Lecture 11
10 Feb 2025

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 (CH_4) has a radiative efficiency of 0.036 Wm^{-2} ppm^{-1}, while CO_2 has a radiative efficiency of 0.0014 Wm^{-2} ppm^{-1}. The atmospheric lifetime of CH_4 is 12 years, while CO_2 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 (CH_4), given that its integrated abundance over 100 years is 12.4 ppm-years and the corresponding value for carbon dioxide (CO_2) is 37.1 ppm-years.

2. Calculate the 20-year GWP (GWP20) for methane. The integrated abundance of CH_4 over 20 years is 3.75 ppm-years while for CO_2 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 Wm^{-2} 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 $AGTP_{100}$ 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
+
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13 Feb 2025

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Biogeochemical cycles

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Paris agreement 2015

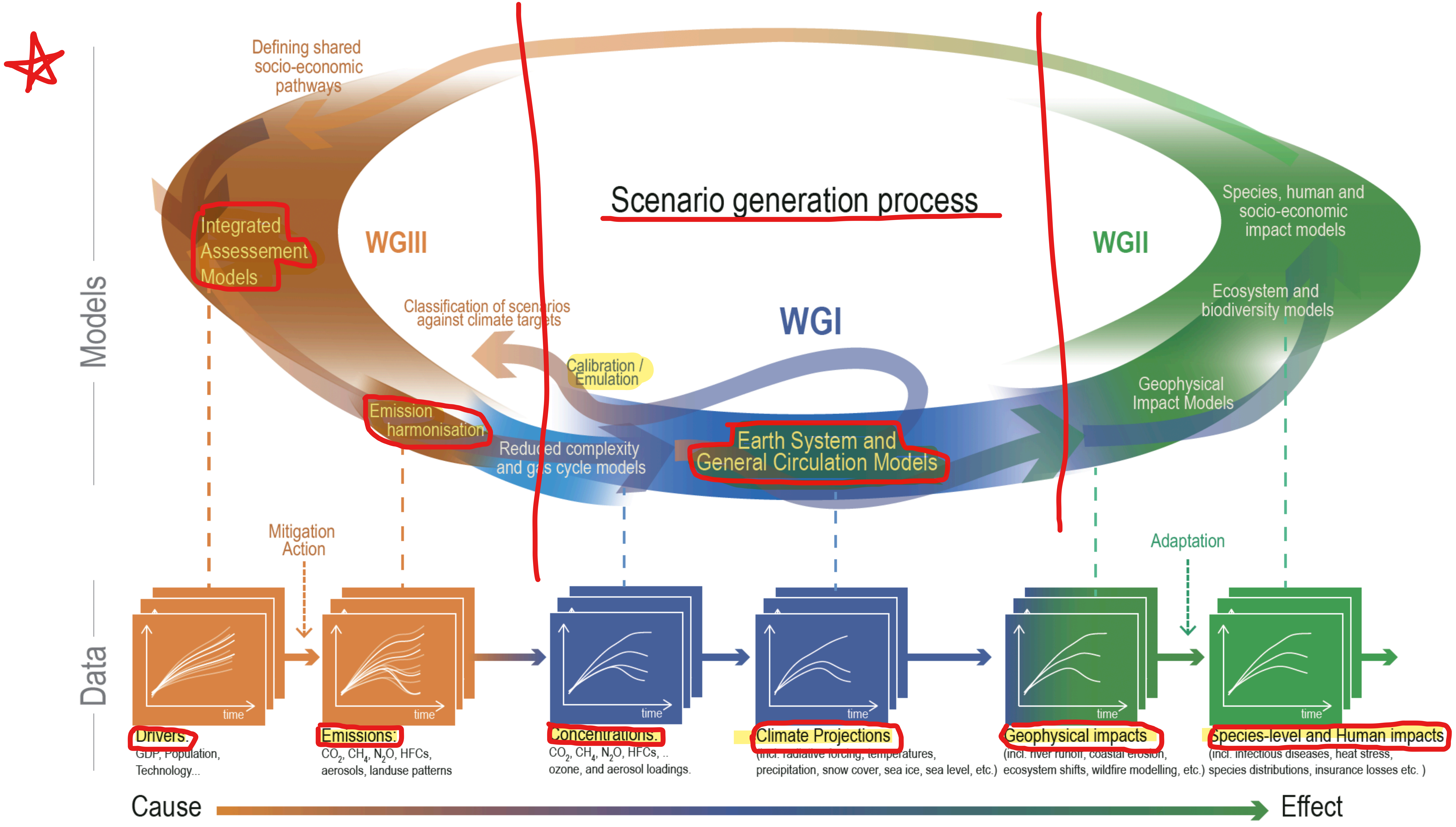
The overarching goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”

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
‘SSPX’ with X standing for the Shared Socio-economic Pathway family (1–5)

Description
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).



Defining shared socio-economic pathways
Integrated Assessment Models
WGIII
Scenario generation process
WGII
Species, human and socio-economic impact models
Ecosystem and biodiversity models
Classification of scenarios against climate targets
WGI
Calibration / Emulation
Geophysical Impact Models
Emission harmonisation
Reduced complexity and gas cycle models
Earth System and General Circulation Models
Models
Mitigation Action
Adaptation
Data
time
Drivers:
GDP, Population, Technology...
Emissions:
CO2, CH4, N2O, HFCs, aerosols, landuse patterns
Concentrations:
CO2, CH4, N2O, HFCs, .. ozone, and aerosol loadings.
Climate Projections
(incl. radiative forcing, temperatures, precipitation, snow cover, sea ice, sea level, etc.)
Geophysical impacts
(incl. river runoff, coastal erosion, ecosystem shifts, wildfire modelling, etc.)
Species-level and Human impacts
(incl. infectious diseases, heat stress, species distributions, insurance losses etc.)
Cause
Effect

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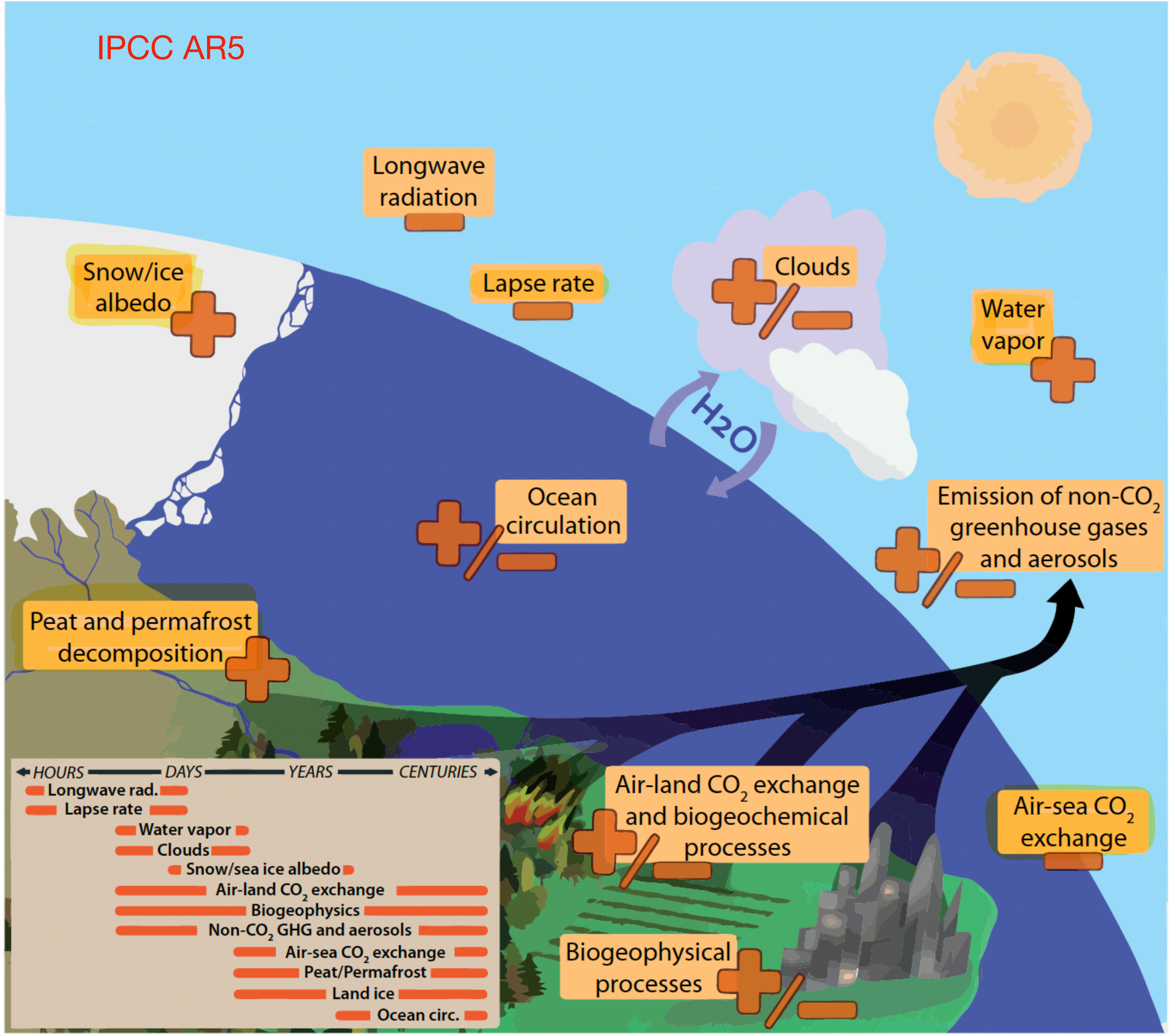


Figure 1.2 | Climate feedbacks and timescales. The climate feedbacks related to increasing CO_2 and rising temperature include negative feedbacks (–) such as LWR, lapse rate (see Glossary in Annex III), and air–sea carbon exchange and positive feedbacks (+) such as water vapour and snow/ice albedo feedbacks. Some feedbacks may be positive or negative (±): clouds, ocean circulation changes, air–land CO_2 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.

- 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?

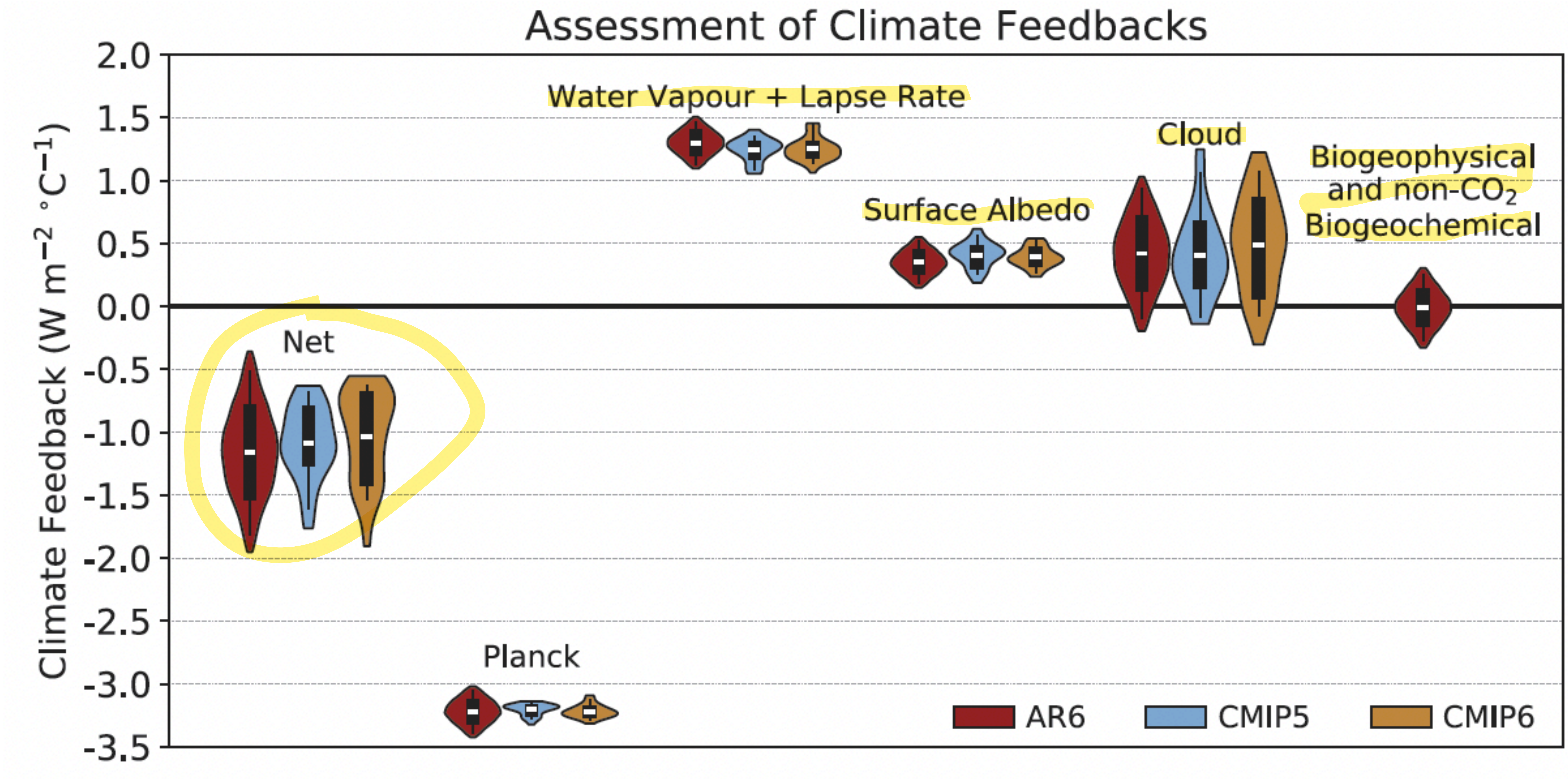


Figure 7.10 | Global mean climate feedbacks estimated in *abrupt4xCO2* simulations of 29 CMIP5 models (light blue) and 49 CMIP6 models (orange), compared with those assessed in this Report (red). Individual feedbacks for CMIP models are averaged across six radiative kernels as computed in Zelinka et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

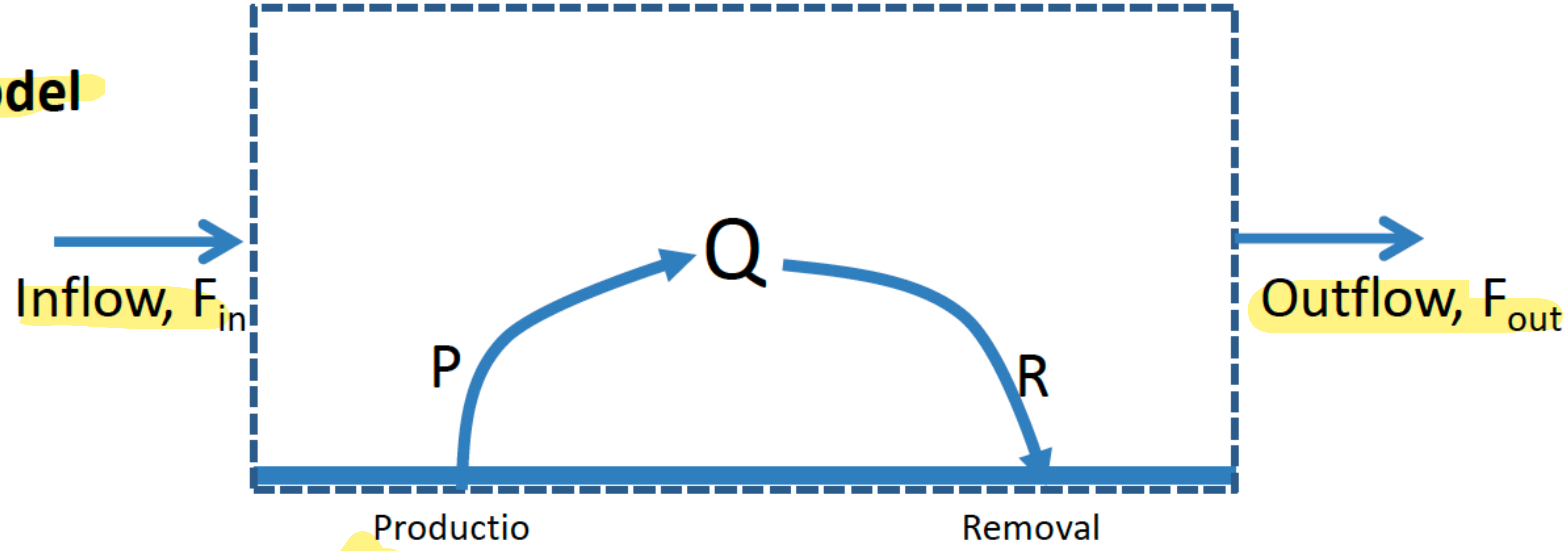
IPCC AR6

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

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

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

For entire atmosphere taken as reservoir: $F_{in} = 0$ and $F_{out} = 0$

Atmospheric Lifetime: $$\tau = \frac{Q}{R} = \frac{Q}{P}$$

For non-equilibrium and considering,

$F_{in} = 0$ 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 cycle: Pools & Fluxes

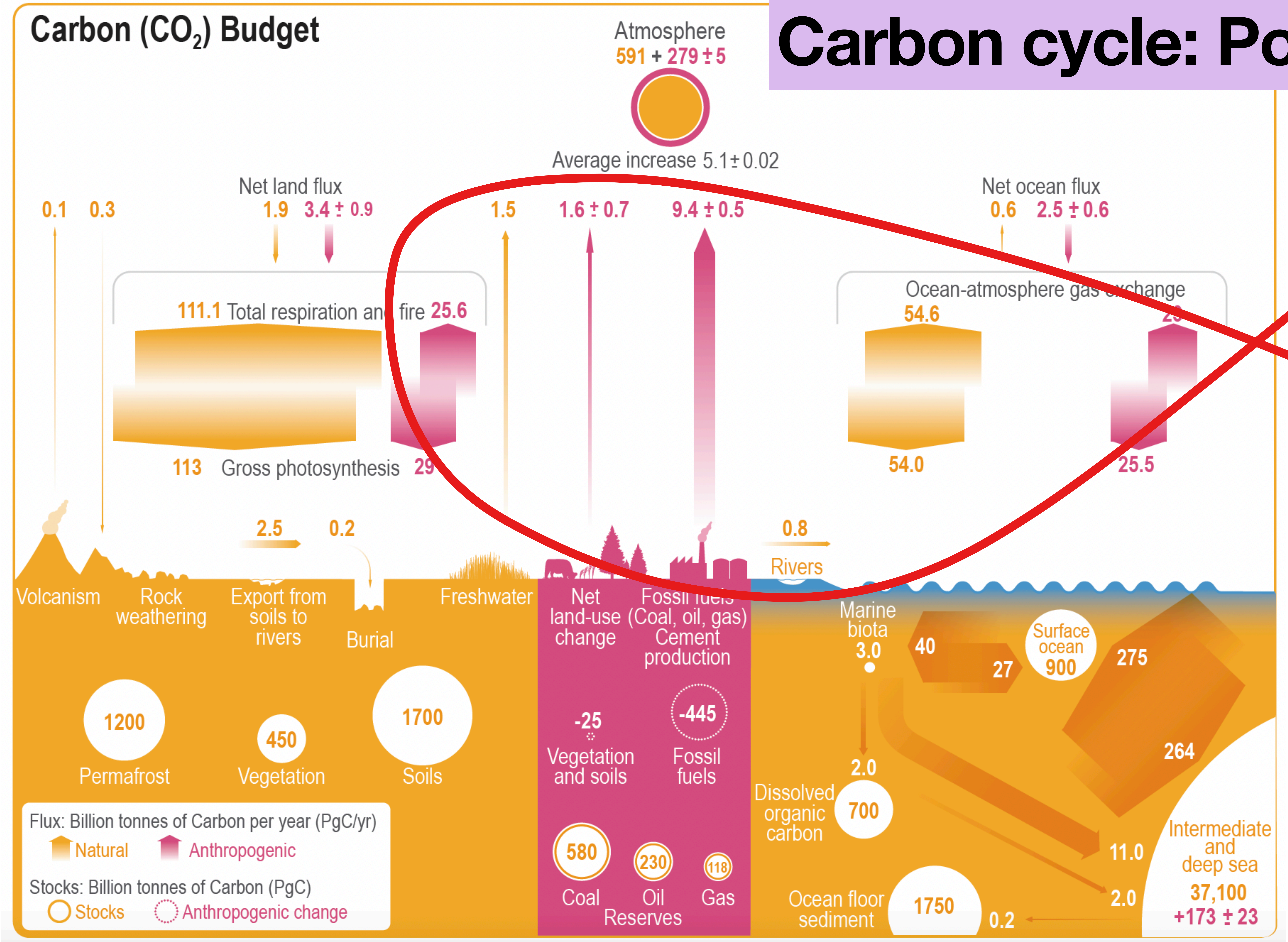


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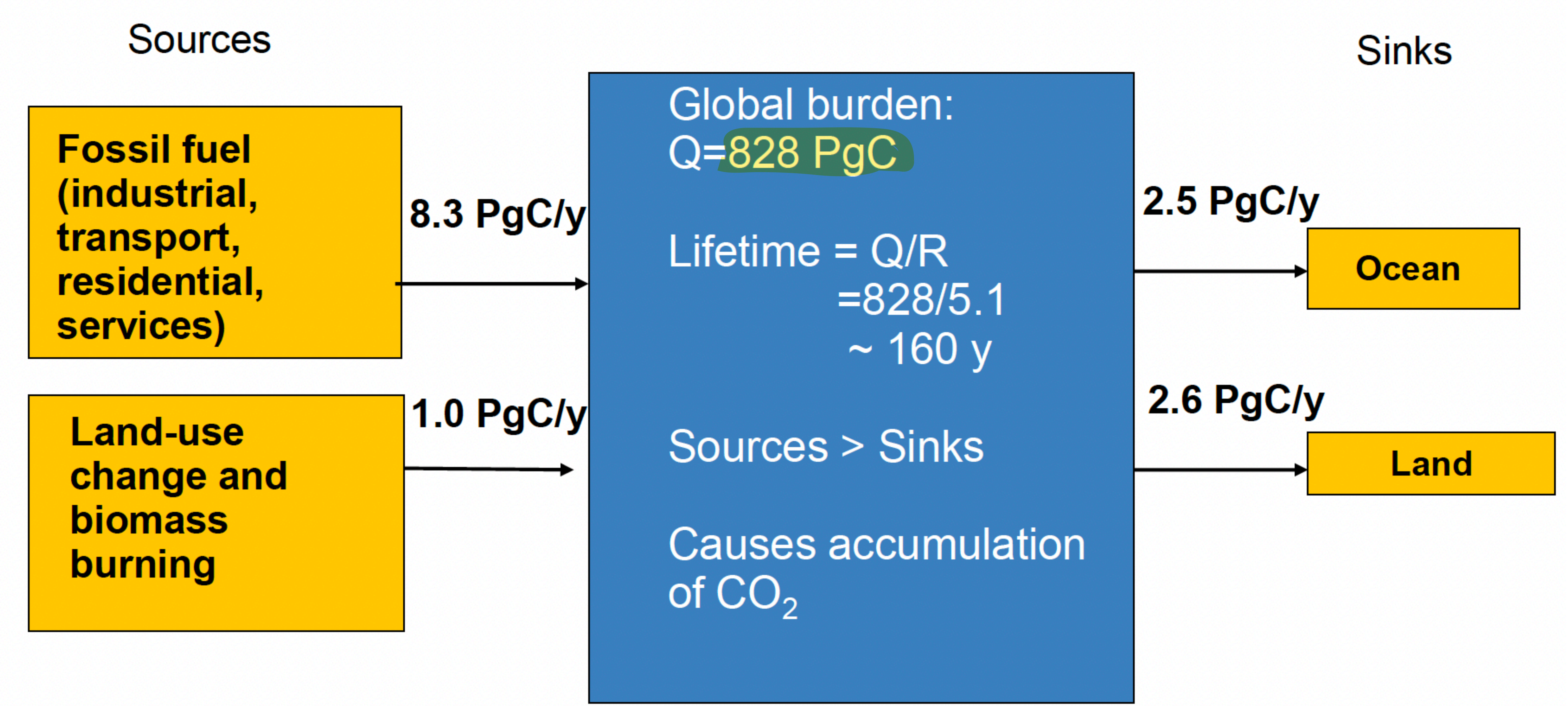
Figure 5.12 I Global carbon (CO2) budget (2010–2019).

Deep Ocean cycling: 3 mechanisms

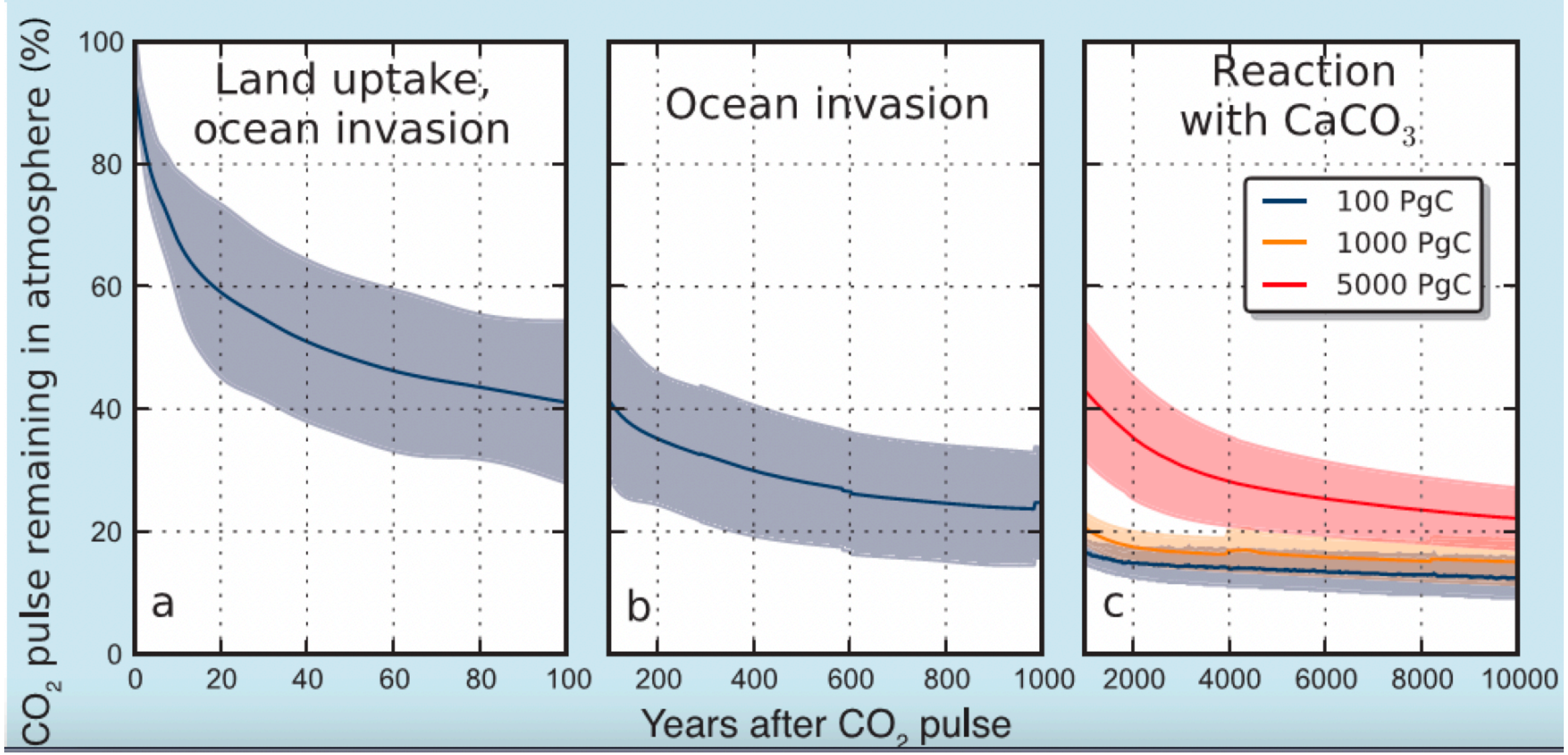
- Solubility pump (CO2.H2O, HCO3 and CO3)
- Biological pump (ocean plankton)
- Marine carbonate pump (formation of calcareous shells of certain oceanic microorganisms in the surface ocean)

CO2 sources, sinks, lifetime



Multiple residence times for excess CO2

Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6O_2$ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat}$
Ocean invasion: Seawater buffer	$10–10^3$	$CO_2 + CO_3^{2-} + H_2O \rightleftharpoons 2HCO_3^-$
Reaction with calcium carbonate	$10^3–10^4$	$CO_2 + CaCO_3 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$
Silicate weathering	$10^4–10^6$	$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$



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

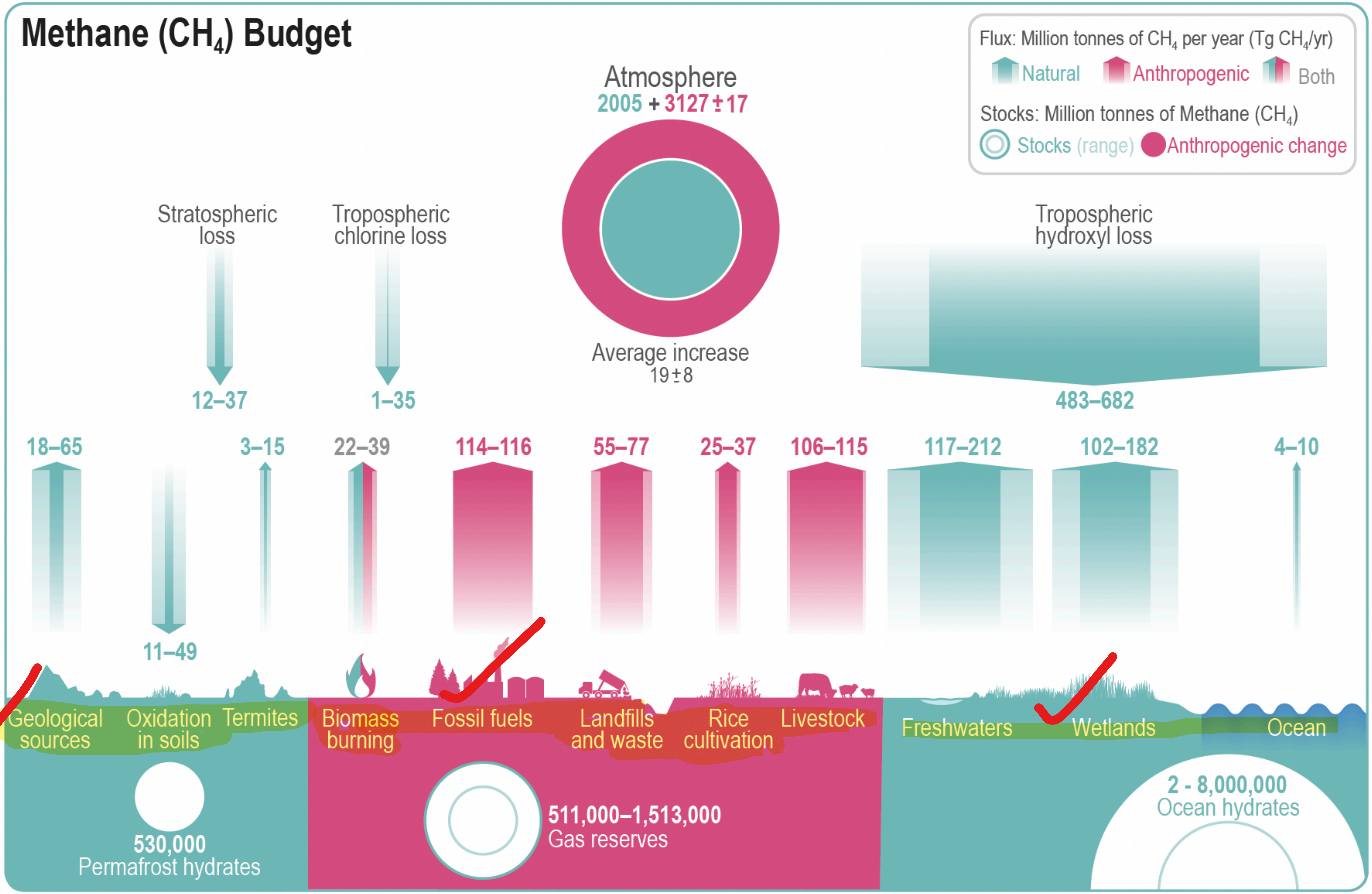


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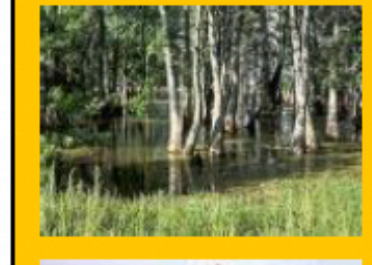
Figure 5.14 | Global methane (CH4) budget (2008–2017).

CH4 sources, sinks, lifetime

Sources


Wetlands


Termites


Lakes

Natural

160 Tg/y


Ruminants


Rice Paddies


Fossil fuel / biomass

Anthropogenic

375 Tg/y

Total 535 Tg/y

Global burden: Q= 4850 Tg

Lifetime = Q/R
=4850/515
~ 9 y

Emissions > Sinks

515 Tg/y

Sinks

Tropospheric OH

Stratospheric reactions

Soils

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.