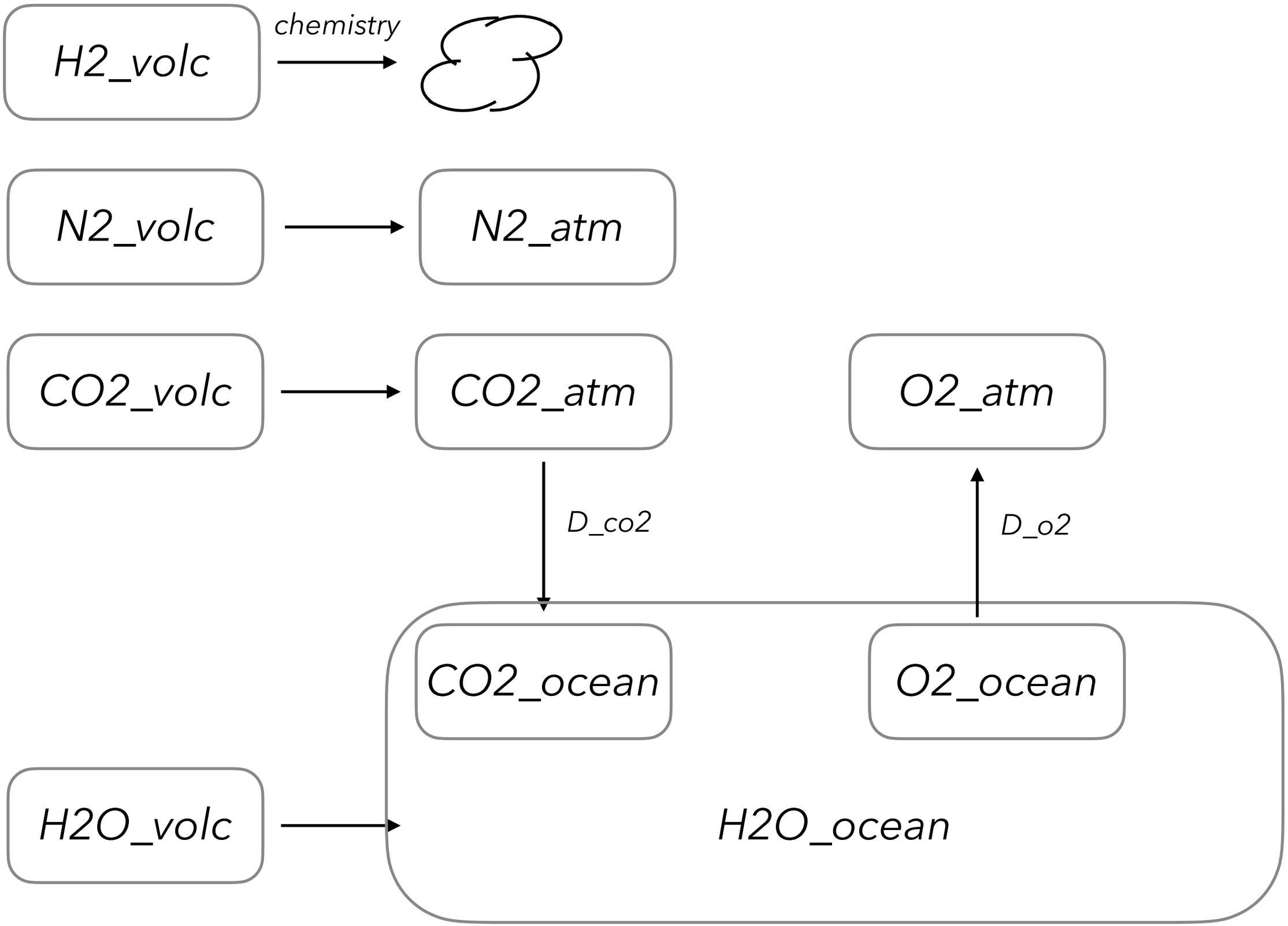
Two box model: we can add feedback



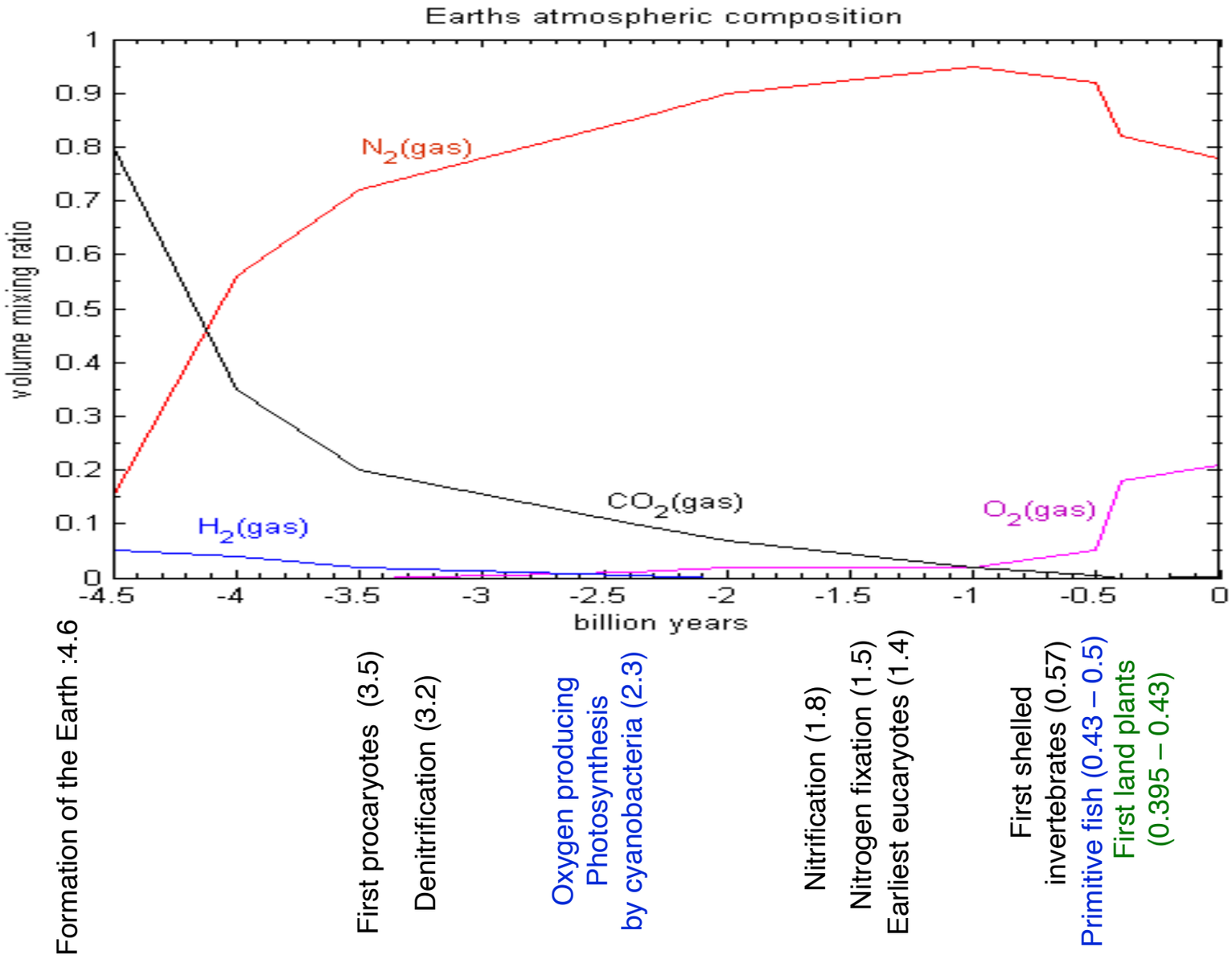
Multi box model: we can add feedback



one possible suggestion, no feedback...



History of Earths atmospheric composition



Jacobson, 2002

A note on volcanic carbon dioxide

- Volcanos and magmatically active regions on land and in the oceans.
  They emit yearly **280 - 360 million** tonnes 0.28 - 0.36 GT/yr CO2
- Humans emit yearly ~**40 billion** tonnes or 40 GT/yr CO2 (2023)
- That is **~110 - 140 times the volcanic source per year!**

- It takes **just 3 days** for humankind to emit the same as all volcanoes do **in one year**!
- There are about ~60 active Volcanoes per year!

Humans add ~7500 Volcanoes!

per year!

Bárðabunga eruption Iceland, Sept. 2014 Photo Steffen M. Noe

Task - Try to express the Estonian annual emission in Volcanoes

1: Find Estonia’s annual CO2 emission

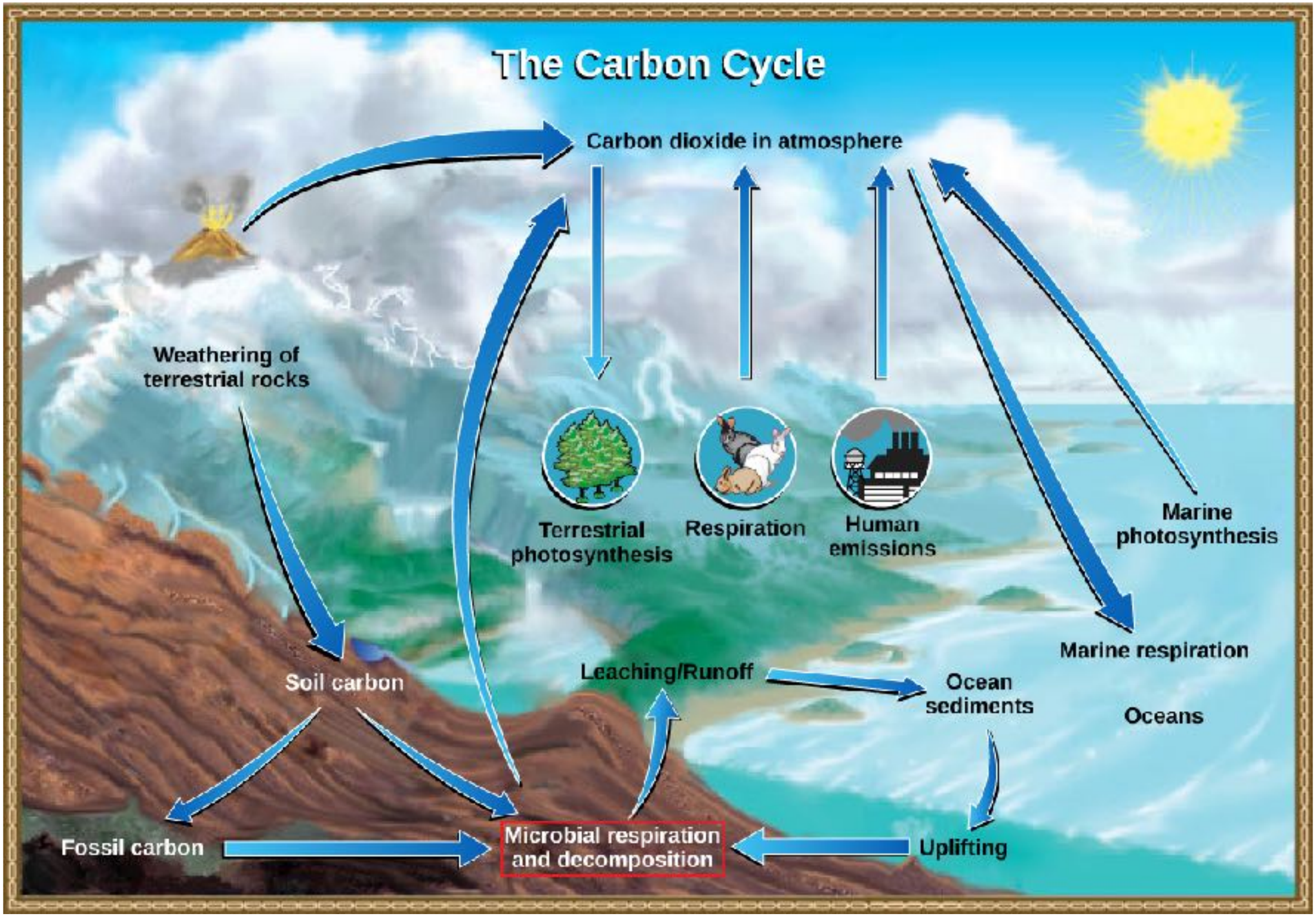
https://globalcarbonatlas.org/emissions/carbon-emissions/

2: Relate it with the Volcano emission

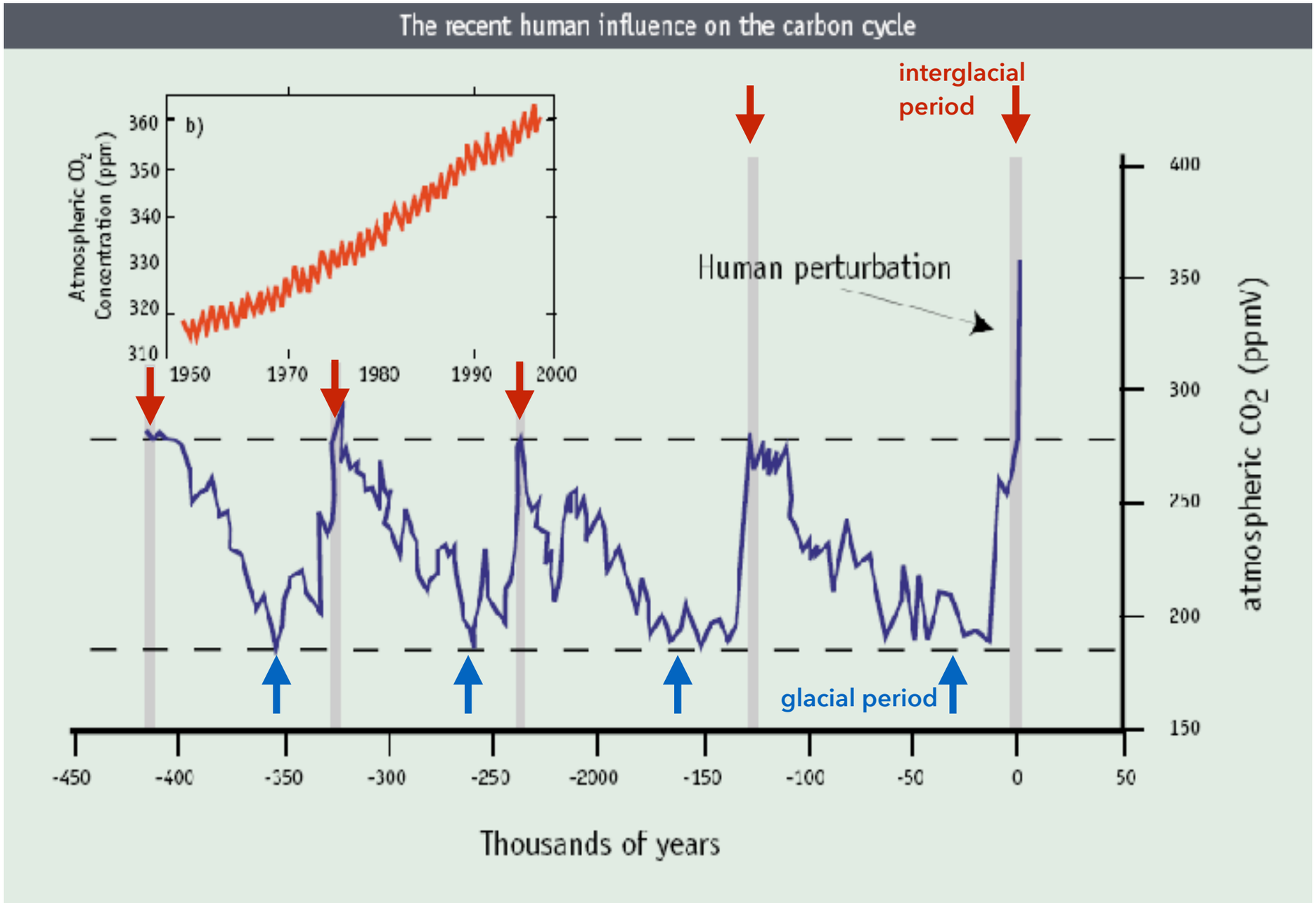
Bárðabunga eruption Iceland, Sept. 2014

Photo Steffen M. Noe

Carbon cycle



CO_2 over the past 400 000 years

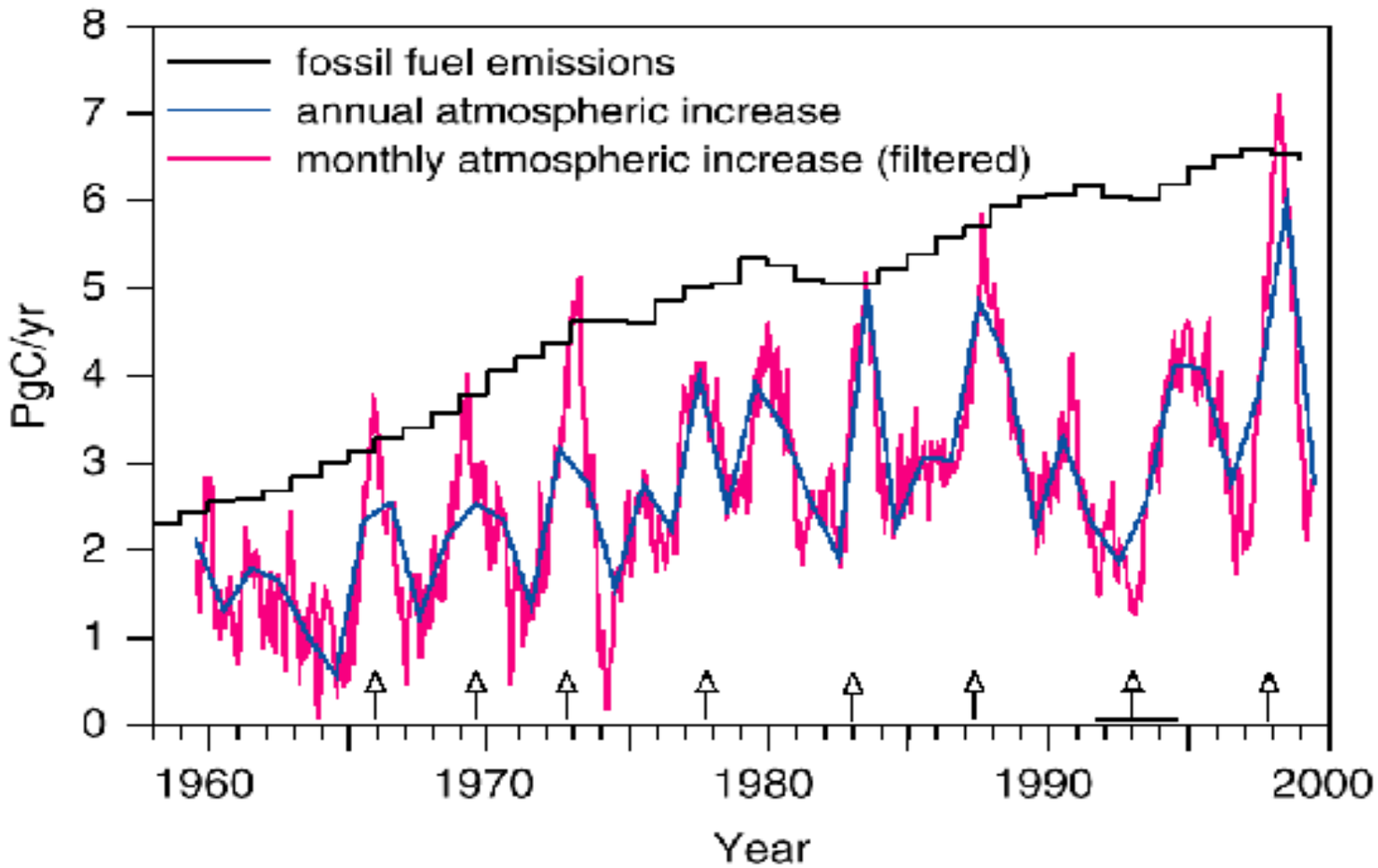


Vostok ice core data set, Petit et al., 1999

Recent atmospheric CO_2 growth rates

Notice:

- atmospheric increase is ~50% of fossil fuel emissions
- large inter-annual variability



Arrows indicate
El Nino events

D.J. Jacob

Recent atmospheric CO_2 growth rates until 2022

Notice:

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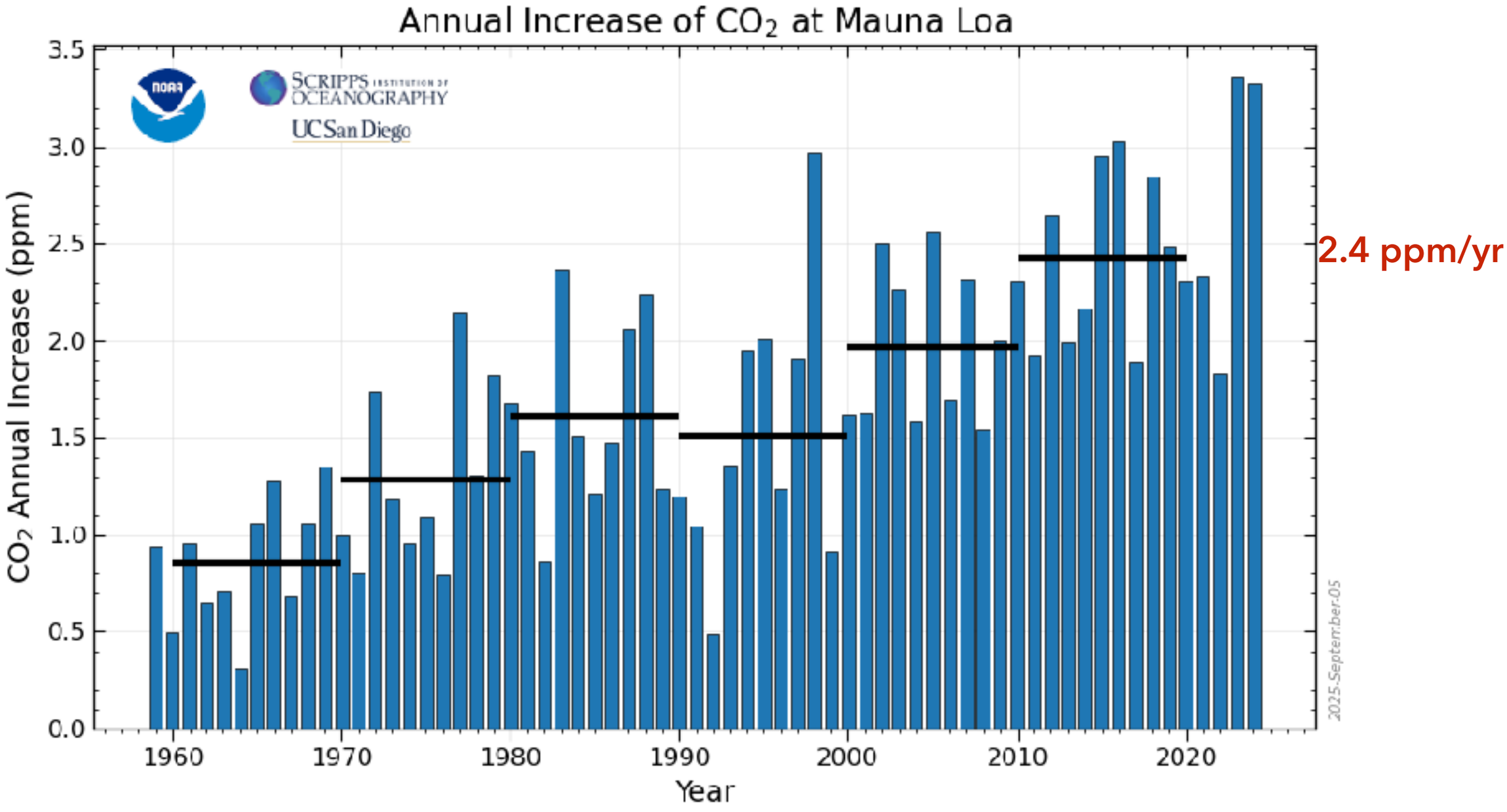
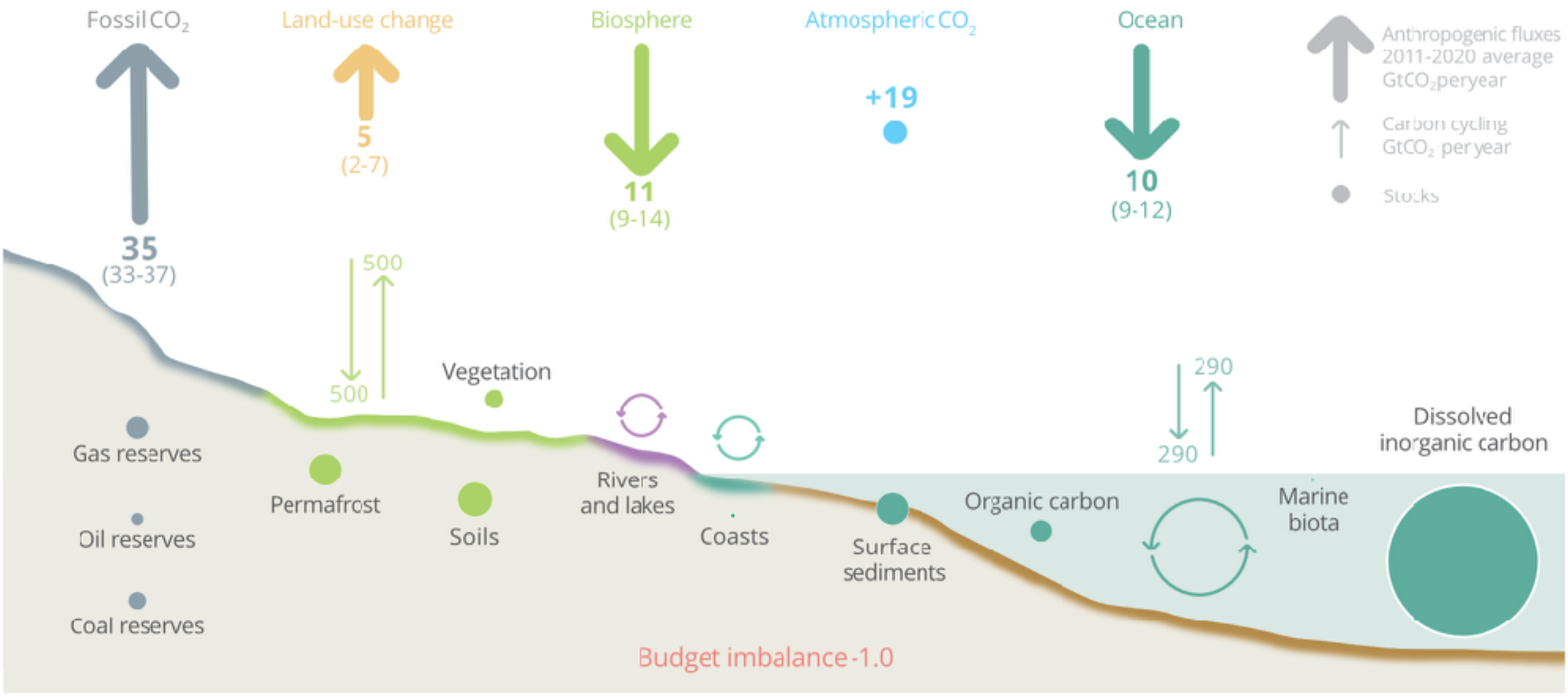
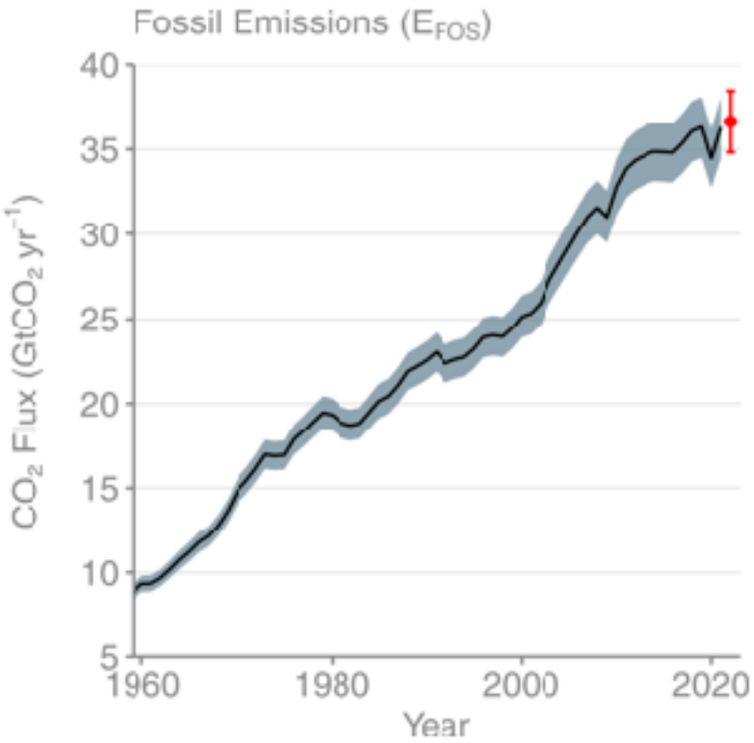
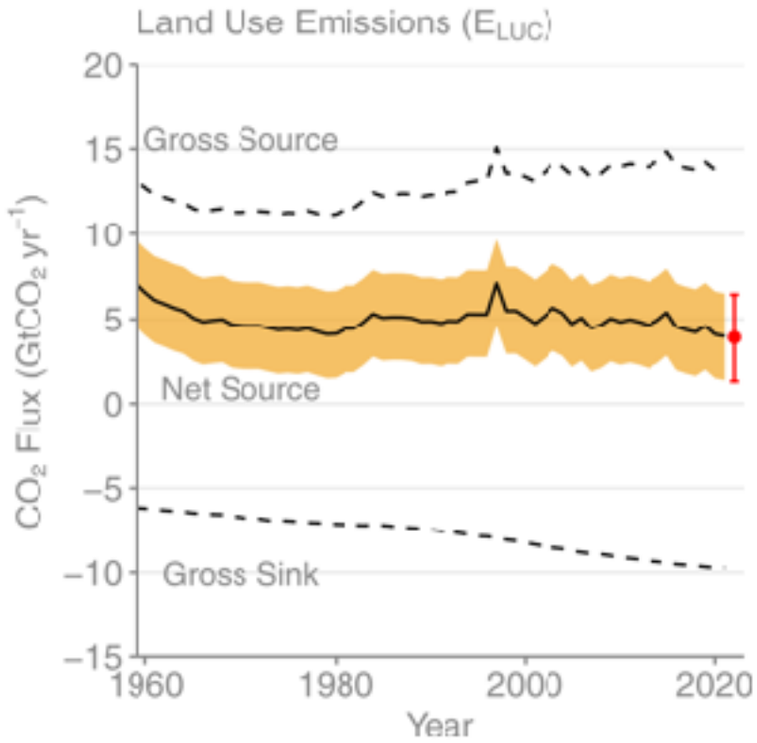


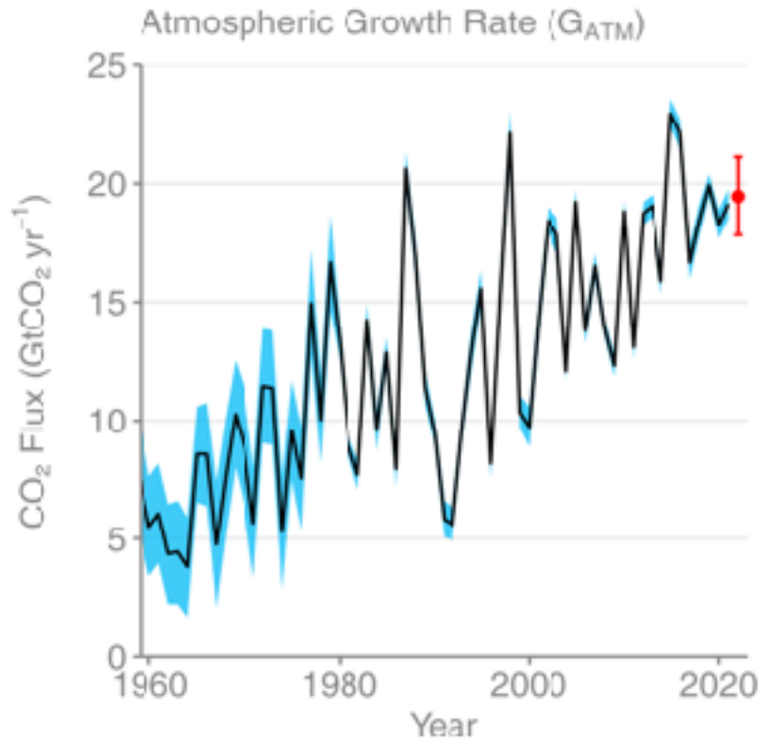
Carbon fluxes schematic (2022)

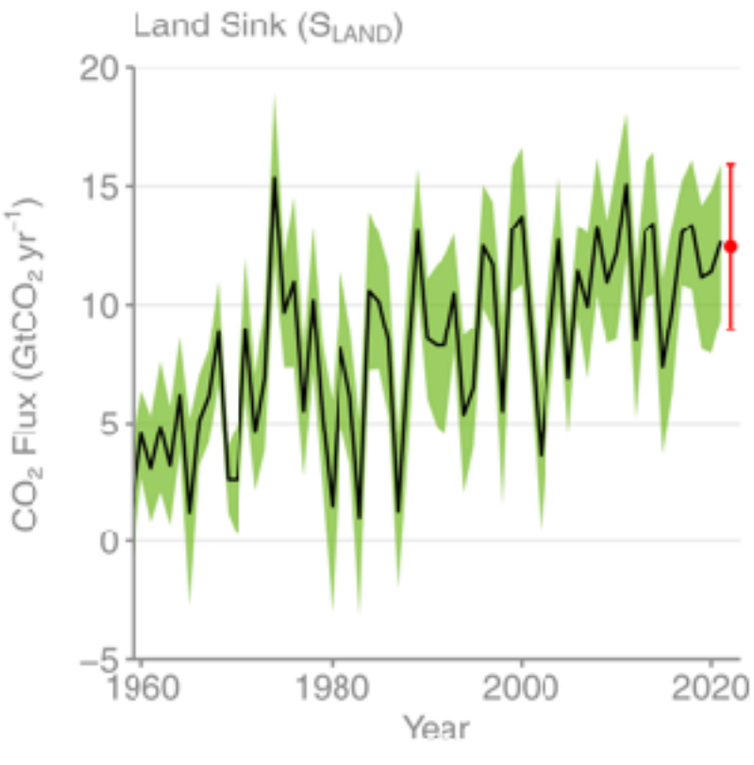


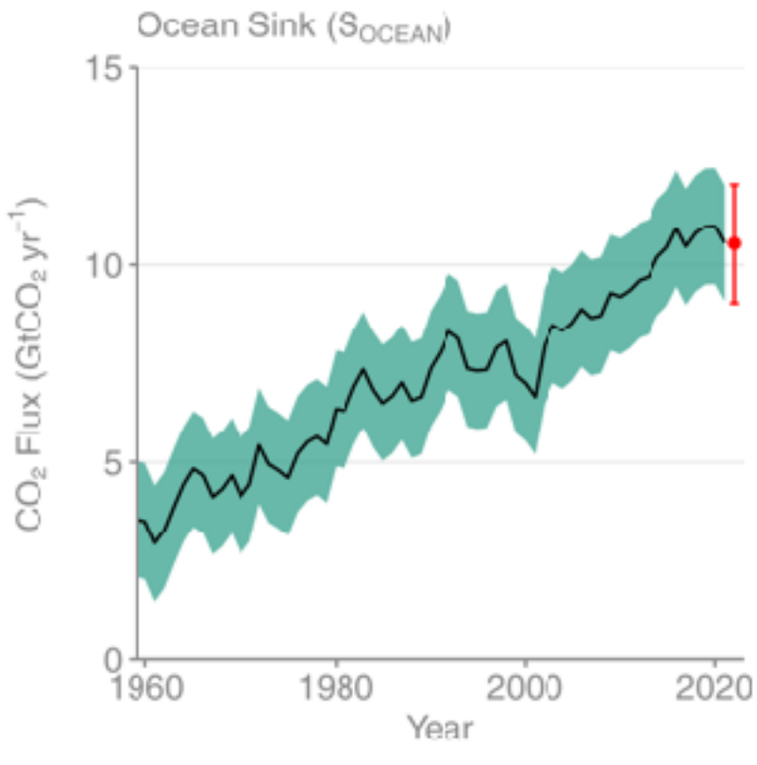
Changes in the sources/sinks over time

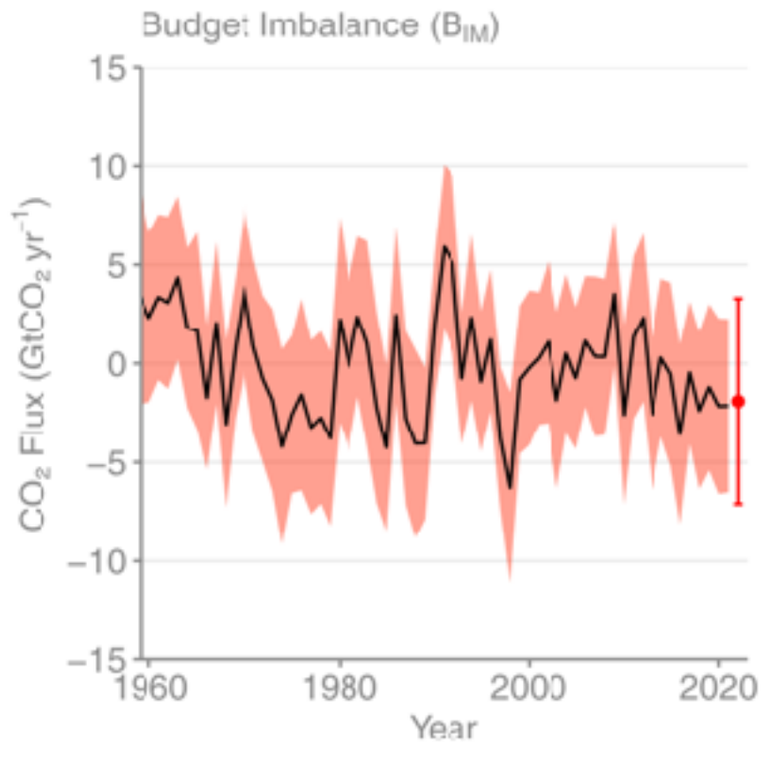












CO_2 ocean uptake chemistry

ATMOSPHERE $CO_2(g)$

OCEAN $CO_2 \cdot H_2O$ $K_H = 3 \times 10^{-2}$ M atm^{-1}

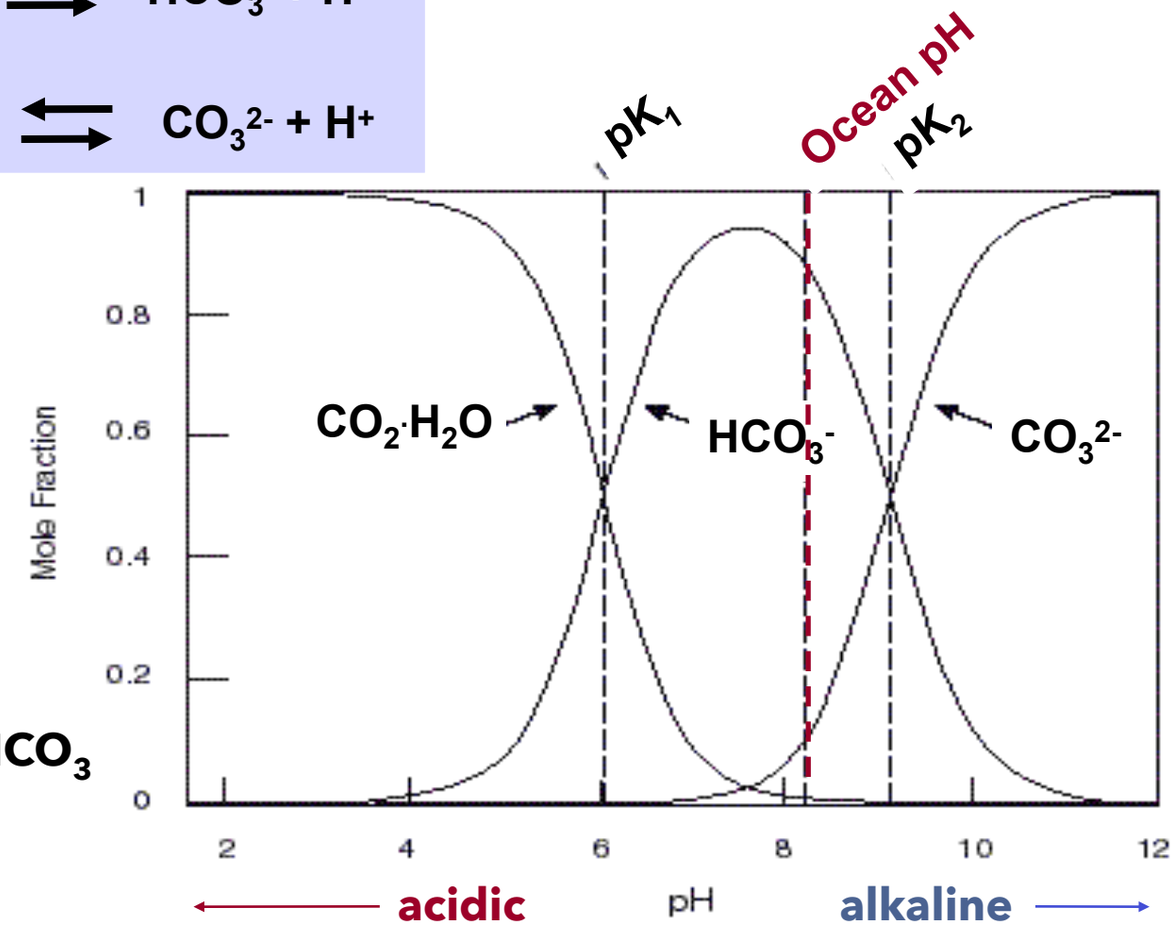
$K_1 = 9 \times 10^{-7}$ M $\quad CO_2 \cdot H_2O \rightleftharpoons HCO_3^- + H^+$

$K_2 = 7 \times 10^{-10}$ M $\quad HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$

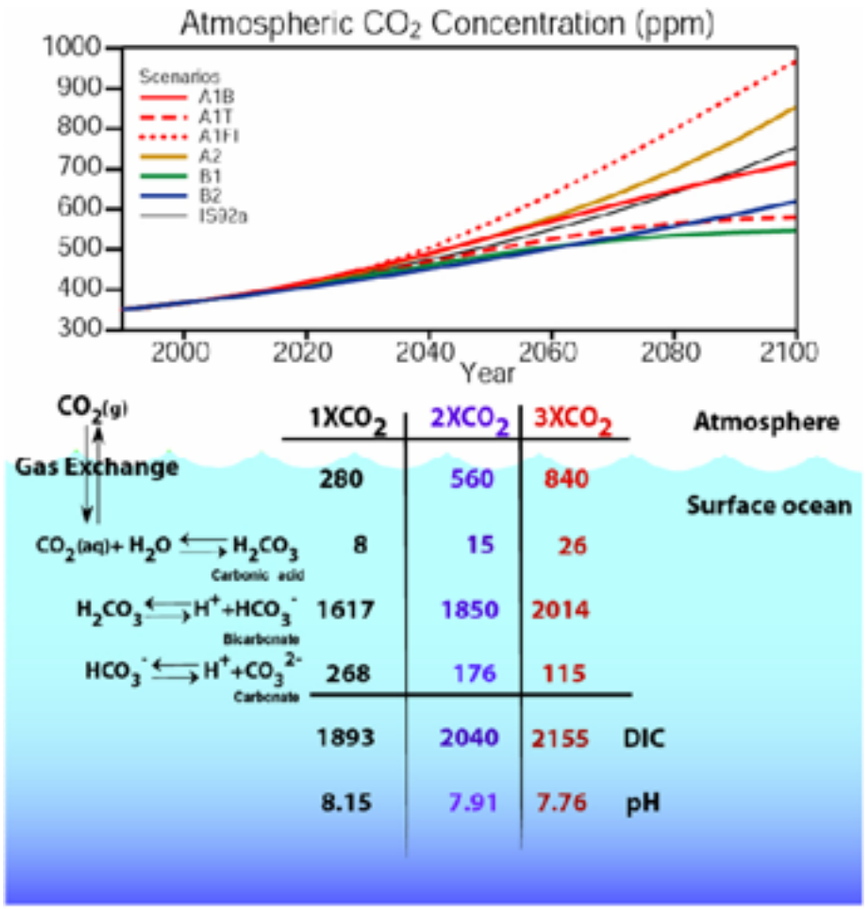
K: equilibrium constants for partitioning

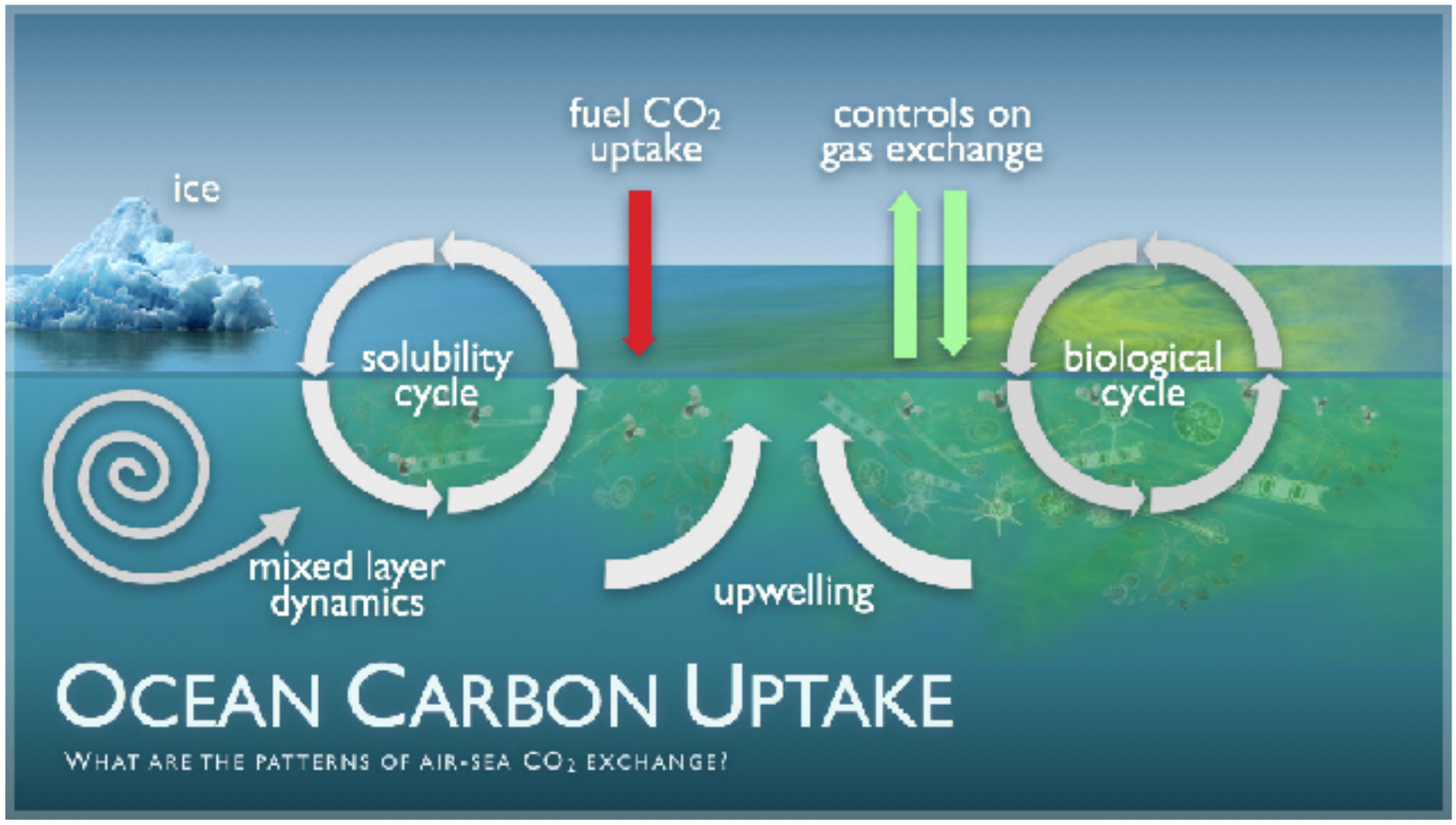
Net uptake:

$CO_2(g) + CO_3^{2-} \rightleftharpoons 2HCO_3$



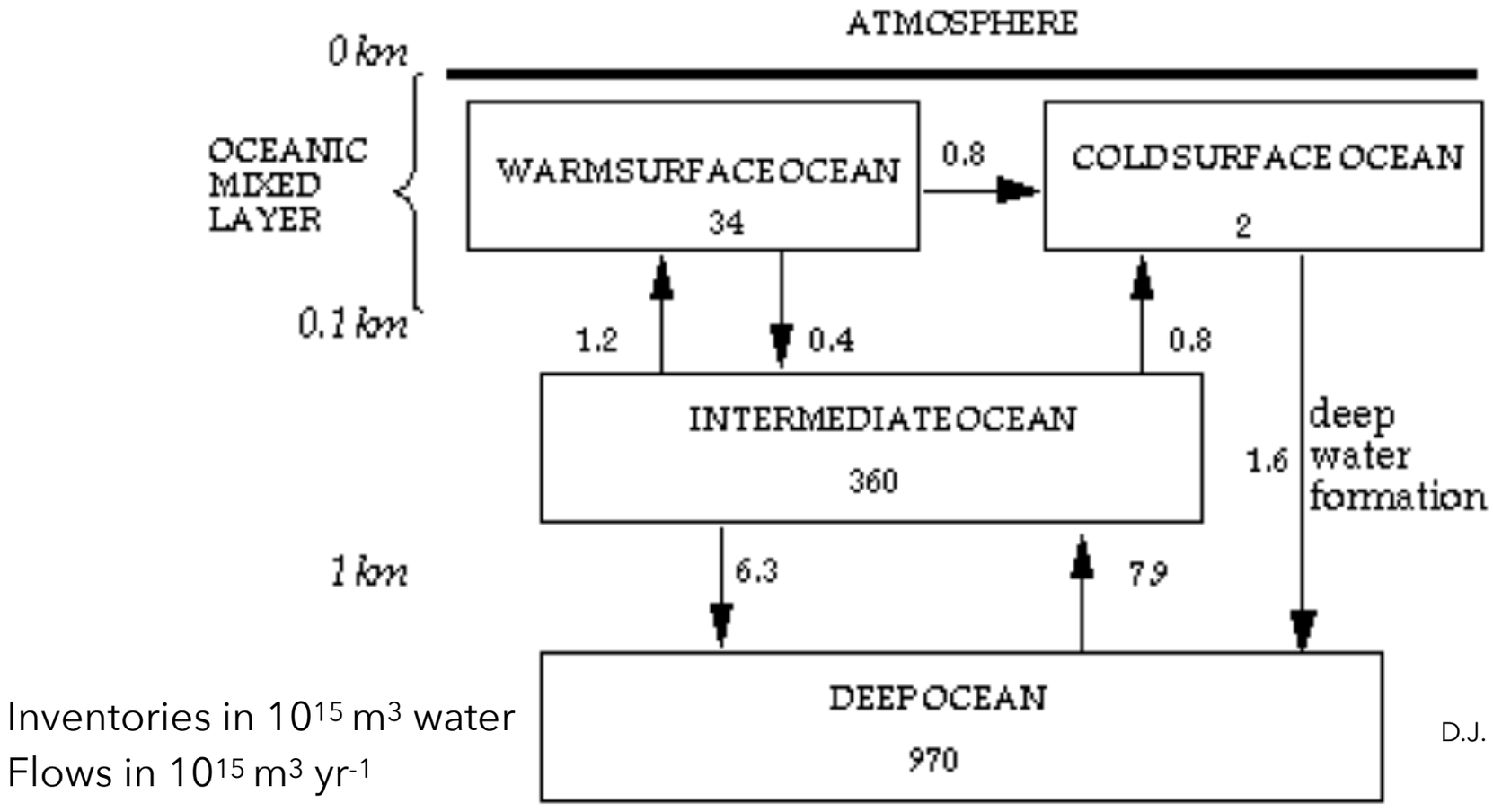
CO_2 ocean uptake - it's more than chemistry





Limits for ocean uptake

slow ocean turnover time (~200 years)



Inventories in 10^{15} m^3 water
Flows in 10^{15} m^3 yr^{-1}

D.J. Jacob

Uptake by oceanic mixed layer only (V_{OC}= 3.6×10^{16} m^3)
would give f = 0.94 (94% of added CO_2 remains in atmosphere)

Uptake by the terrestrial biosphere

(1.4 Pg C yr^{-1} in the 1990s; IPCC [2001])
is a small residual of large atmosphere-biosphere exchange

- Gross primary production (GPP):
  GPP = CO_2 uptake by photosynthesis = 120 Pg C yr^{-1}

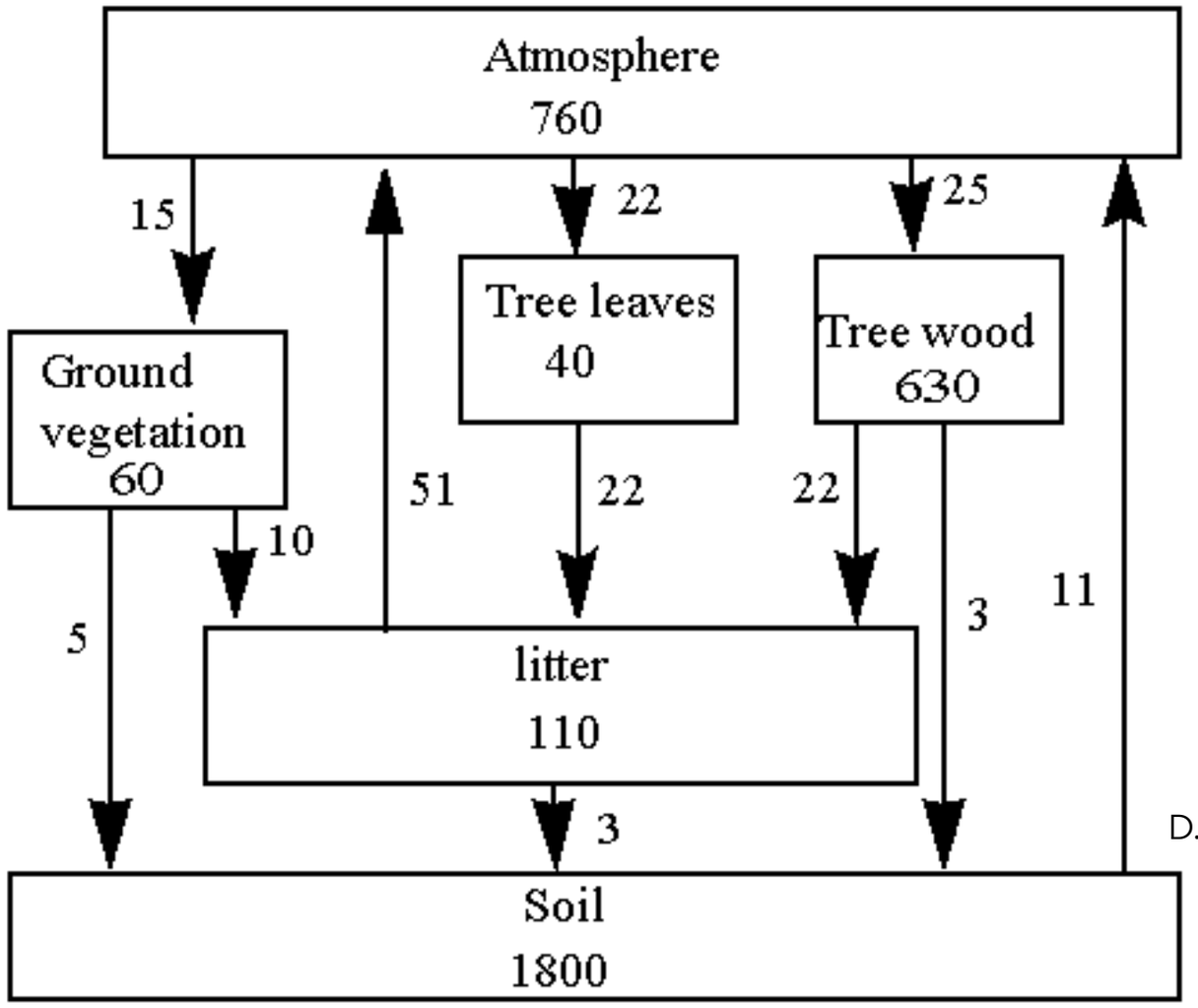
- Net primary production (NPP):
  NPP = GPP – "autotrophic" respiration by green plants = 60 Pg C yr^{-1}

- Net ecosystem production (NEP):
  NEP = NPP – "heterotrophic" respiration by decomposers = 10 Pg C yr^{-1}

- Net biome production (NBP)
  NBP = NEP – fires/erosion/harvesting = 1.4 Pg C yr^{-1}

Atmospheric CO_2 observations show that the net uptake is at northern midlatitudes but cannot resolve American vs. Eurasian contributions

Box model of carbon cycling with terrestrial biosphere



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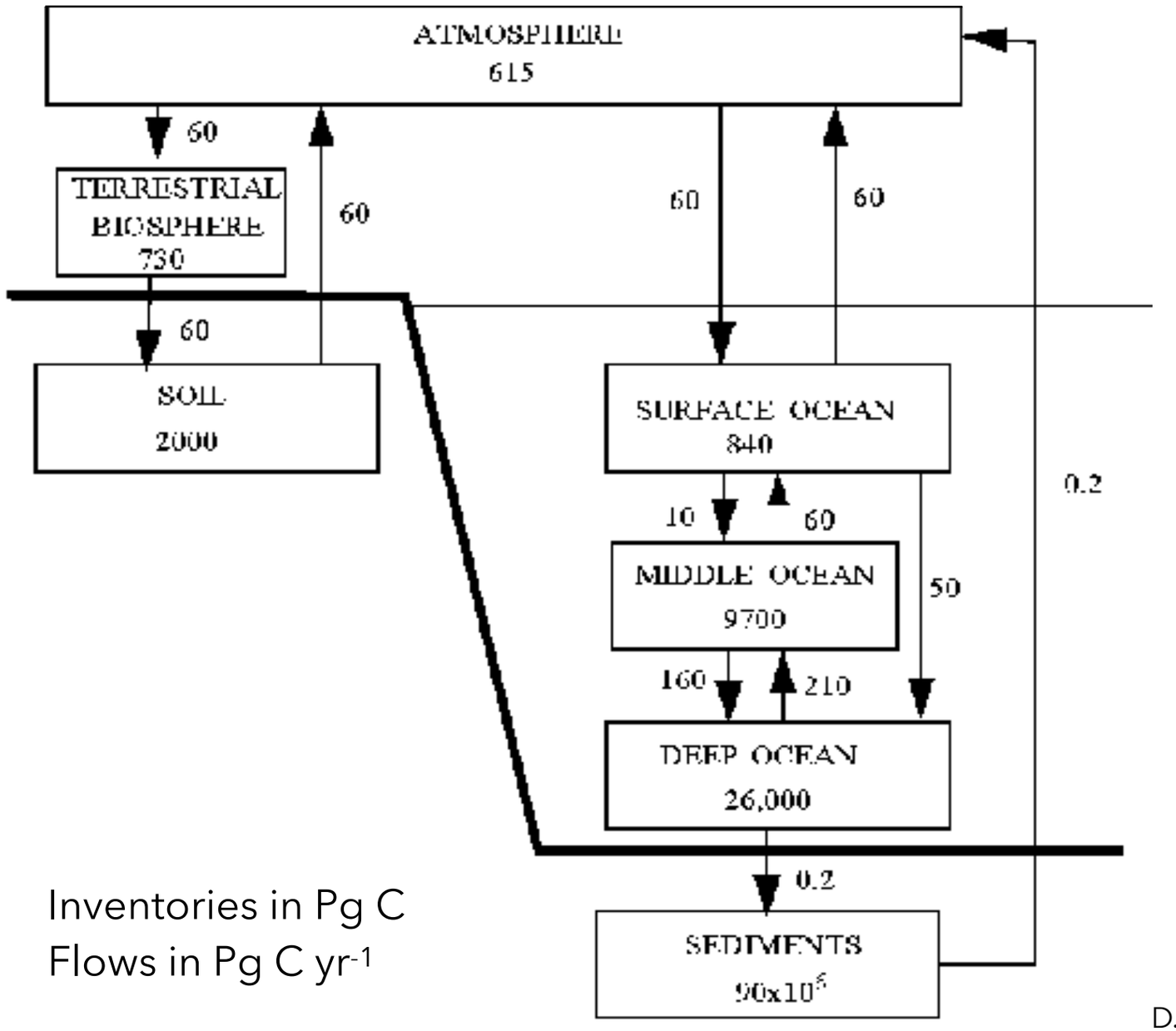
Inventories in Pg C
Flows in Pg C yr^{-1}

Time scales are short → net uptake from reforestation is transitory

Box model of the pre-industrial global carbon cycle



Inventories in Pg C
Flows in Pg C yr^{-1}

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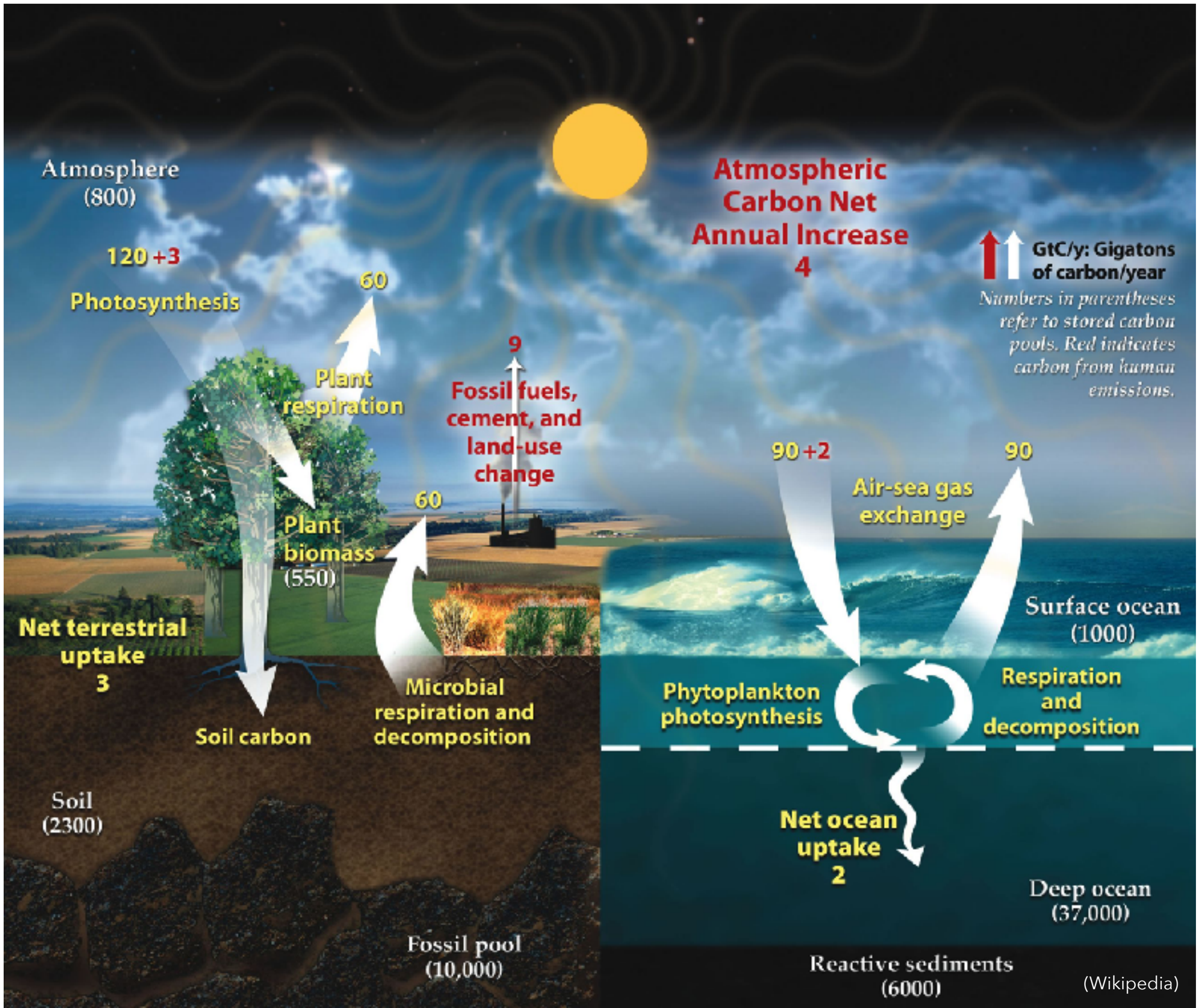
Carbon cycle incl. human activity



(Wikipedia)

Lecture