

CM 615

Climate change Impacts & Adaptation

Emission scenarios for future climate change

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~~Class exercise~~



- A small blackbody satellite is orbiting the Earth at a distance far enough away so that the flux density of Earth radiation is negligible, compared to that of solar radiation. Suppose that the satellite suddenly passes into the Earth's shadow. At what rate will it initially cool? The satellite has a mass $m=1000$ kg and a specific heat $c = 10^3$ J / (kg K), it is spherical with a radius $r = 1$ m, and temperature is uniform over its surface.

~~Class exercise~~

- Methane (CH₄) has a radiative efficiency of $0.036 \text{ Wm}^{-2} \text{ ppm}^{-1}$, while CO₂ has a radiative efficiency of $0.0014 \text{ Wm}^{-2} \text{ ppm}^{-1}$. The atmospheric lifetime of CH₄ is 12 years, while CO₂ follows a more complex decay function but is assumed to have an effective adjustment time of 100 years.
- 1.Calculate the 100-year Global Warming Potential (GWP100) for methane (CH₄), given that its integrated abundance over 100 years is 12.4 ppm-years and the corresponding value for carbon dioxide (CO₂) is 37.1 ppm-years.
 - 2.Calculate the 20-year GWP (GWP20) for methane. The integrated abundance of CH₄ over 20 years is 3.75 ppm-years while for CO₂ 0.9 ppm-years. Explain what this difference in GWP20 compared to GWP100 indicates about gases that don't stay in the atmosphere for long.

~~Class exercise~~

- A new synthetic greenhouse gas, XX, has a radiative efficiency of $0.02 \text{ Wm}^{-2} \text{ ppm}^{-1}$ and an atmospheric lifetime of 25 years, a decay function similar to CH_4 .
- Given that the temperature response function at 100 years for XX is half that of CO_2 , and assuming CO_2 's AGTP₁₀₀ is 1.1 K per unit emission:
 - Estimate the GTP100 of XX.
 - Compare it to CO₂ and CH₄. Would it be considered a priority for climate mitigation?
 - How does its lifetime influence whether GWP or GTP is a better metric for this gas?

Quiz 1
+
Lecture 12
13 Feb 2025

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Biogeochemical cycles

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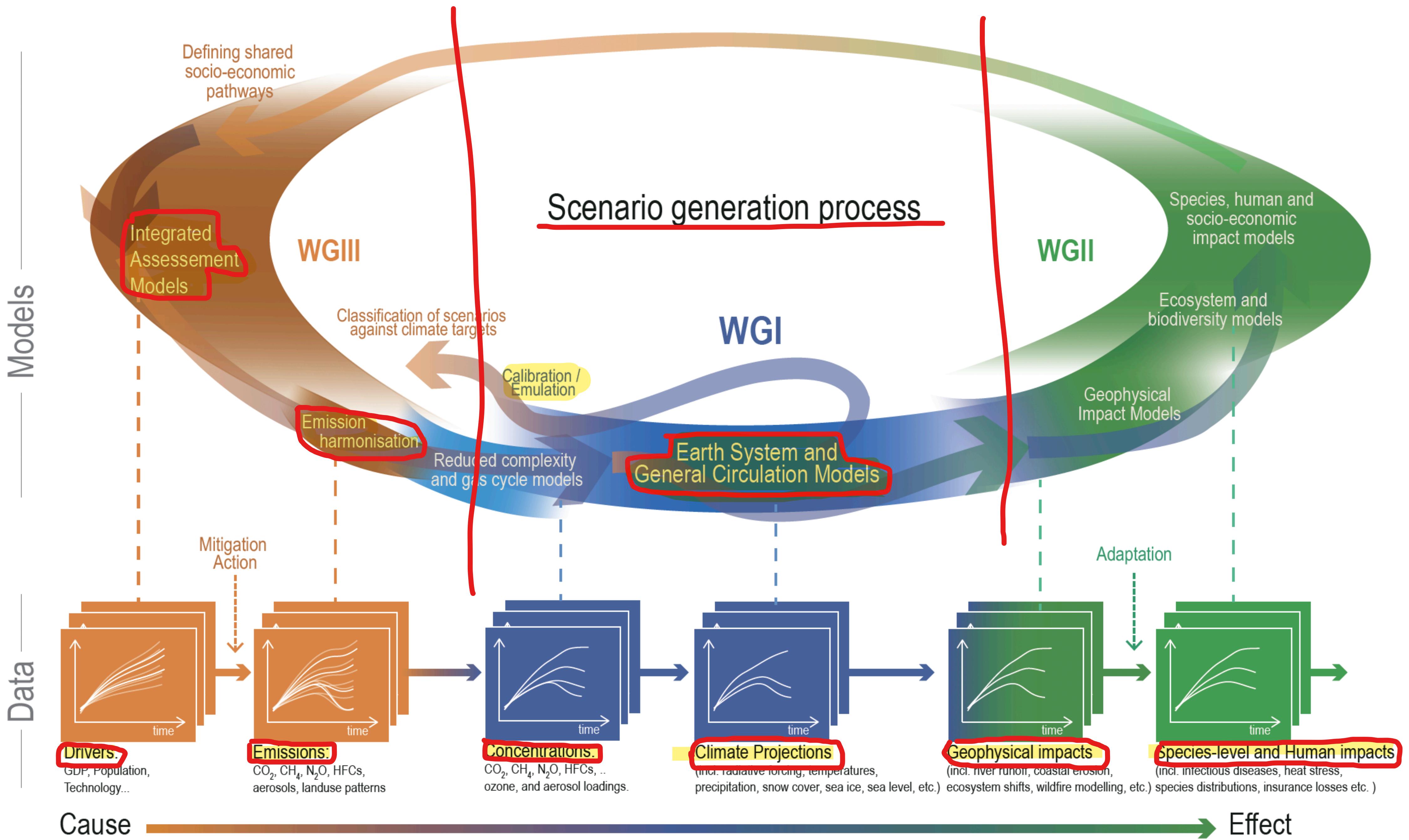
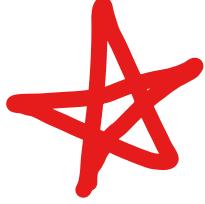
Paris agreement 2015

The **overarching** goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”

2015	COP 21	CMP 11	Paris	France	?
2016	COP 22	CMP 12 / CMA 1	Marrakech	Morocco	?
2017	COP 23	CMP 13 / CMA 1-2	Bonn	Germany	?
2018	COP 24	CMP 14 / CMA 1-3	Katowice	Poland	?
2019	SB50		Bonn	Germany	?
2019	COP 25	CMP 15 / CMA 2	Madrid	Spain	?
2021	COP 26	CMP 16 / CMA 3	Glasgow	United Kingdom	?
2022	COP 27	CMP 17 / CMA 4	Sharm El Sheikh	Egypt	?
2023	COP 28	CMP 18 / CMA 5	Dubai	United Arab Emirates	?
2024	COP 29	CMP 19 / CMA 6	Baku	Azerbaijan	?

What are SSP scenarios?

Scenario Acronym	Description
'SSPX' with X standing for the Shared Socio-economic Pathway family (1–5)	The Shared Socio-economic Pathway family, i.e., the socio-economic developments with storylines regarding (among other things) GDP, population, urbanization, economic collaboration, and human and technological development projections that describe different future worlds in the absence of climate change and additional climate policy (O'Neill et al., 2014). The quantification of energy, land use and emissions implications in those storylines is not part of the SSPX narratives, but follows in a second step in which their climate outcomes are defined. This second step is dependent upon the integrated assessment model (IAM) that is used for this quantification (see SSPX-Y below; Riahi et al., 2017).

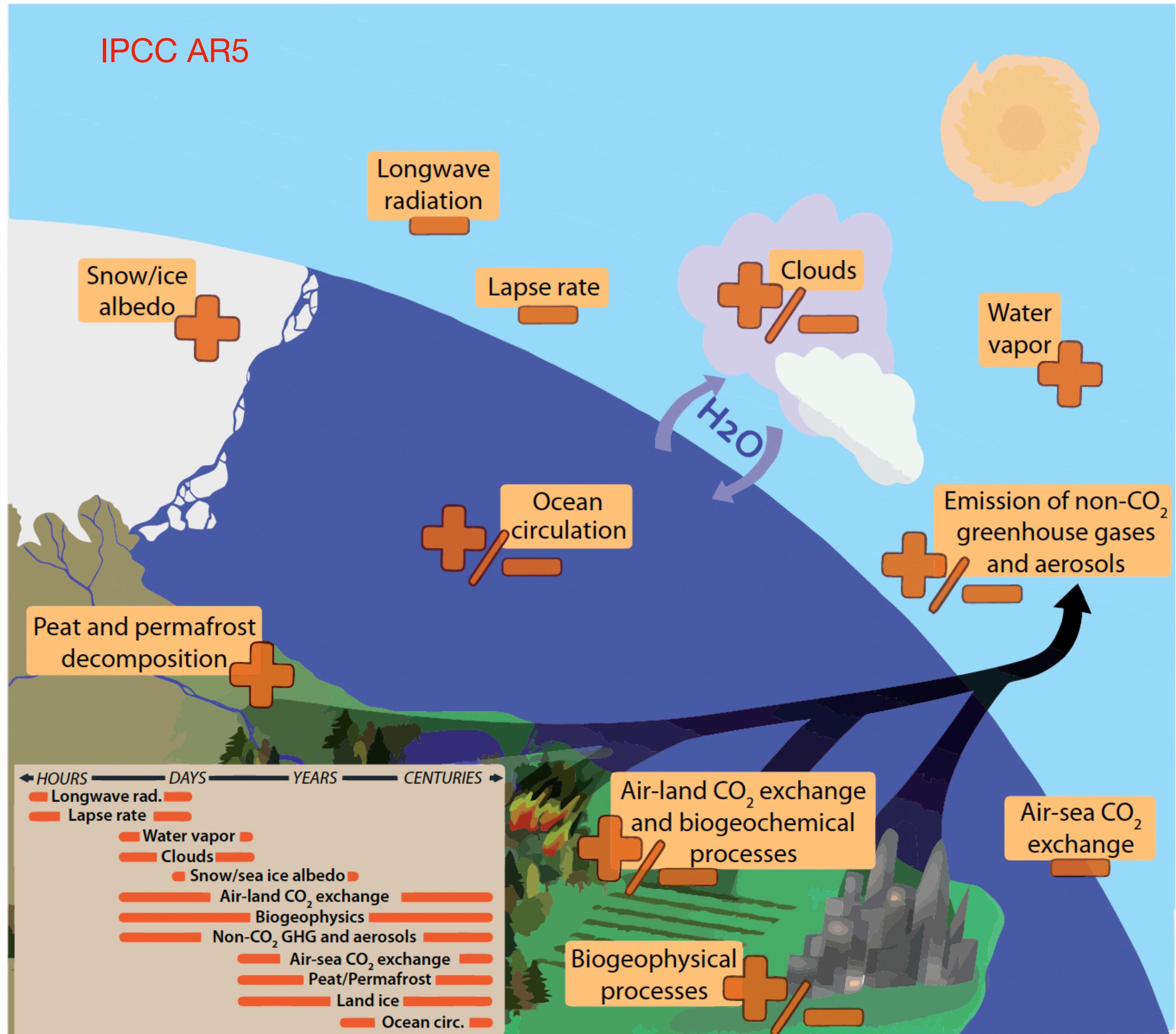


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Biogeochemical cycles

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- Climate feedbacks & associated timescales
- What are feedbacks other than radiative feedbacks?
- Biogeochemical feedbacks are feedbacks that involve interactions between climate, biological activity and the biogeochemical cycles on Earth
- **Biogeophysical feedbacks** are feedbacks that involve interactions between climate and some physical characteristics of the surface that are influenced by biological activity
- What is the magnitude of Biogeophysical and non-CO₂ biogeochemical feedback?

Figure 1.2 | Climate feedbacks and timescales. The climate feedbacks related to increasing CO₂ and rising temperature include negative feedbacks (-) such as LWR, lapse rate (see Glossary in Annex III), and air-sea carbon exchange and positive feedbacks (+) such as water vapour and snow/ice albedo feedbacks. Some feedbacks may be positive or negative (\pm): clouds, ocean circulation changes, air-land CO₂ exchange, and emissions of non-GHGs and aerosols from natural systems. In the smaller box, the large difference in timescales for the various feedbacks is highlighted.

Assessment of Climate Feedbacks

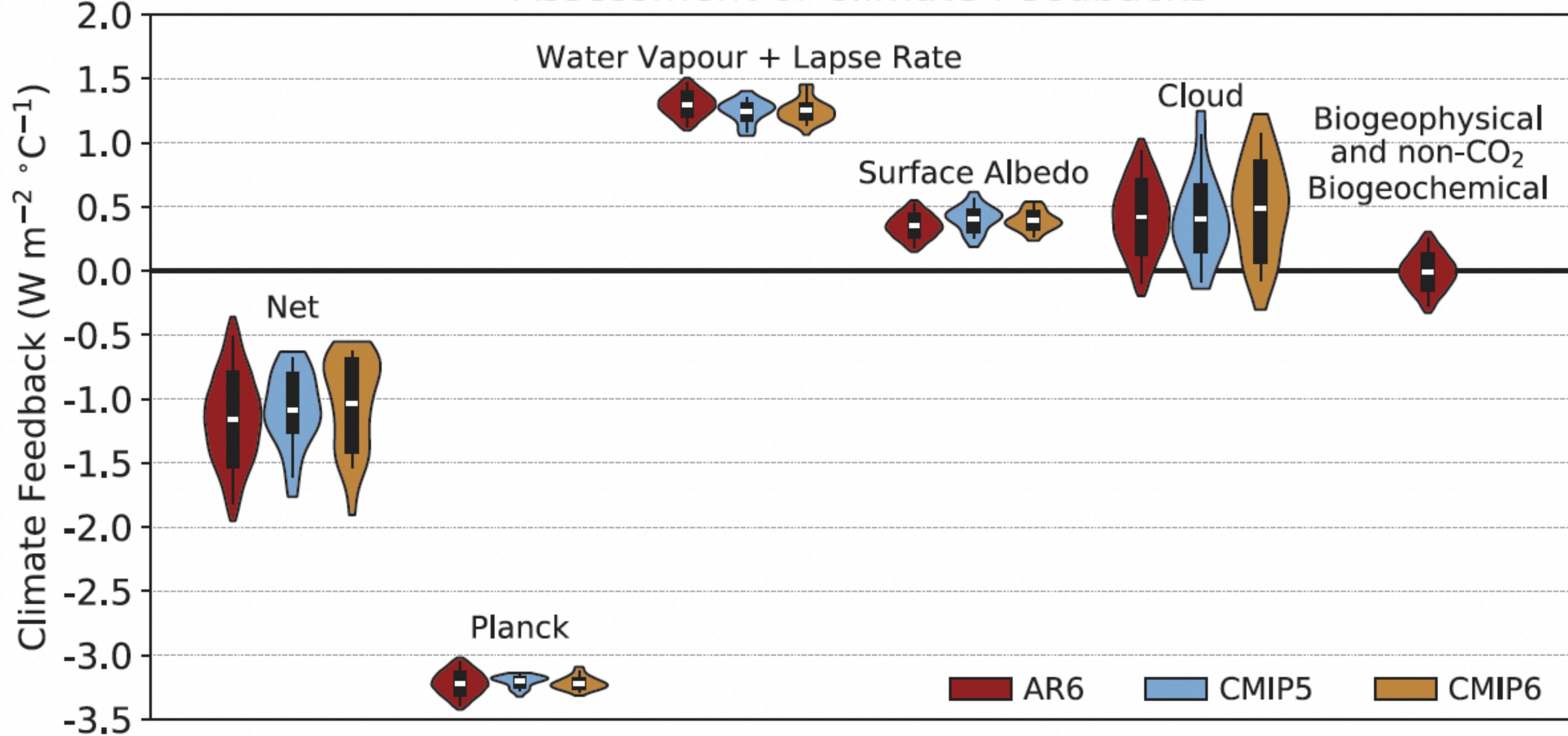


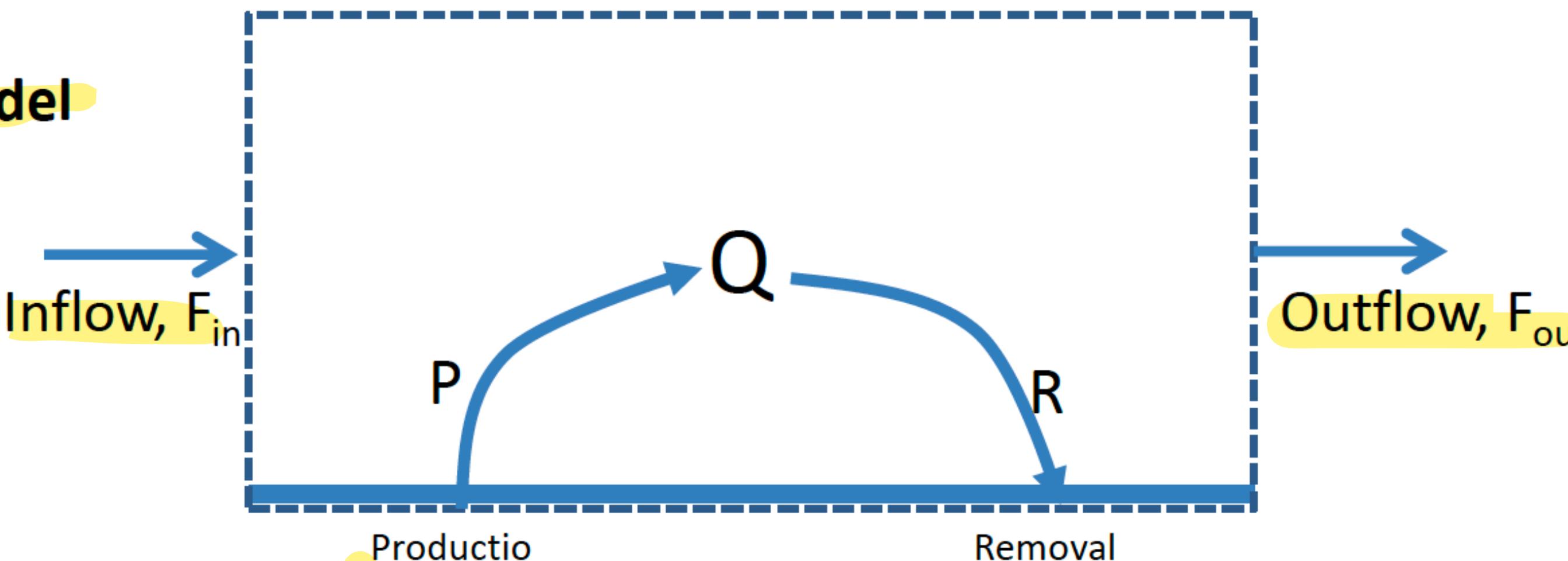
Figure 7.10 | Global mean climate feedbacks estimated in *abrupt4xCO₂* simulations of 29 CMIP5 models (light blue) and 49 CMIP6 models (orange), compared with those assessed in this Report (red). Individual feedbacks for CMIP models are averaged across six radiative kernels as computed in Zelinka et al. (2020).

Biogeochemical cycles

- Biogeochemical cycles are processes which control the complex flows and transformations of the elements between the different components of the Earth System (i. atmosphere, ii. ocean, iii. biosphere, iv. lithosphere) by biotic and abiotic processes.
- Since most of these processes are themselves also dependent on the prevailing environment, changes in climate and human impacts on ecosystems (e.g., land use and land use change), influence biogeochemical cycles.
- Biogeochemical cycles thus constitute feedbacks in the Earth System.
- Reservoirs: atmosphere, ocean, surface ocean sediments, terrestrial vegetation, soils and freshwaters
- For specifying a biogeochemical cycle, we need to estimate:
 - the “pool size” or total amount of a species present in various reservoirs.
 - exchange rates of fluxes between or among reservoirs
 - thus, the “turnover time” for specific exchange processes

Atmospheric lifetime

One-Box Model



Mass Balance Equation:

$$\frac{dQ}{dt} = \sum \text{sources} - \sum \text{sinks} = (F_{in} - F_{out}) + (P - R)$$

Q is mass in the reservoir, Production (P) includes emissions, chemical production etc and Removal (R) includes processes such as deposition ,chemical loss etc.

At steady state:

$$\frac{dQ}{dt} = 0$$

$$\sum \text{sources} = \sum \text{sinks}$$

$$F_{in} + P = F_{out} + R$$

For entire atmosphere taken as reservoir:

$$F_{in} = 0 \text{ and } F_{out} = 0$$

Atmospheric Lifetime:

$$\tau = \frac{Q}{R} = \frac{Q}{P}$$

For non-equilibrium and considering,

$$F_{in} = 0 \text{ and } F_{out} = 0$$

$$\frac{dQ}{dt} = P - \frac{Q}{\tau}$$

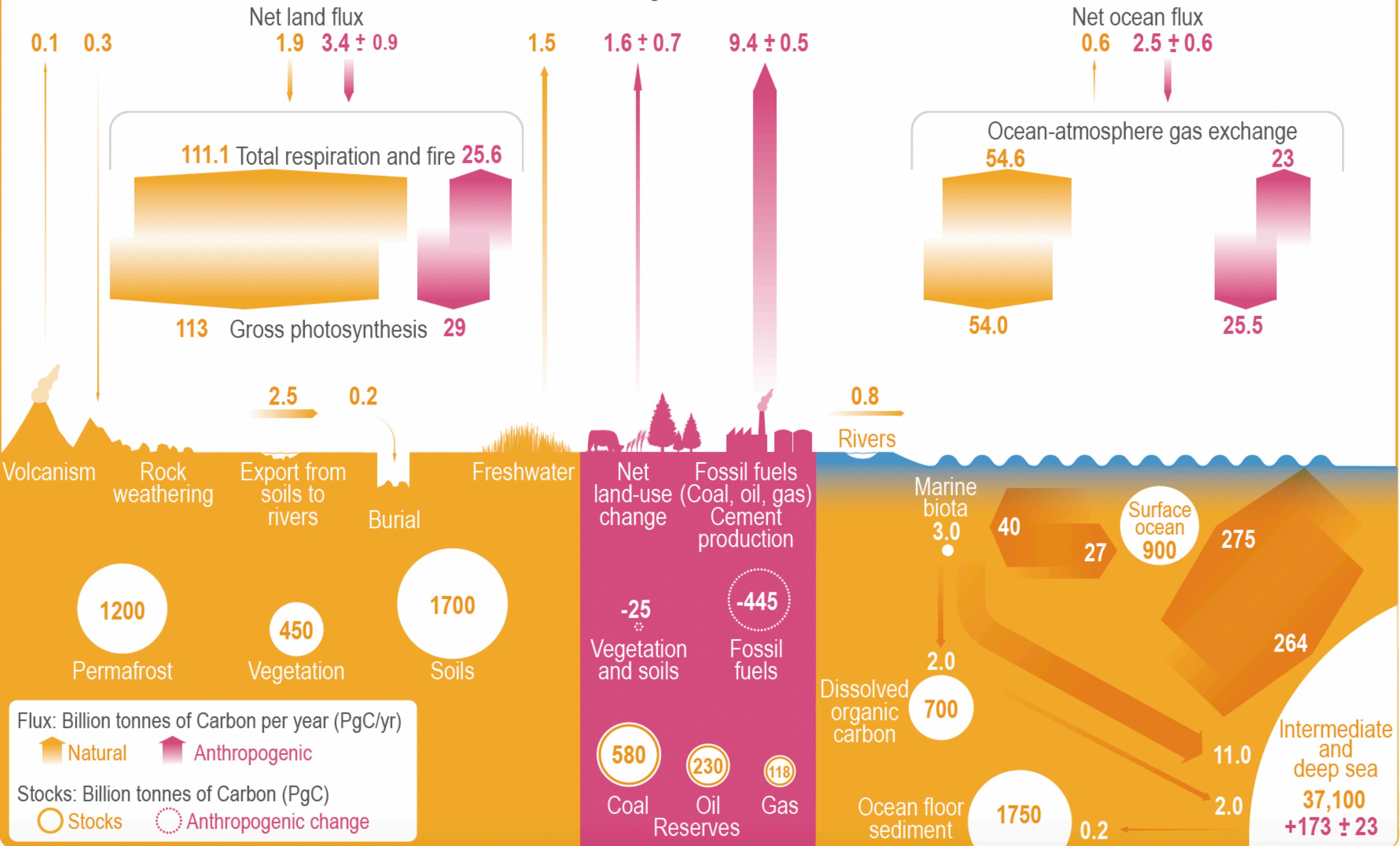
a first-order differential equation that describes how the amount of the species changes over time due to production and removal processes.

Carbon (CO₂) Budget

Atmosphere
591 + 279 ± 5



Average increase 5.1 ± 0.02



Carbon cycle: Pools & Fluxes

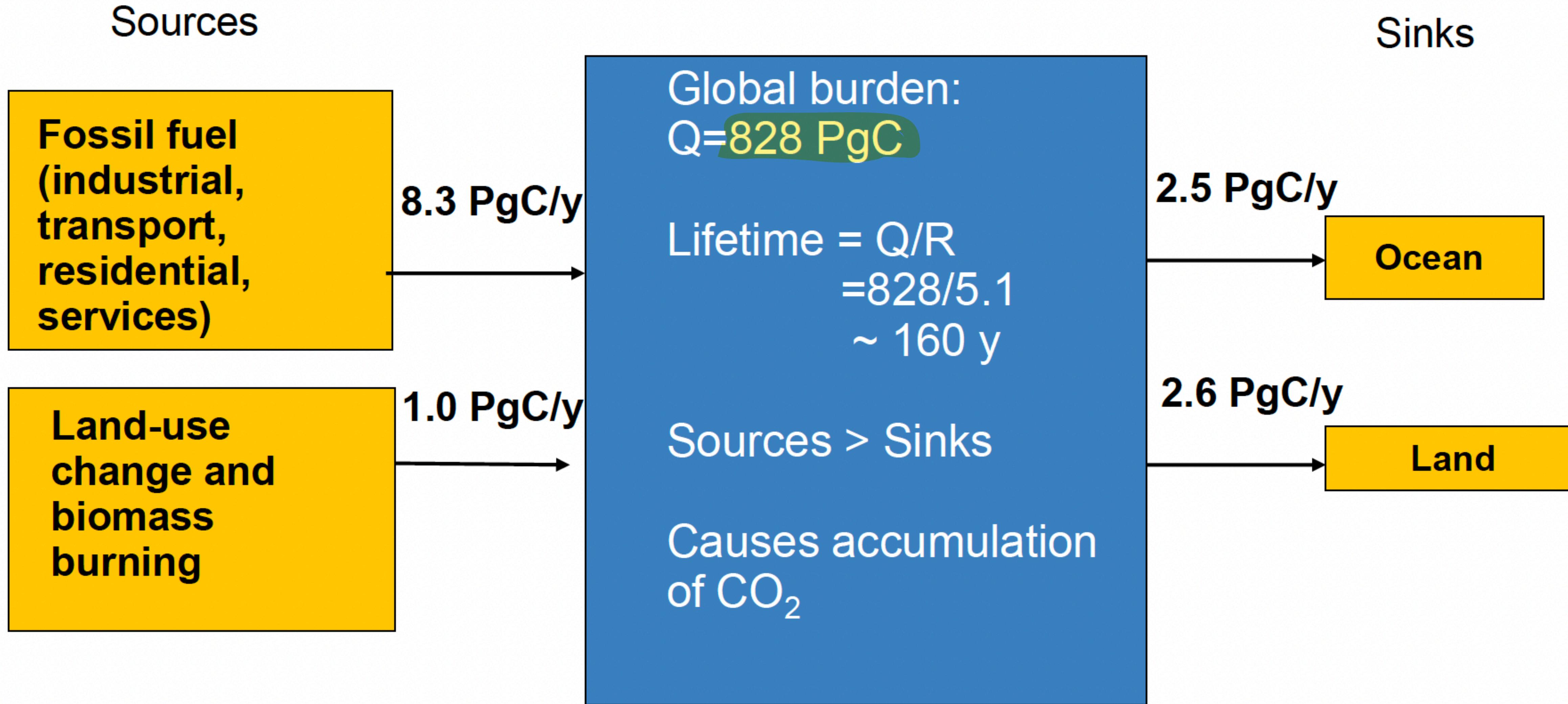
IPCC AR6

Figure 5.12 | Global carbon (CO₂) budget (2010–2019).

Deep Ocean cycling: 3 mechanisms

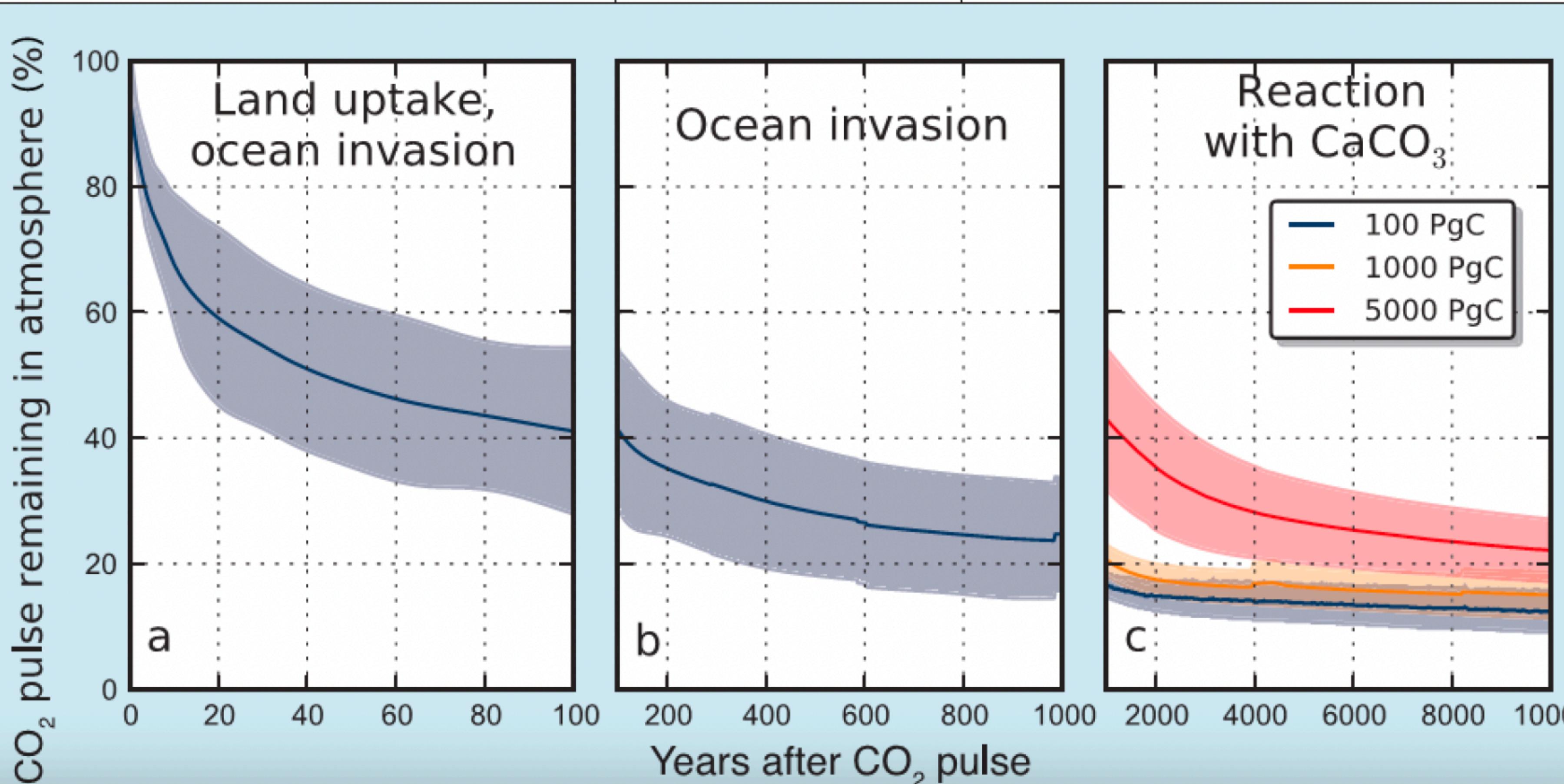
- Solubility pump (CO₂.H₂O, HCO₃ and CO₃)
- Biological pump (ocean plankton)
- Marine carbonate pump (formation of calcareous shells of certain oceanic microorganisms in the surface ocean)

CO₂ sources, sinks, lifetime



Multiple residence times for excess CO₂

Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	1–10 ²	$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{photons} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{heat}$
Ocean invasion: Seawater buffer	10–10 ³	$\text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \rightleftharpoons 2\text{HCO}_3^-$
Reaction with calcium carbonate	10 ³ –10 ⁴	$\text{CO}_2 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-$
Silicate weathering	10 ⁴ –10 ⁶	$\text{CO}_2 + \text{CaSiO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2$



These processes are active on all time scales, but the relative importance of their role in the CO₂ removal is changing with time and depends on the level of emissions.

Accordingly, the times of atmospheric CO₂ adjustment to anthropogenic carbon emissions can be divided into three phases associated with increasingly longer time scales.

Methane: Pools & Fluxes

Methane (CH_4) Budget

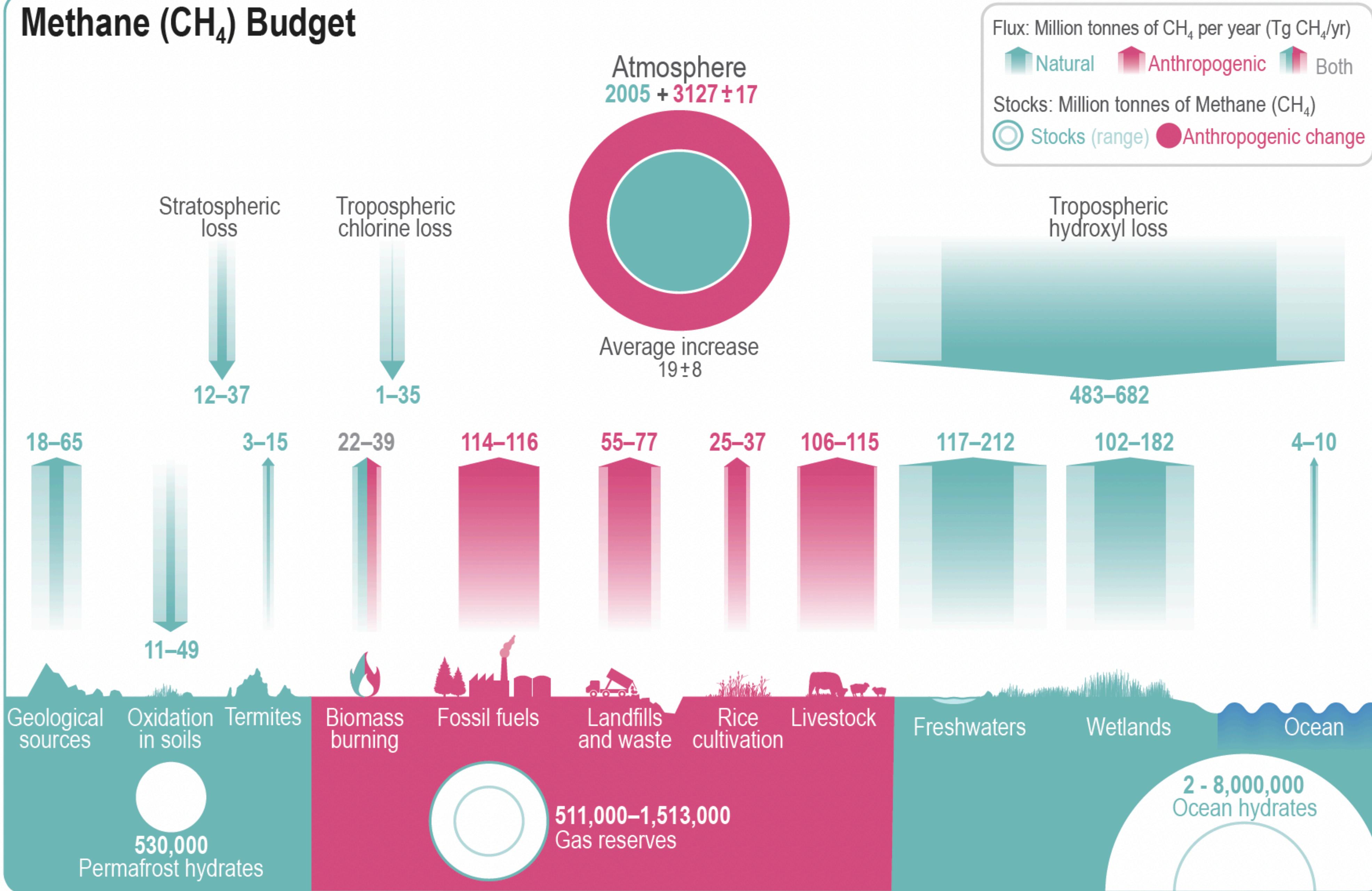
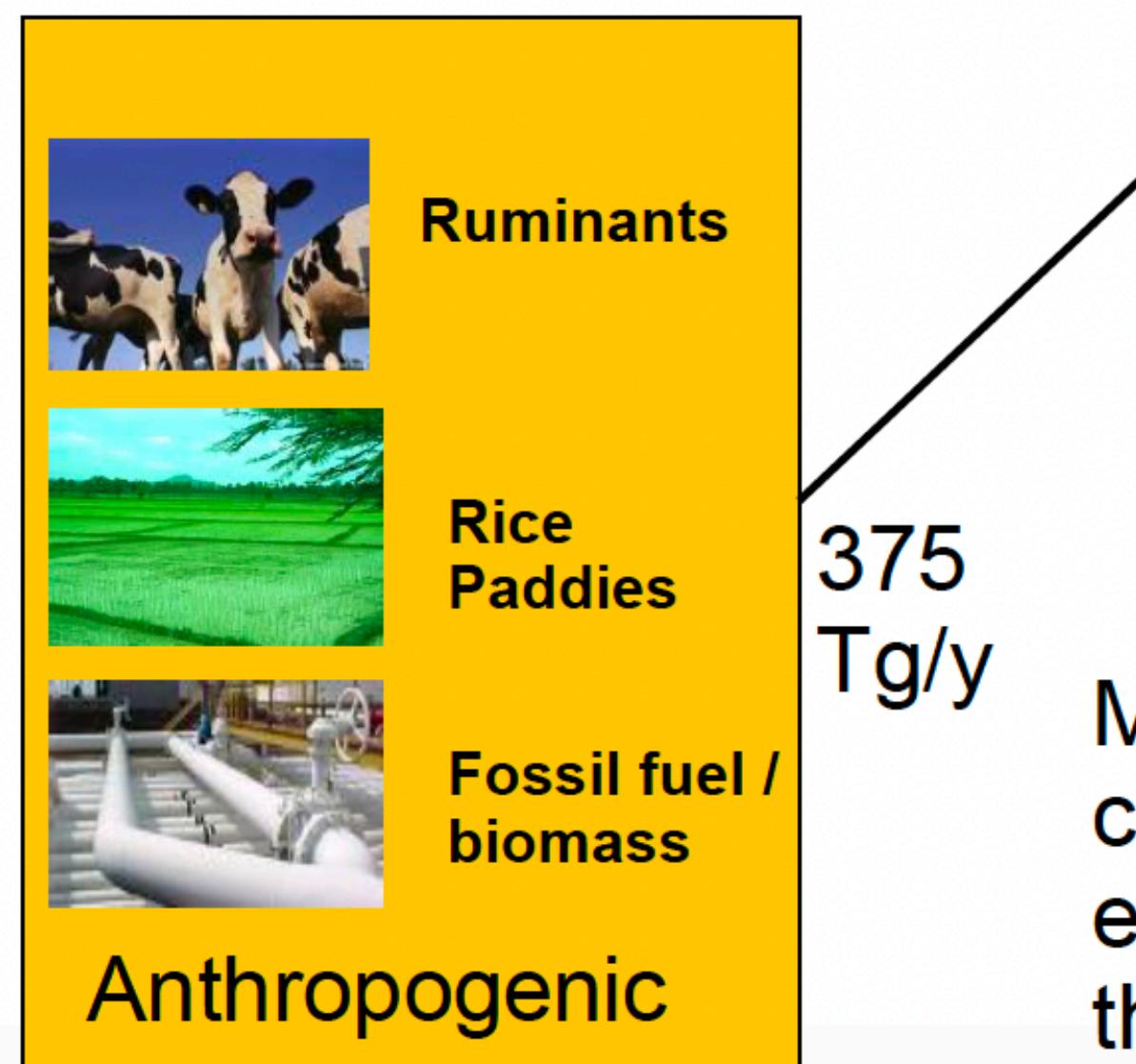
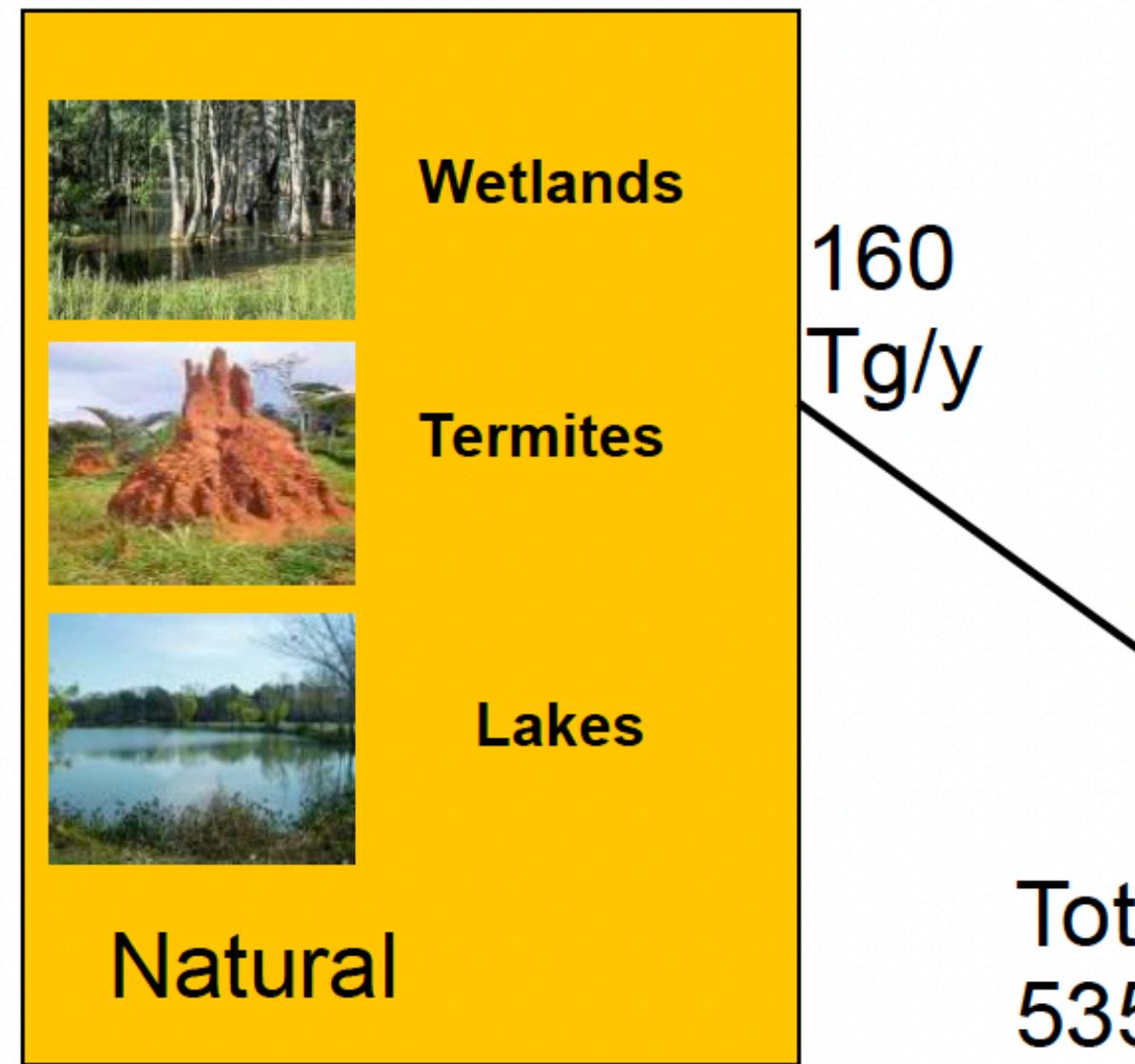


Figure 5.14 |
Global
methane
(CH_4) budget
(2008–2017).

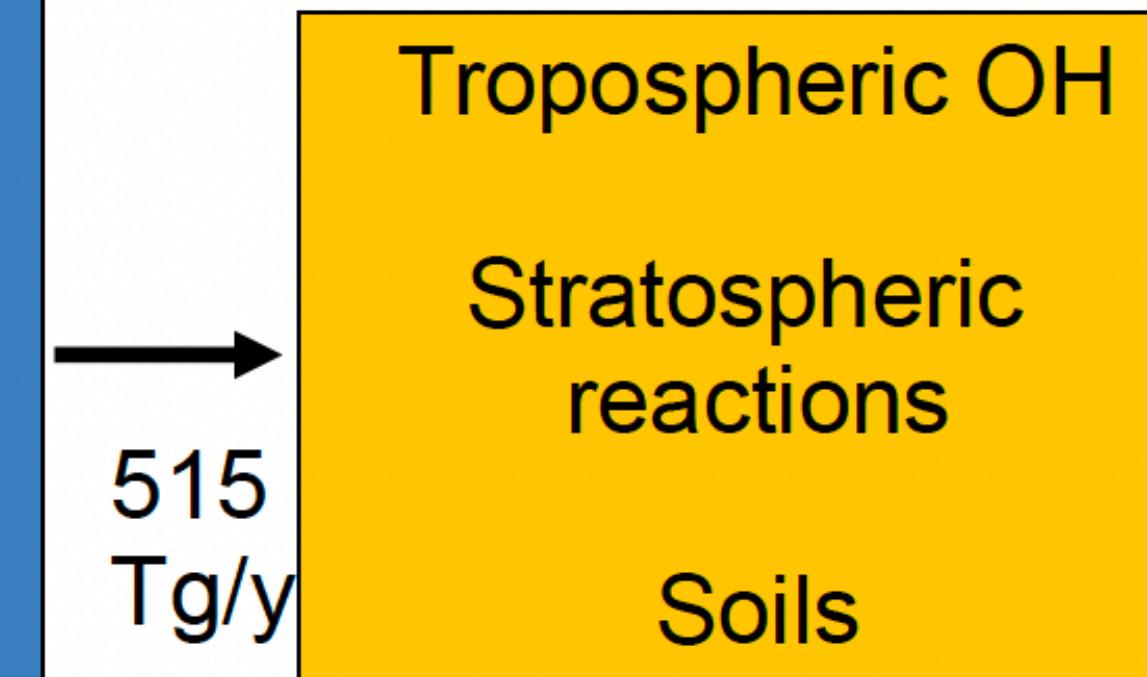
CH₄ sources, sinks, lifetime

Sources



Global burden: Q= 4850 Tg
Lifetime = Q/R
=4850/515
~ 9 y
Emissions > Sinks

Sinks



Methane sinks: reaction with OH radical, affected by CO concentration, which is a product of CH₄ oxidation, and emitted from fossil fuel & biomass burning. CH₄ can affect the total amount of ozone, which affects OH.