



Oct 7 & 12: Carbon Cycle and Climate Change

- Q&A for Quiz 2

Foci of the Day

- Terminology and basics
- Recap: Greenhouse Gas Effects and Changes
- Global carbon budget

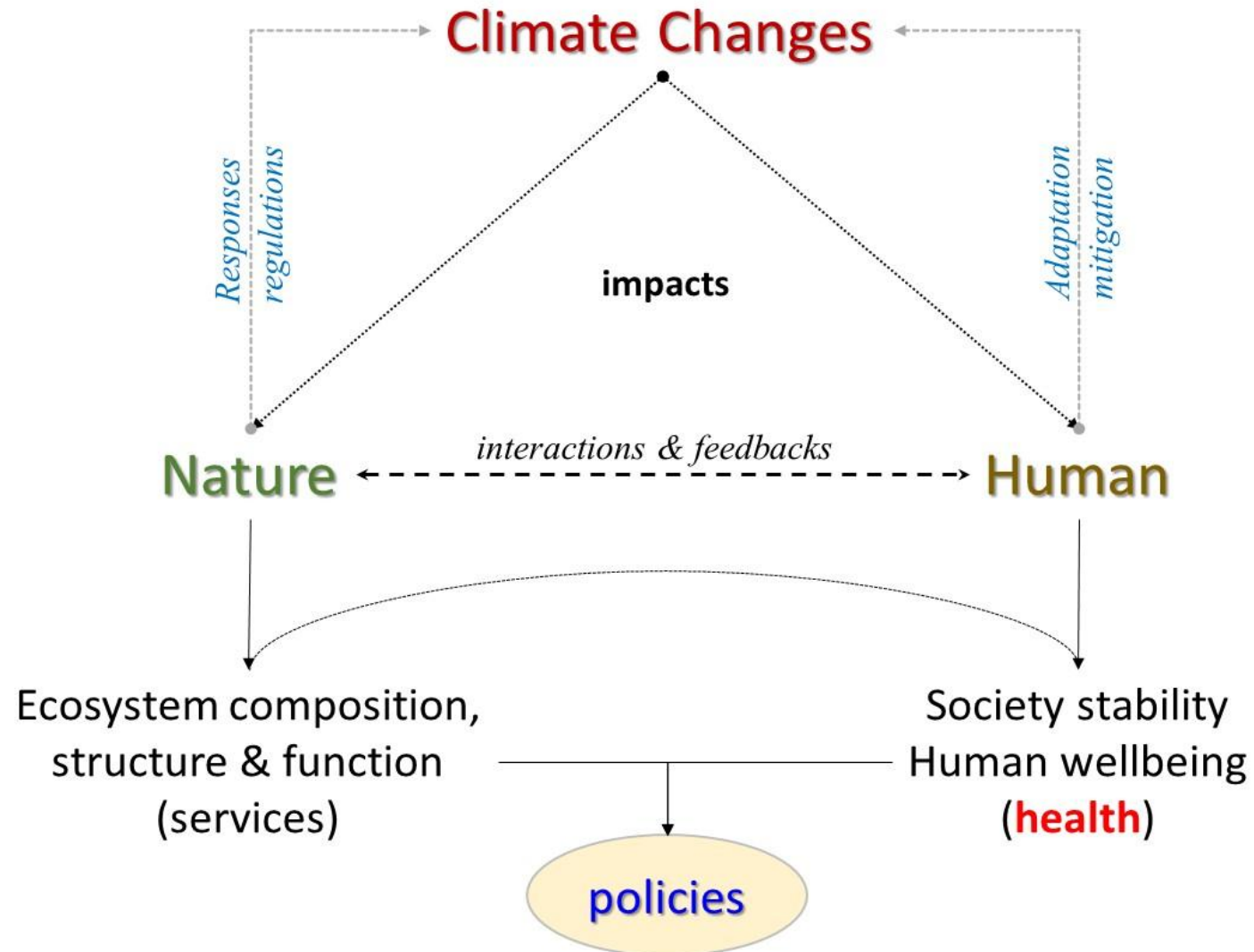
Reading

[Executive summary \(Pages 968-969\) of](#)

Friedlingstein, P., O'sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Landschützer, P., ... & Zeng, J. (2024). Global carbon budget 2024. *Earth System Science Data Discussions*, 2024, 1-133.



Climate-Ecosystem-People Feedback





A Few Basics

Molecular weight (**molar mass**) (g mol^{-1}):

C = **12.01**

O₂ = 16.00

CO₂ = **44.01**

H = **1.008**

H₂O = 18

CH₄ = 16

Biomass vs carbon

1 biomass = 0.5 x carbon

1 GtC = 10^9 metric tons of C = = **1 billion** metric tons C

1 Mg C = 1 metric ton C = = 1,000 kg C = 12 metric ton biomass

Burning 1 U.S. gallon of regular gasoline produces approximately 8.9 kg CO₂ (19.6 lb CO₂, or **20 lb**)

Relevant Terminology

- **Carbon cycle:** the movement of carbon among the atmosphere, oceans, land, and living organisms.
- **Ocean uptake and release:** The ocean absorbs CO₂ and stores it as dissolved carbonates; it can also release CO₂ back to the atmosphere.
- **Fossil fuel burning (combustion):** the burning of coal, oil, and natural gas to produce energy, which releases carbon that has been stored underground for millions of years, primarily as CO₂, into the atmosphere.



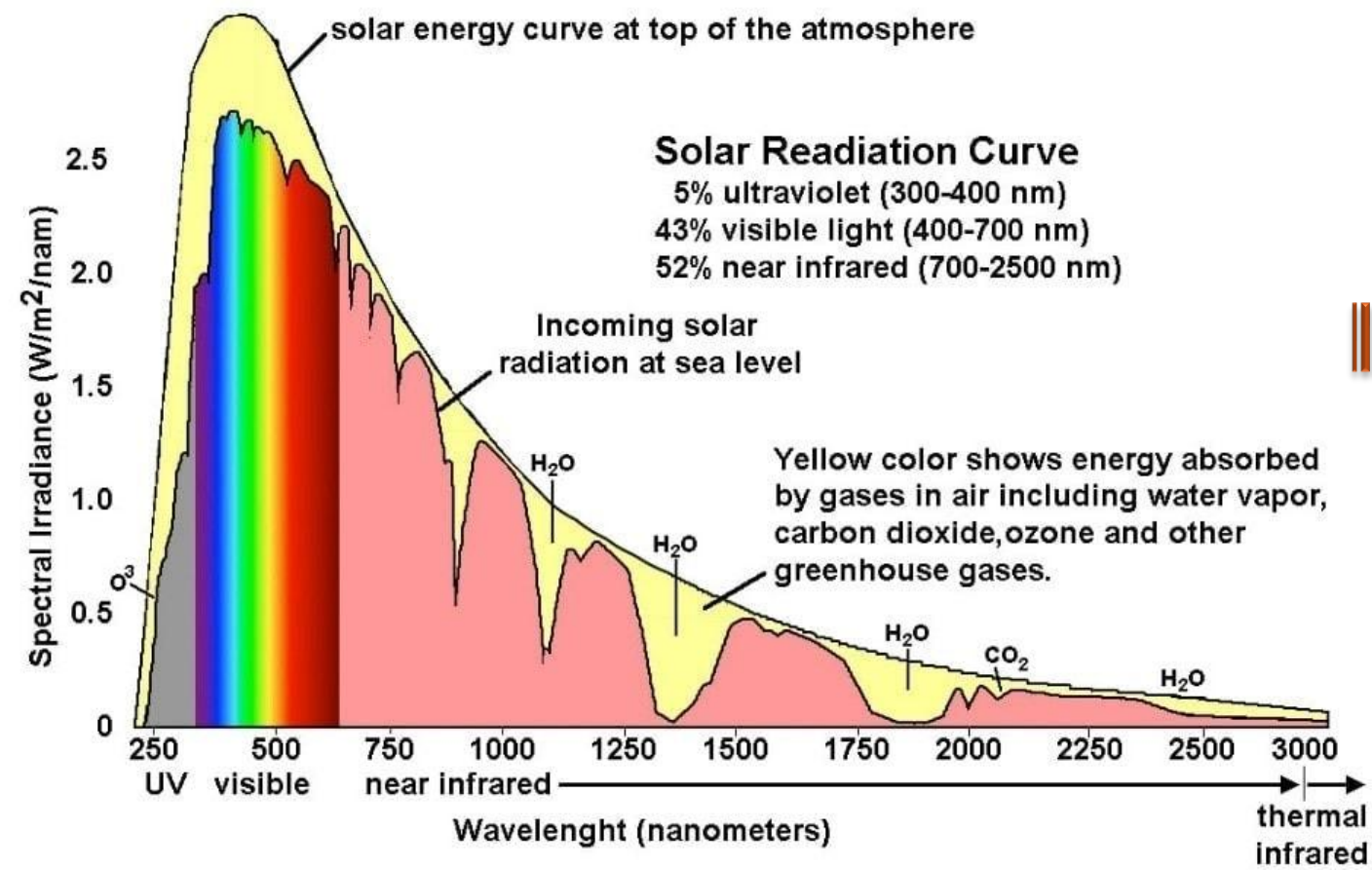
Relevant Terminology

- **Biomass** (Mg ha^{-1}): the total mass of living biological material within a given area or ecosystem at a particular time. It includes Aboveground biomass (**AGB**) and Belowground biomass (**BGB**)
- **Photosynthesis** ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$): Plants/algae absorb CO_2 from the atmosphere to produce organic matter.
- **Respiration** ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) (R_e): Organisms release CO_2 back into the air during metabolism.
- **Gross Primary Productivity (GPP)** ($\text{Mg C ha}^{-1} \text{ yr}^{-1}$): the total rate of carbon fixed by plants through photosynthesis.
- **Net Primary Productivity (NPP)** ($\text{Mg C ha}^{-1} \text{ yr}^{-1}$): the rate at which plants accumulate new biomass after accounting for the carbon they use for their own respiration (R_a).
- **Net Ecosystem Production (NEP)** ($\text{Mg C ha}^{-1} \text{ yr}^{-1}$): the net rate at which an ecosystem accumulates carbon after accounting for respiration by both plants and heterotrophs (R_a , R_h).



Greenhouse effects on incoming solar radiation

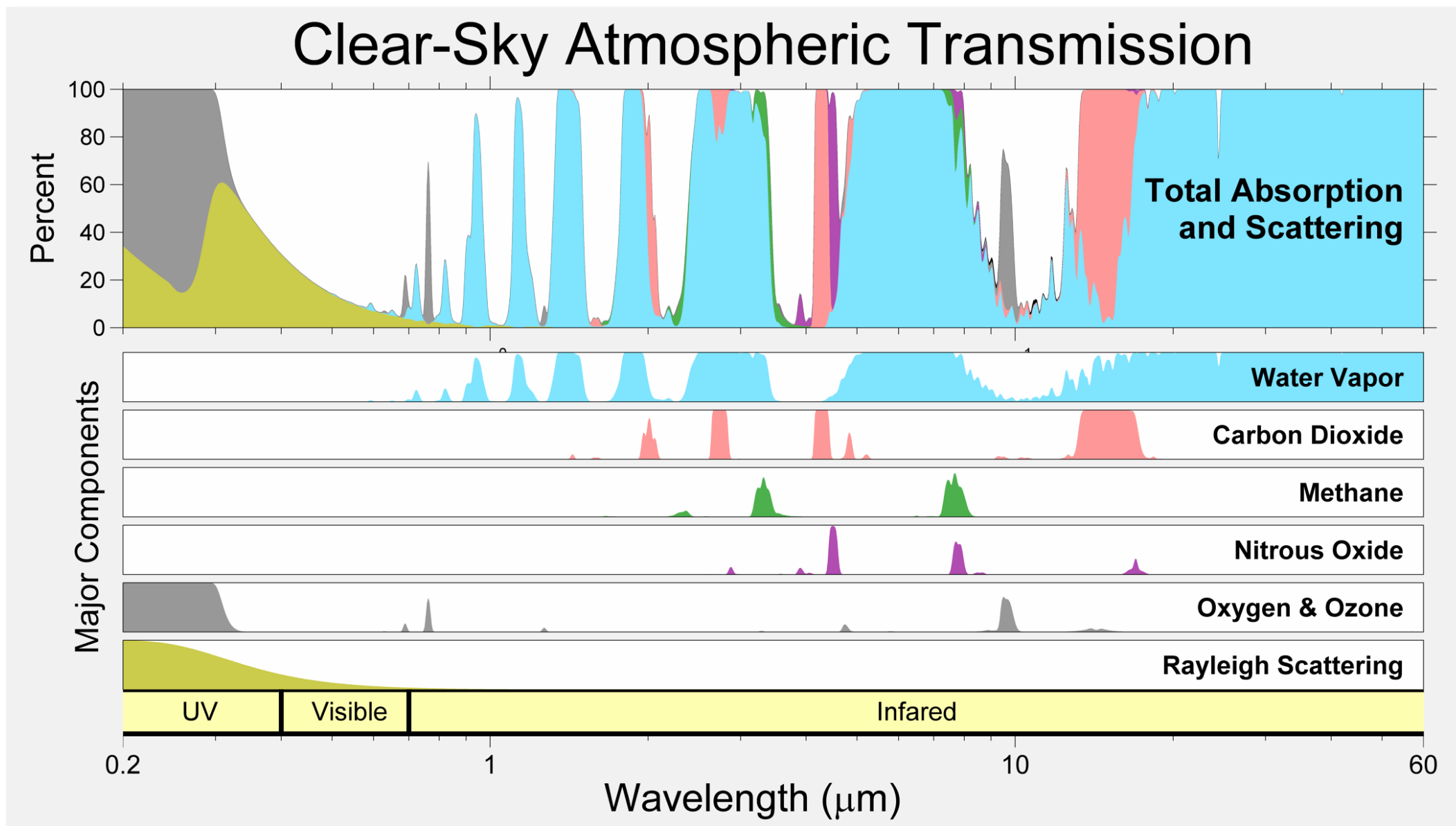
Solar Energy Distribution



Increase in global temperature through greenhouse effects (**direct** and **indirect**)



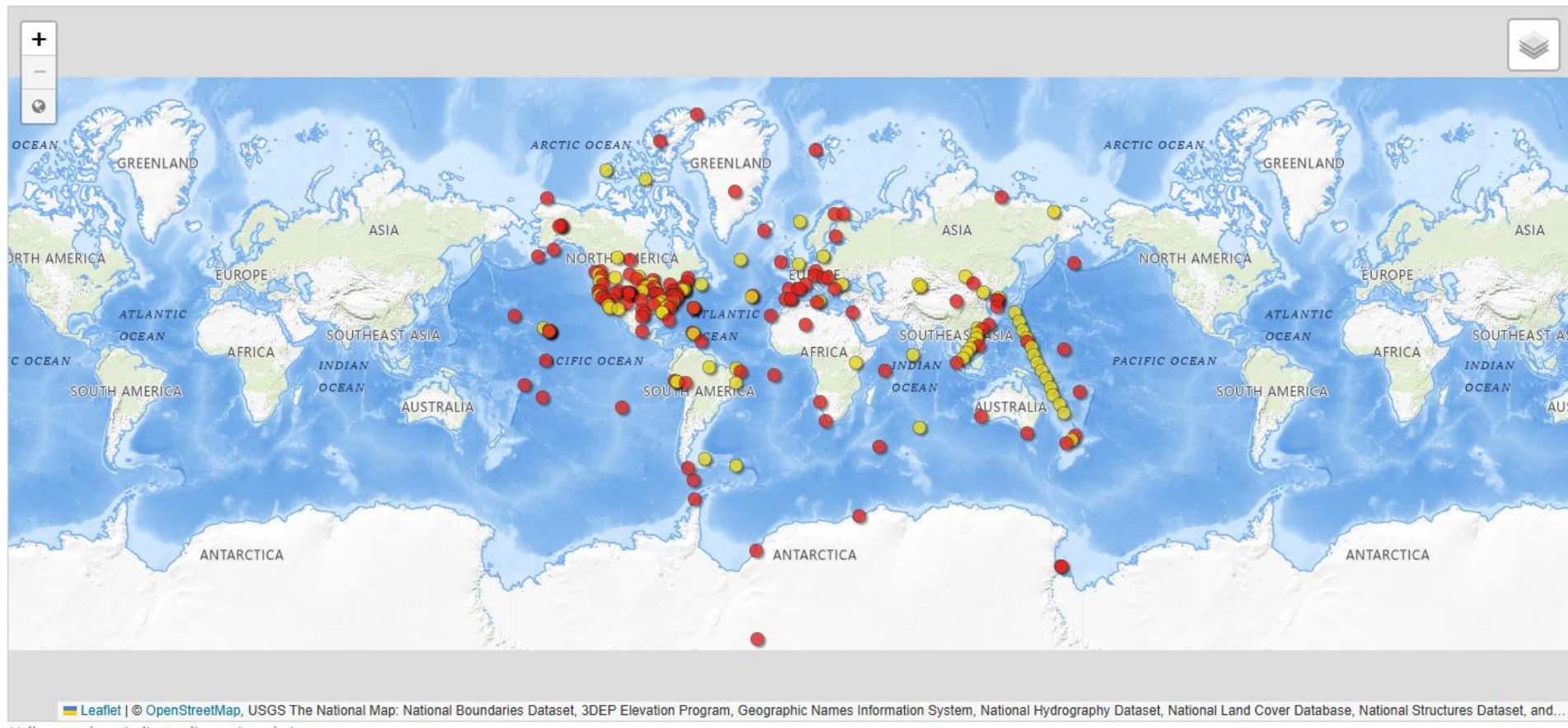
Three major greenhouse gases (GHGs): CO_2 , CH_4 , and N_2O





Surface average atmospheric CO₂ concentration (ppm) since 1960

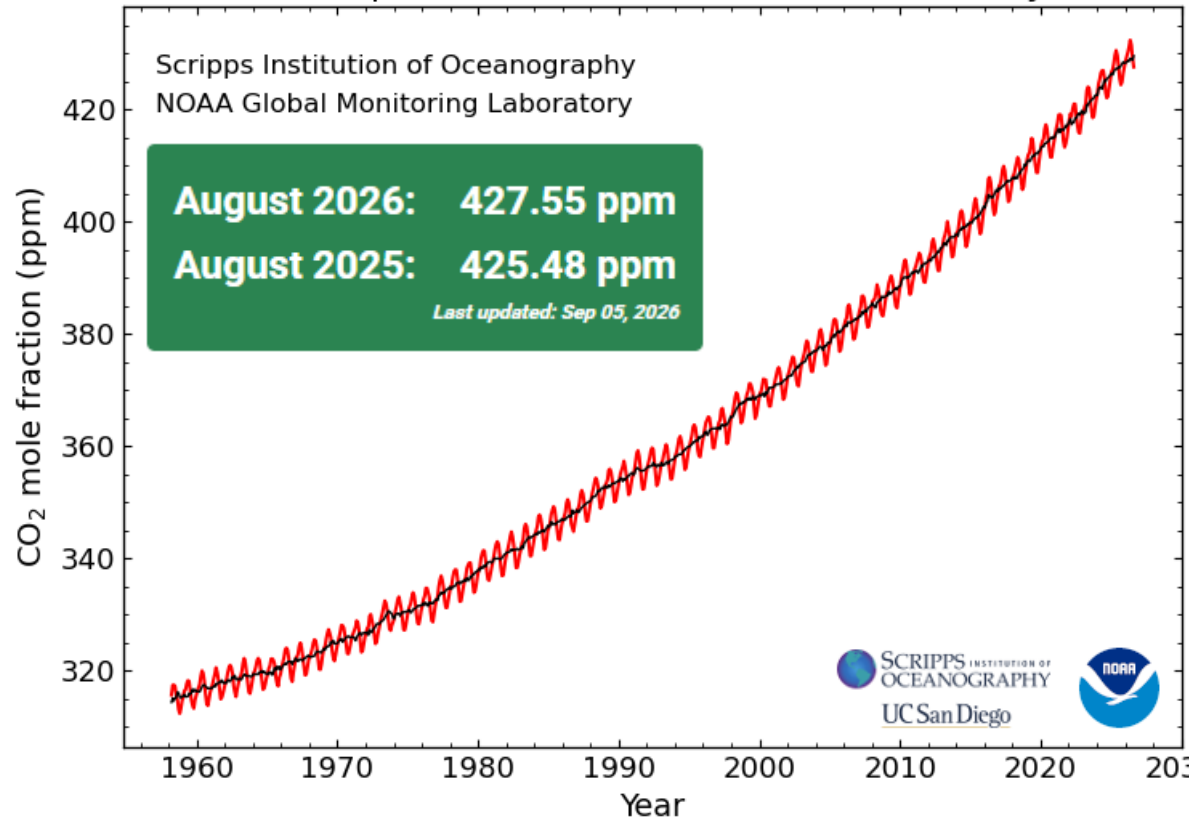
The CO₂ data on Mauna Loa constitute the longest record of direct measurements of CO₂ in the atmosphere. They were started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958. NOAA started its own CO₂ measurements in May of 1974, and they have run in parallel with those made by Scripps since then.



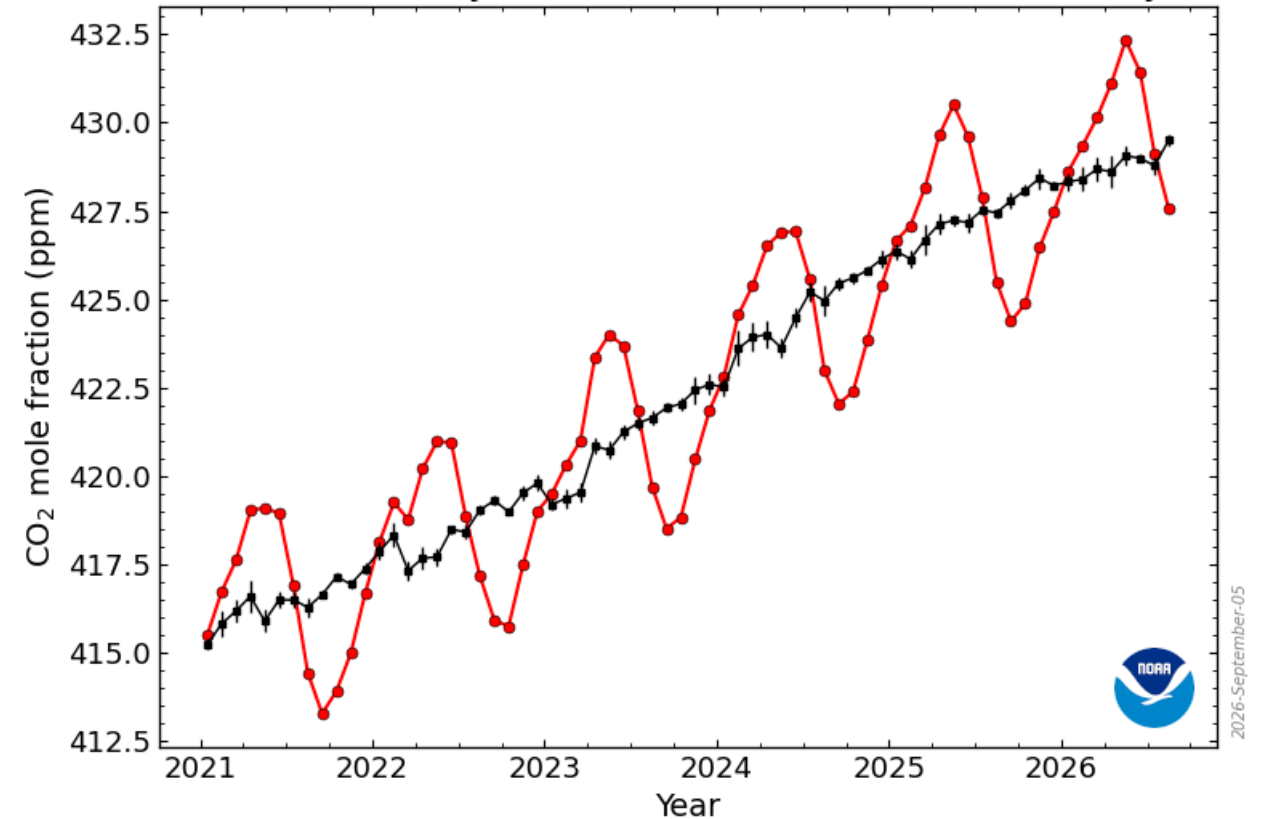


Surface average atmospheric CO₂ concentration (ppm) since 1960

Atmospheric CO₂ at Mauna Loa Observatory

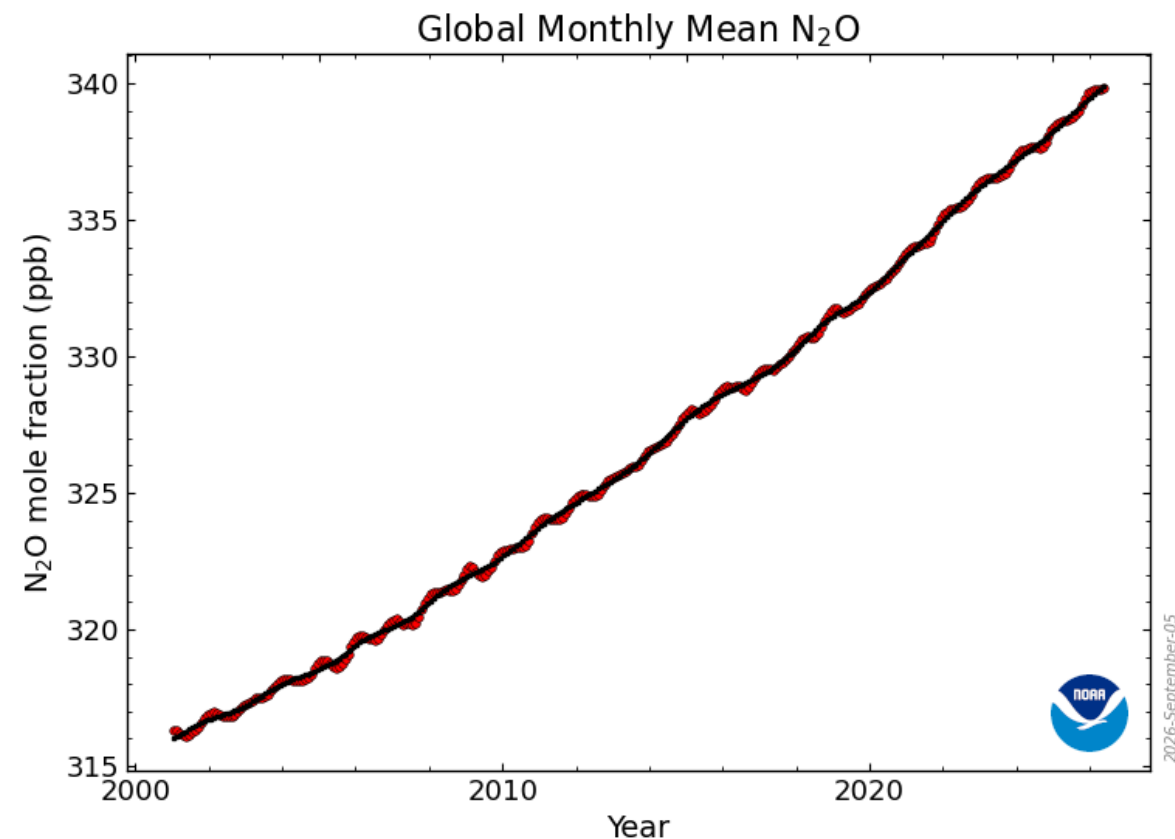
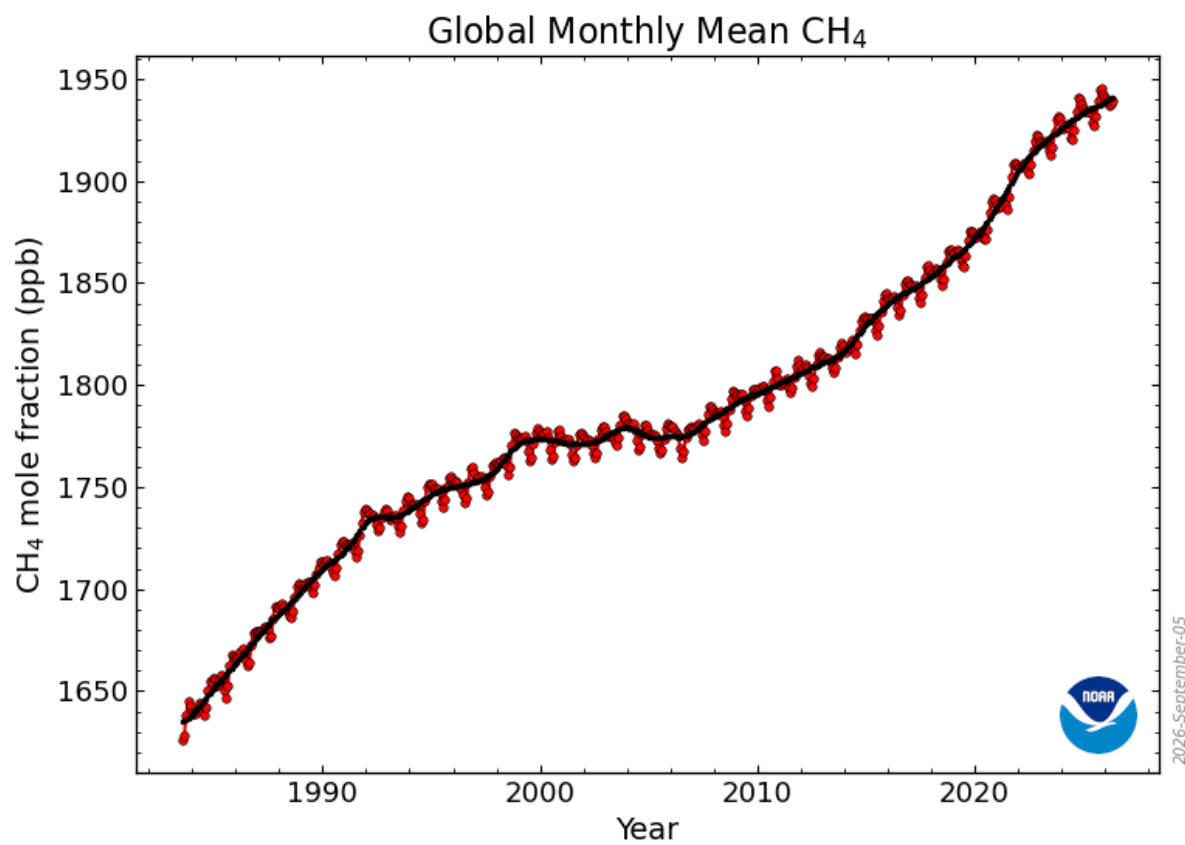


Recent Monthly Mean CO₂ at Mauna Loa Observatory



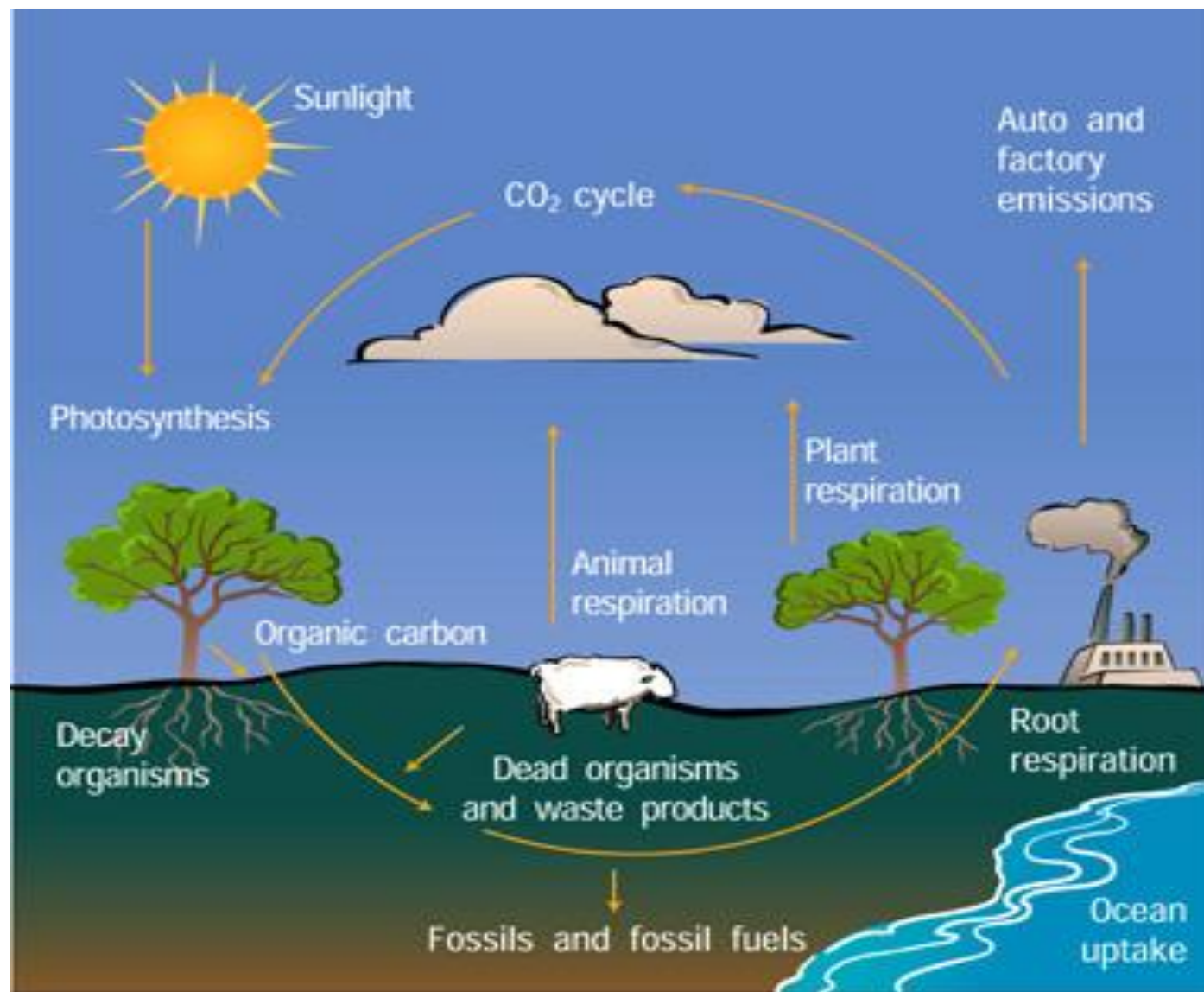


Monthly mean atmospheric CH_4 and N_2O abundance determined from marine surface sites

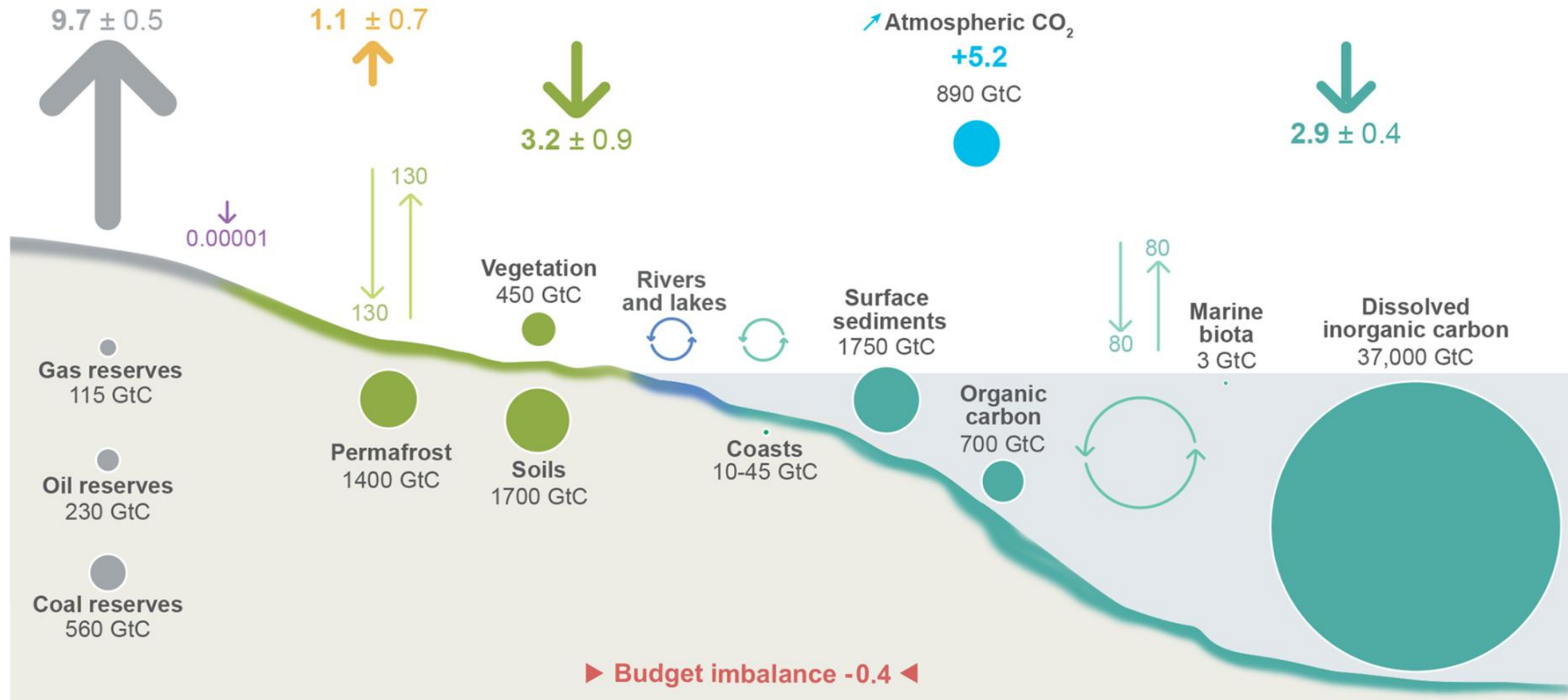




Global Carbon Cycle



The global carbon cycle



**Anthropogenic fluxes
2014-2023 average
GtC per year**

↑ Fossil CO₂ E_{FOS}
 ↑ Land-use change E_{LUC}
 ↓ CDR not included in E_{LUC}

↓ Land uptake S_{LAND}
 ↓ Ocean uptake S_{OCEAN}
 + Atmospheric increase G_{ATM}

▶ Budget imbalance B_{IM}
 ● Stocks GtC
 ↓↑ Natural carbon fluxes in GtC

independent estimates (1) to (5) above do not necessarily add up to zero. We hence estimate a budget imbalance (B_{IM}), which is a measure of the mismatch between the estimated emissions and the estimated changes in the atmosphere, land, and ocean, as follows:

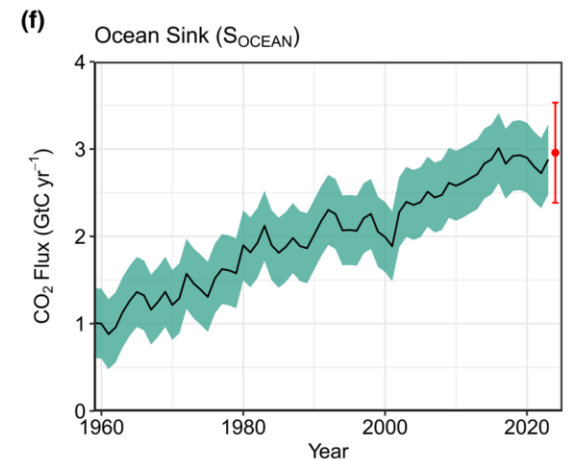
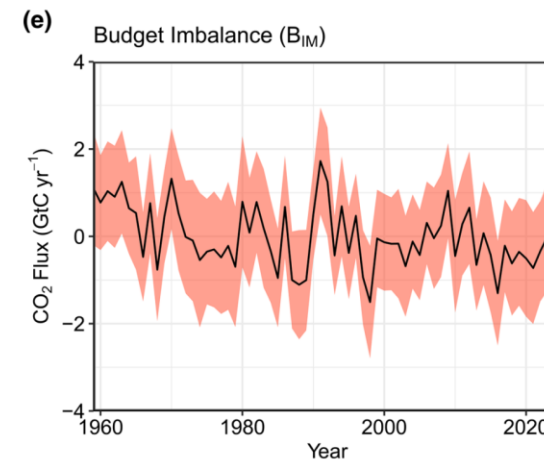
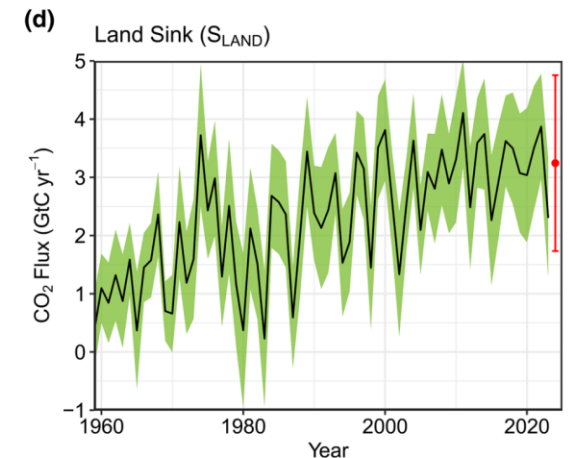
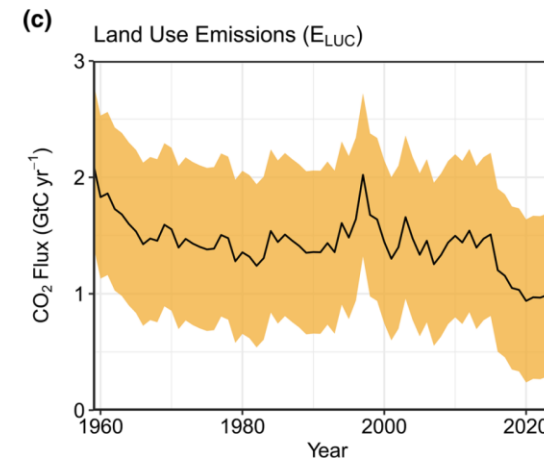
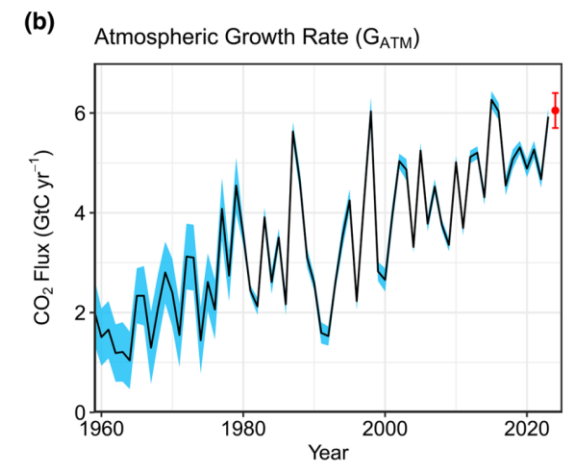
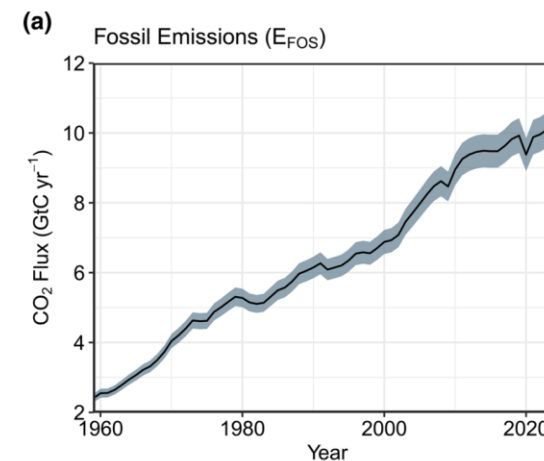
$$B_{IM} = E_{FOS} + E_{LUC} - (G_{ATM} + S_{OCEAN} + S_{LAND}). \quad (1)$$

G_{ATM} is usually reported in ppm yr^{-1} , which we convert to units of carbon mass per year, GtC yr^{-1} , using $1 \text{ ppm} = 2.124 \text{ GtC}$ (Ballantyne et al., 2012; Table 1). Units of gigatonnes of CO_2 (or billion tonnes of CO_2) used in policy are equal to 3.664 multiplied by the value in units of gigatonnes of carbon (GtC).

- Fossil CO_2 emissions (E_{FOS})
- CO_2 emissions from land-use, land-use change, and forestry (E_{LUC})
- CO_2 removal (CDR) not based on vegetation
- Growth rate in atmospheric CO_2 concentration (G_{ATM})
- Ocean CO_2 sink (S_{OCEAN})
- Land CO_2 sink (S_{LAND})

Global Carbon Budget

- Components of the global carbon budget and their uncertainties as a function of time
- Emissions from land use continue decline (stabilized)
- Sink strength from lands and oceans appear stabilized



Global Carbon Budget

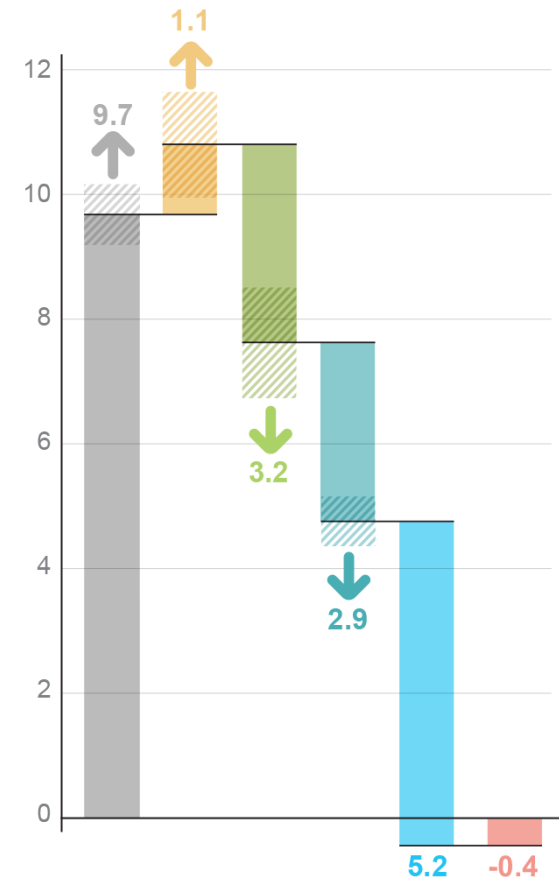
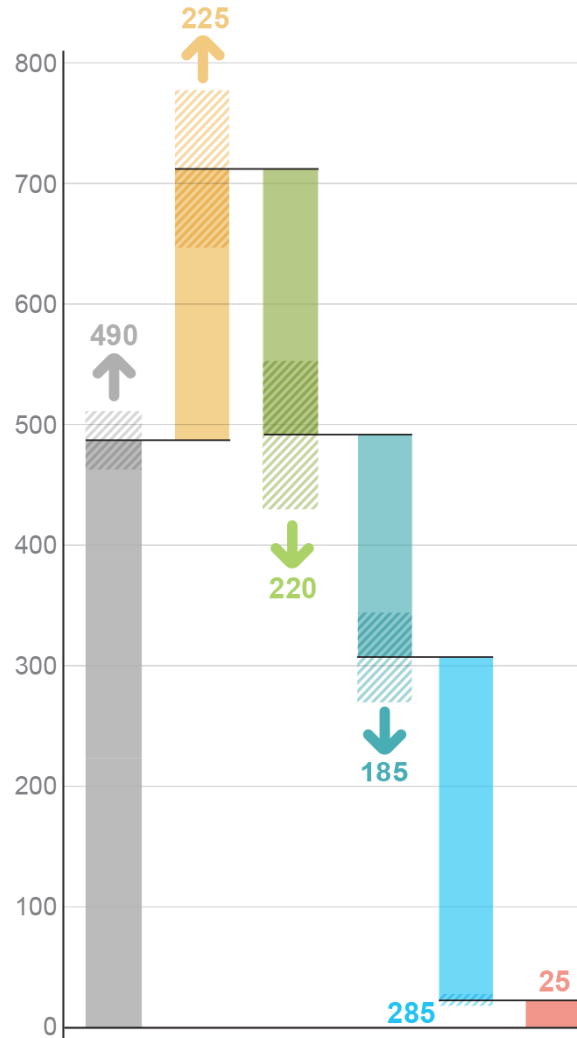
Cumulative changes (1850–2023)

- 90% of the total emissions ($E_{\text{FOS}} + E_{\text{LUC}}$) were from fossil CO₂ emissions (E_{FOS}) and 10% from land-use change (E_{LUC}).
- The total emissions were partitioned among the atmosphere (48%), ocean (26%), and land (30 %),

Anthropogenic carbon flows

(a) Cumulative changes 1850–2023 GtC

(b) Mean fluxes 2014–2023 GtC per year



↑ Fossil CO₂ E_{FOS}

↓ Land uptake S_{LAND}

+ Atmospheric increase G_{ATM}

↑ Land-use change E_{LUC}

↓ Ocean uptake S_{OCEAN}

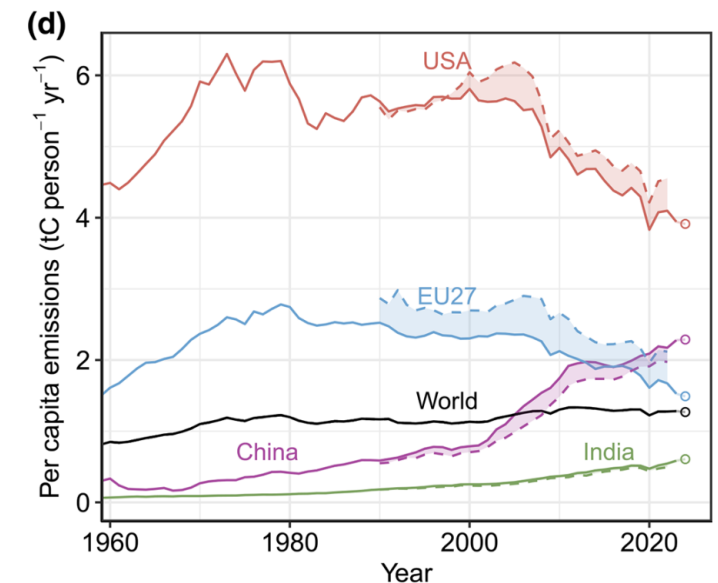
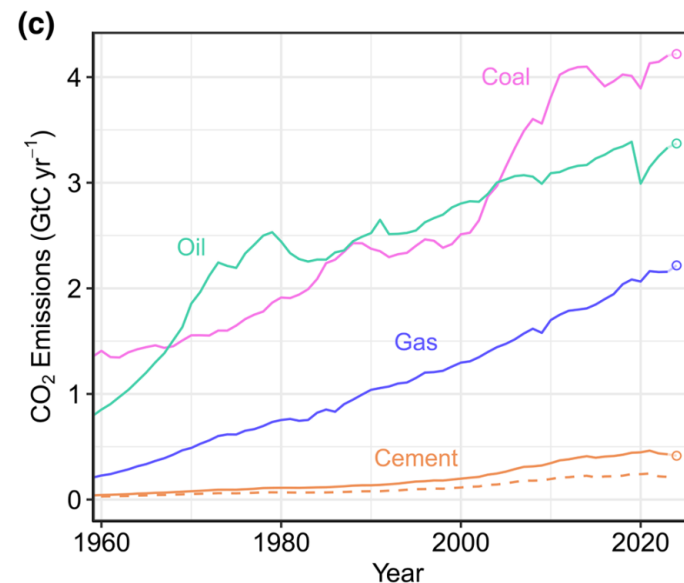
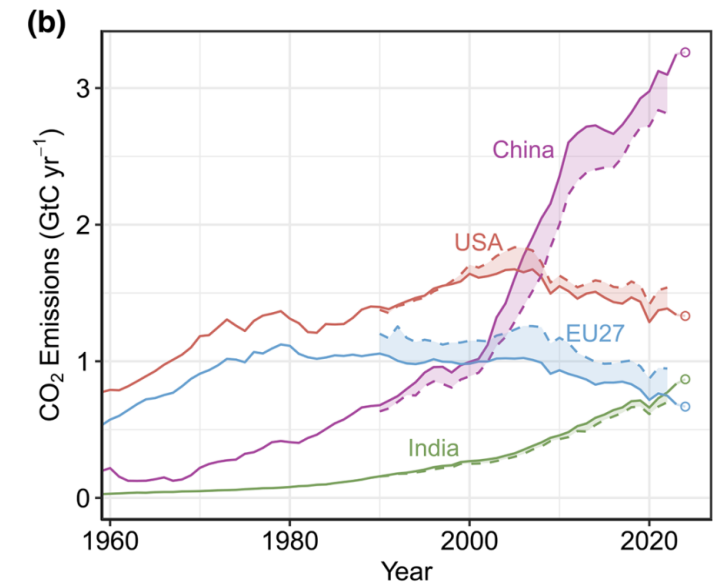
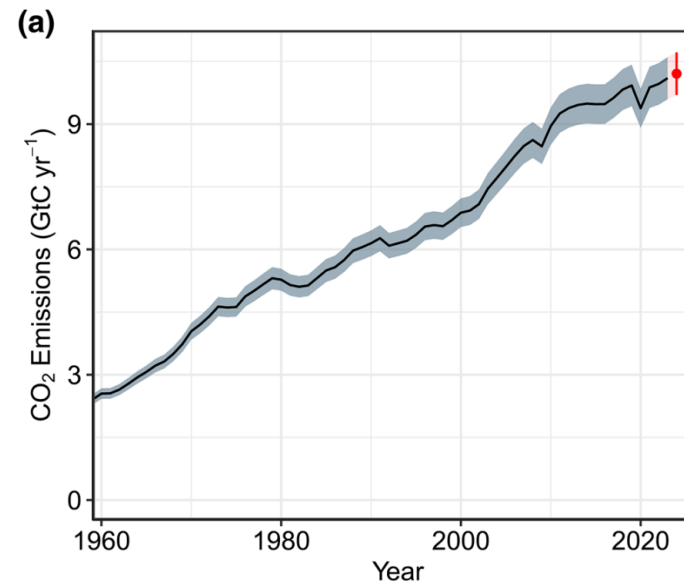
░ Uncertainty values

■ Budget Imbalance B_{IM}

Global Carbon Budget

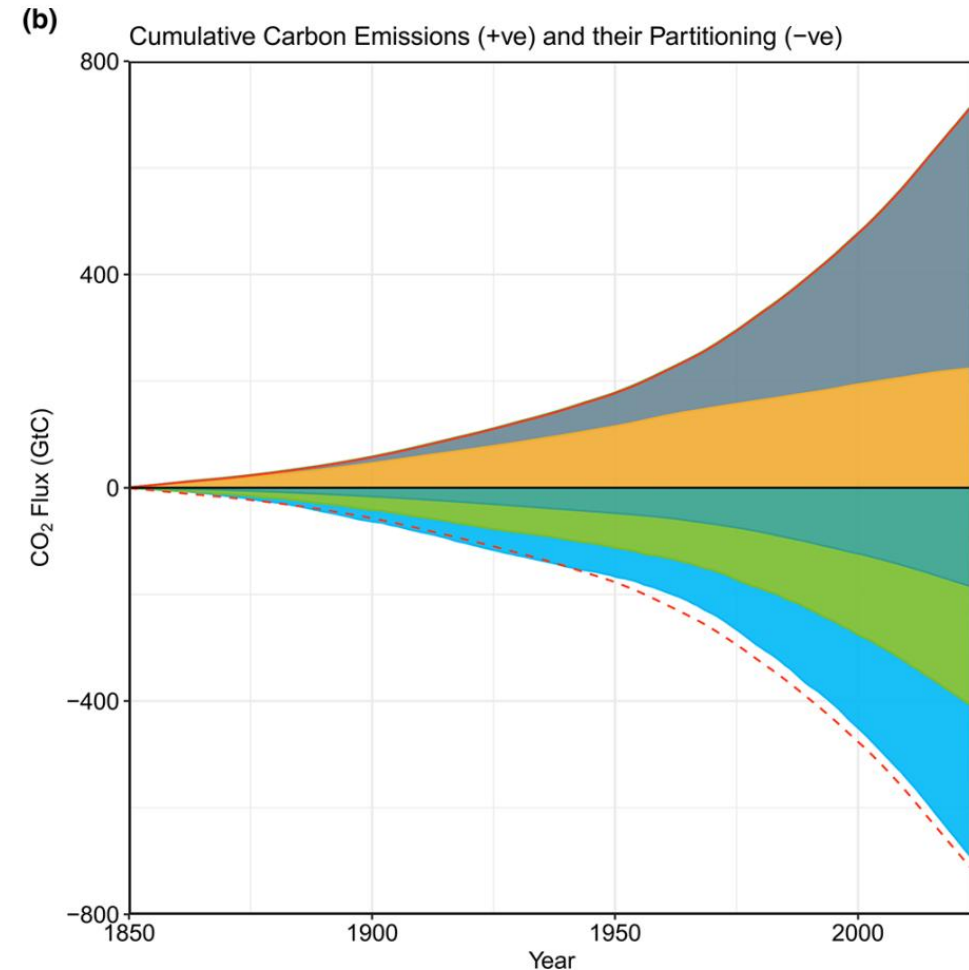
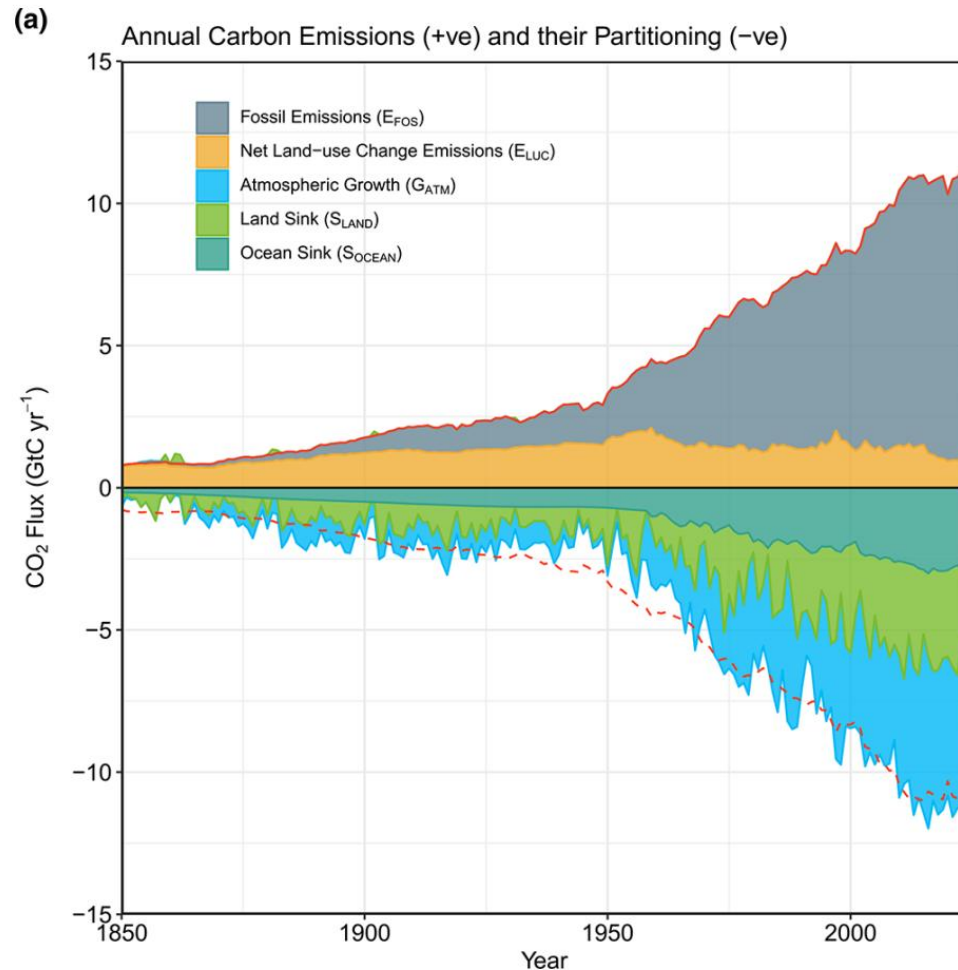
Fossil CO₂ emissions

- Different industries
- Major political entities
- Per capita
- Political debates (Paris Agreement)



Global Carbon Budget

Combined components of the global carbon budget as a function of time, for fossil CO₂ emissions (EFOS, grey) and emissions from land-use change (ELUC; yellow-brown), as well as their partitioning into the atmosphere (G_{ATM}; cyan), ocean (SOCEAN; turquoise), and land (SLAND; green).





Oct 12: Carbon Sequestration and Climate Change

Foci of the Day

- Group exercise (carbon monitoring)
- Carbon sequestration, credit, and market
- Carbon footprint

Reading

- 1) Global carbon budget: <https://carbonmonitor.org/>
- 2) World population: <https://www.worldometers.info/world-population/>
- 3) Primary energy consumption per capita (<https://ourworldindata.org/grapher/per-capita-energy-use>)
- 4) State and trends of carbon pricing dashboard:
https://carbonpricingdashboard.worldbank.org/?utm_source=chatgpt.com