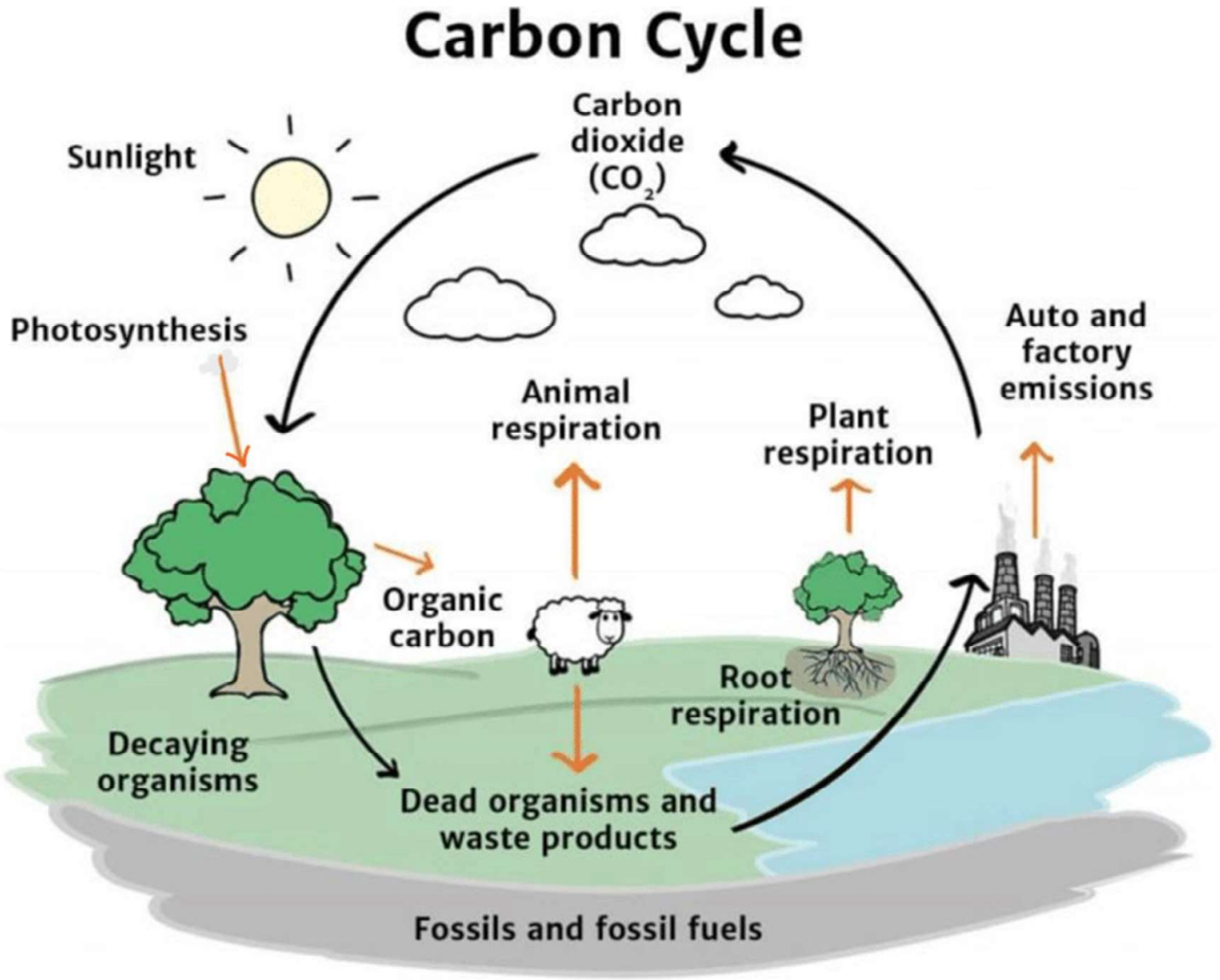
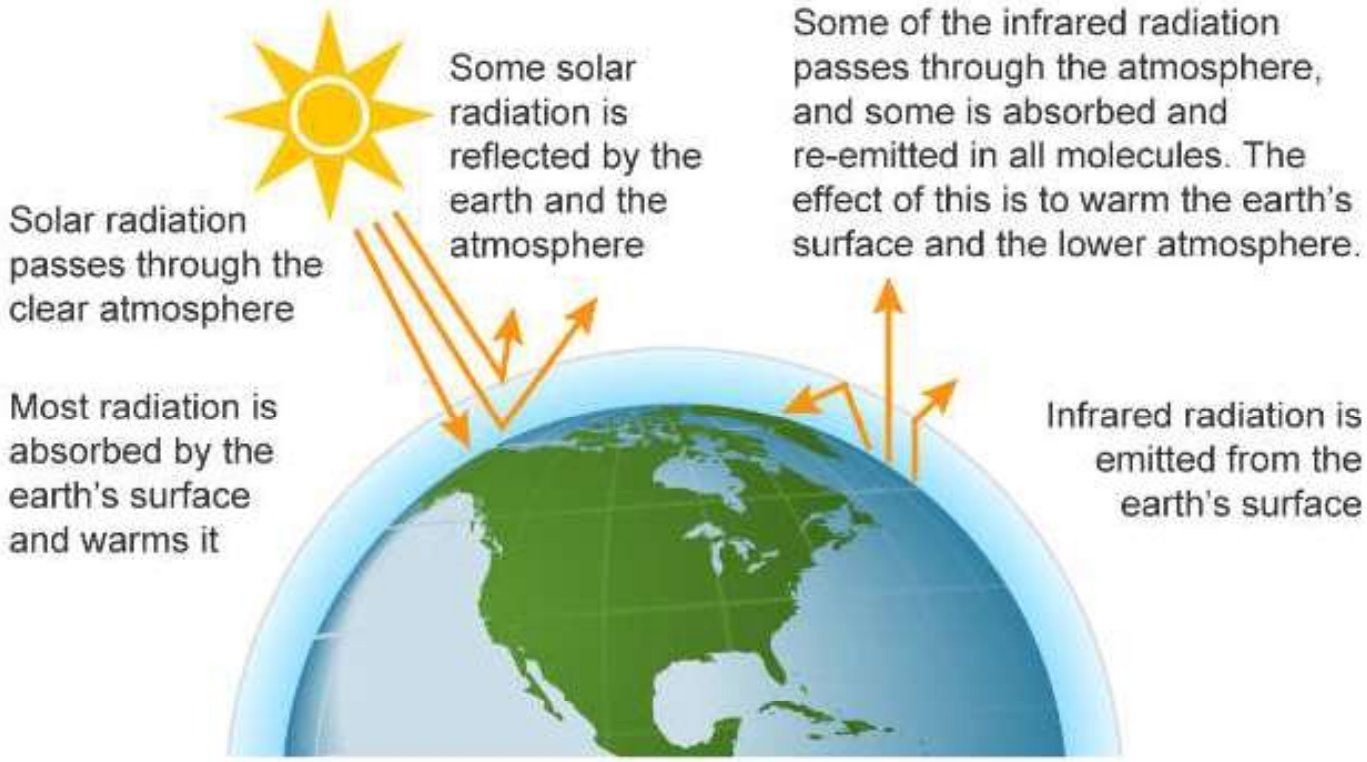
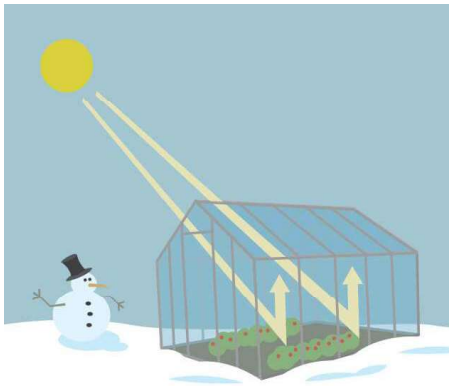
Cycle of Carbon

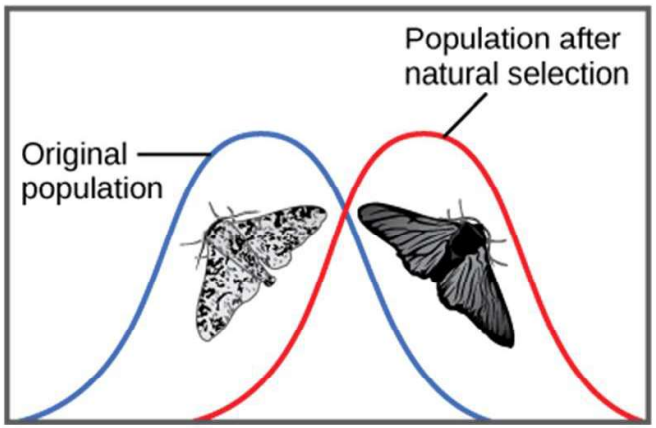


The greenhouse effect



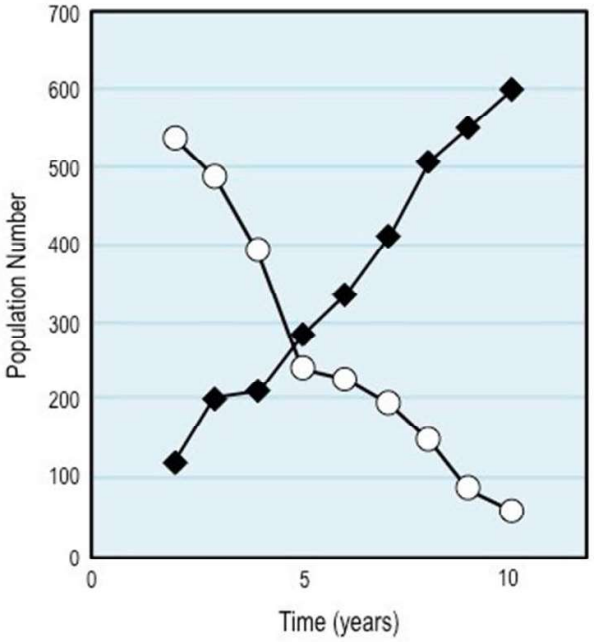
Source: Adapted from U.S. Environmental Protection Agency (public domain)





Light-colored peppered moths are better camouflaged against a pristine environment; likewise, dark-colored peppered moths are better camouflaged against a sooty environment. Thus, as the Industrial Revolution progressed in nineteenth-century England, the color of the moth population shifted from light to dark, an example of directional selection.

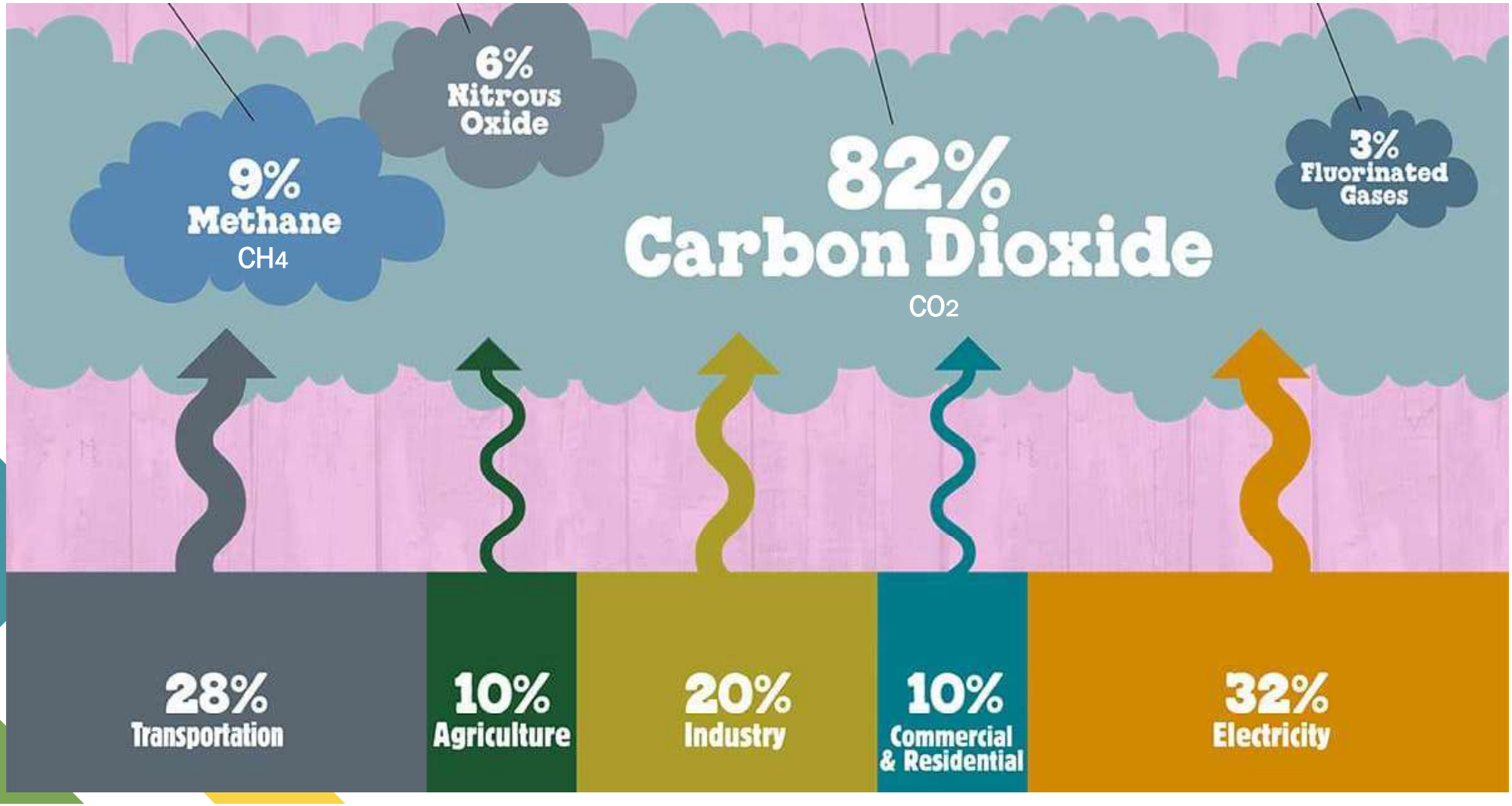
Pre-Industrial Revolution



Post-Industrial Revolution

Greenhouse gases

Industrial gases



Greenhouse gases

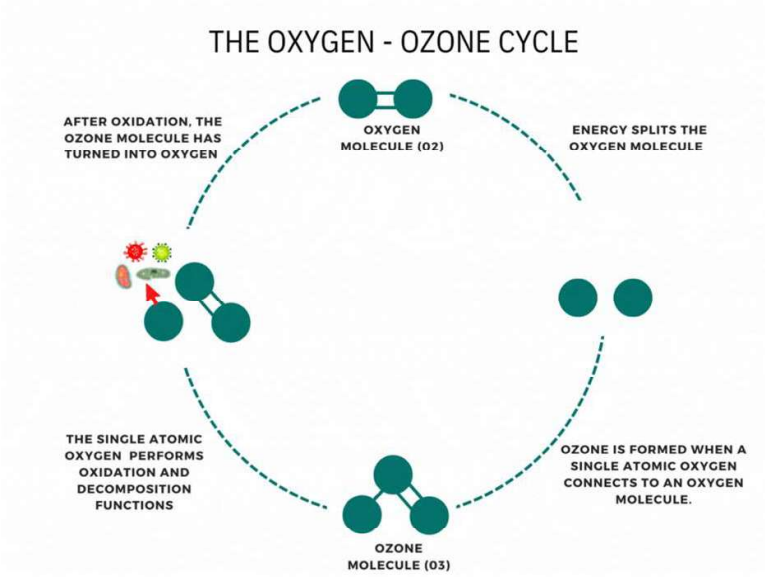
water vapour

- It is the most abundant greenhouse gas
- scientists believe that water vapour produced directly by human activity contributes very little

the U.S. Energy Information Administration (EIA) does not estimate emissions of water vapor

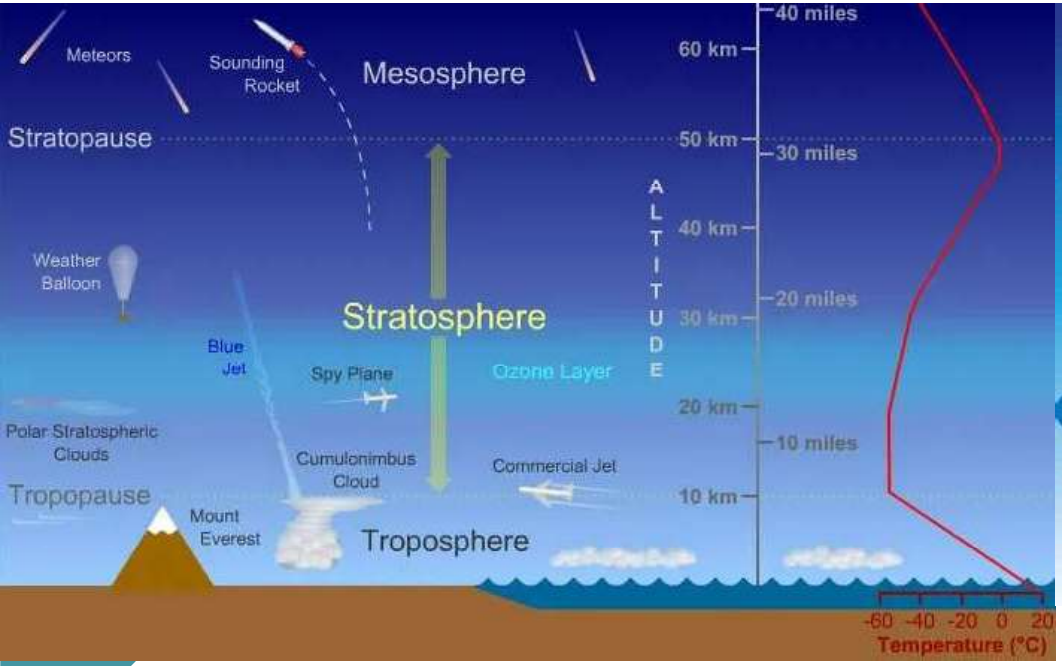
ozone

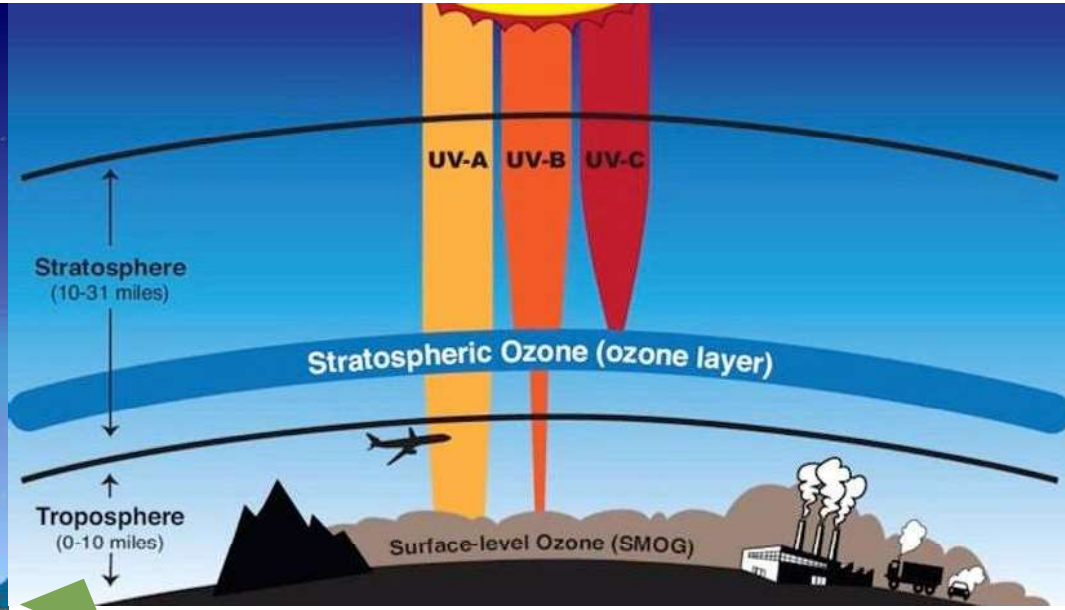
- It is technically a greenhouse gas, but ozone can be **helpful or harmful**, depending on <u>where it is in the earth's atmosphere</u>



Ozone (O_3)

The United States and countries all around the world ban and control production (Montreal protocol) and use of several industrial gases that destroy atmospheric ozone and create holes in the ozone layer.



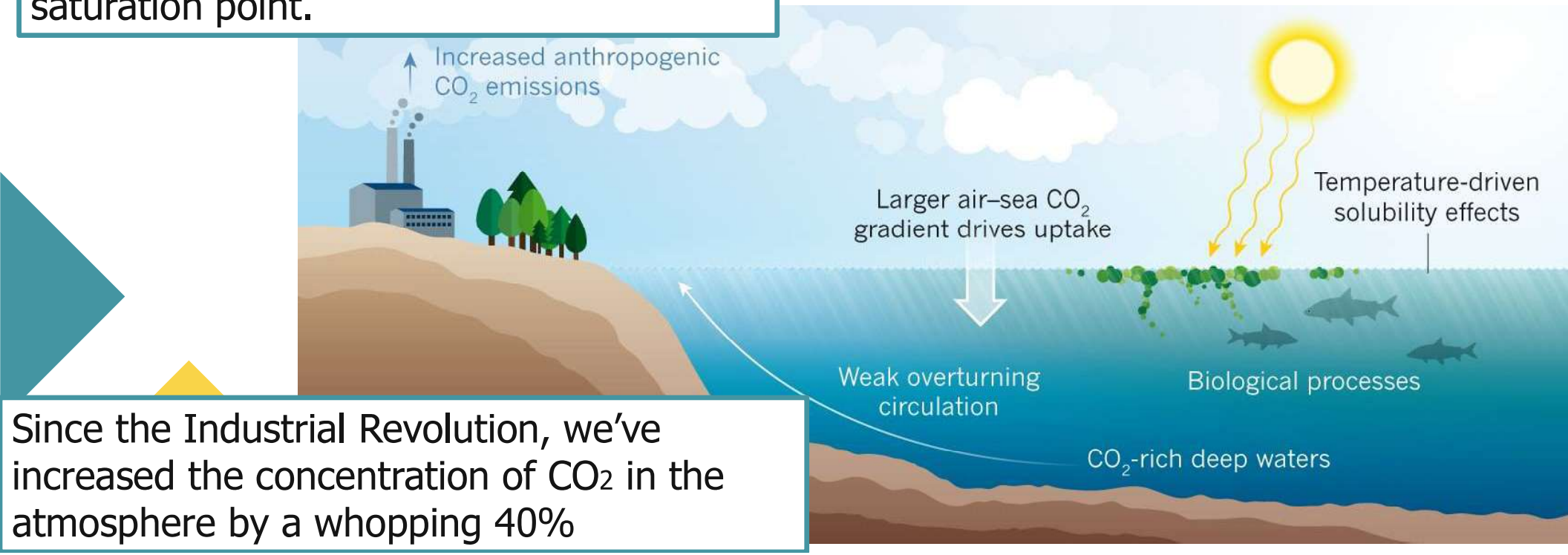


At the troposphere, ozone is harmful to human health: Breathing ground-level ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma.

Carbon dioxide (CO_2)

- CO_2 is perfectly fine in lower concentrations.

Forests and oceans that used to absorb most of that CO_2 are reaching their saturation point.



Since the Industrial Revolution, we've increased the concentration of CO_2 in the atmosphere by a whopping 40%

How can I see for myself that CO2 absorbs heat?

The carbon dioxide we emit today will trap heat for 100 years

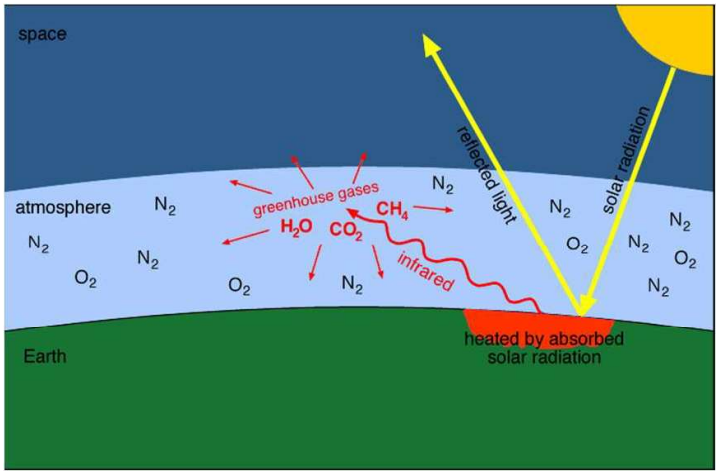
Little experiment

- As an experiment that can be done at home: fill one soda bottle with CO_2 (perhaps from a soda machine) and filling a second bottle with ambient air.
- If you expose them both to a heat lamp, the CO_2 bottle will warm up much more than the bottle with just ambient air.
- PS. Check the bottle temperatures with a no-touch infrared thermometer

https://youtu.be/Ge0jhYDcazY

Why does carbon dioxide let heat in, but not out?

- Energy enters our atmosphere as **visible light**, whereas it tries to leave as **infrared energy**. In other words, energy coming into our planet from the Sun arrives as one currency, and it leaves in another one.



CO_2 molecules don't really interact with sunlight's wavelengths. Only **after the Earth absorbs sunlight** and **reemits the energy as infrared waves** can the **CO_2 and other greenhouse gases absorb the energy**.

For example, in 2019 alone, humans dumped 36.44 billion tonnes of CO_2 into the atmosphere, where it will linger for hundreds of years. So there are plenty of **CO_2 molecules to provide a heat-trapping blanket across the entire atmosphere**.

Methane (CH_4)

Colorless, odorless gas seeping up from wetlands and marshes, the oceans, and the bellies of livestock. It is also, however, the primary component of natural gas.

Methane is responsible for about **20% of man-made climate change** to date, but it's **25 times** more **potent** than carbon dioxide **as a greenhouse gas**

Sample of methane hydrate taken offshore

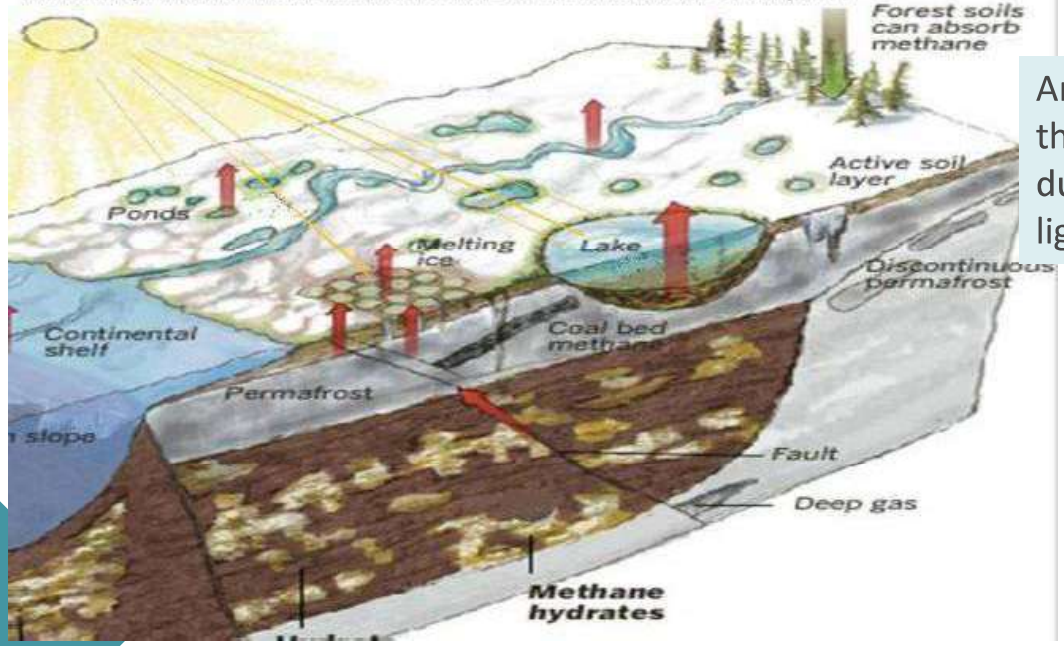
As energy demands ↑ this powerful greenhouse gas is being emitted rapidly.

As the Arctic warms it emits methane

The rapid warming of the Arctic is thawing the solid frozen soil ,called permafrost.

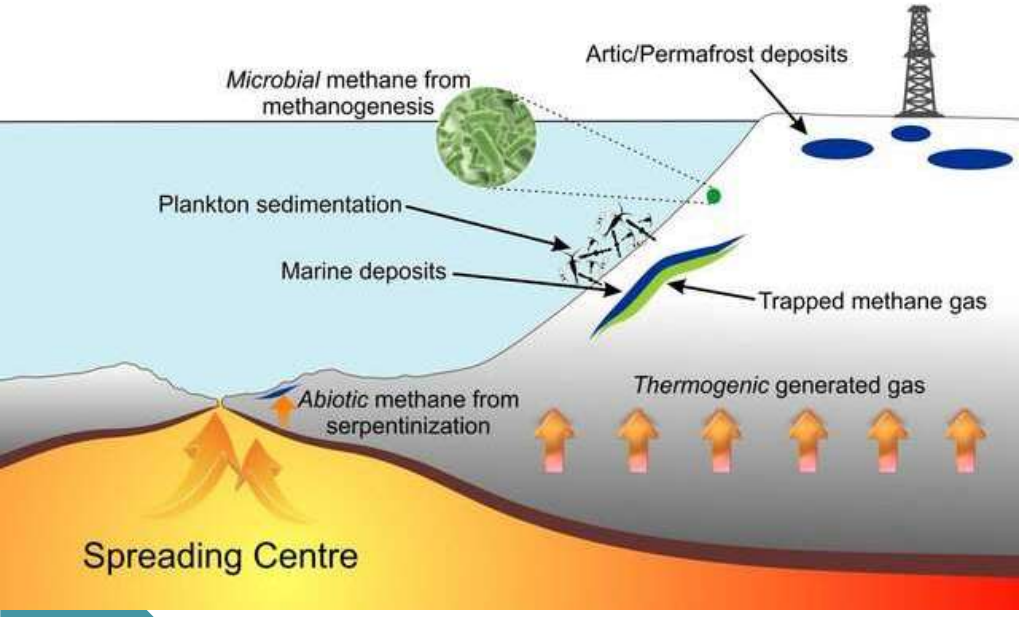
As the permafrost thaws it emits methane. New ponds and thaw lakes keep emitting a lot of methane

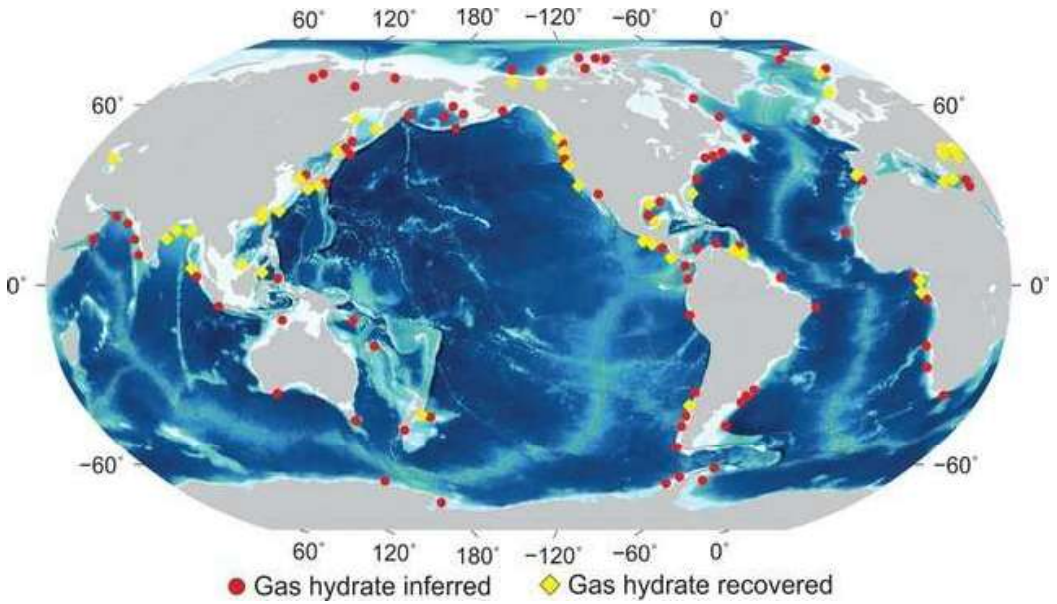
The Arctic permafrost holds double the amount of carbon in the atmosphere



Arctic–boreal regions are warming nearly **four times faster** than the rest of Earth, and fire activity is projected to increase due to associated decreases in fuel moisture and increases in lightning ignitions

The release of methane gas is imminent, should the permafrost begin to thaw out in the summer, the dead plant material will begin to decompose, releasing the gases into the atmosphere, and this is why the tundra, essentially prospering atop the permafrost, can lead to an *accelerated rate* of global warming





Types of methane hydrate deposits (abiotic, biogenic and thermogenic methane origin) present in the marine sediments (diagram not scaled).

Villar-Muñoz, 2019

Nitrous Oxide (N_2O)

Like most greenhouse gases, nitrous oxides are a **totally normal component of our planet.** It is an **odorless, colorless, non-flammable gas.** While nitrous oxide is not flammable, it will support combustion to the same extent as oxygen.

Nitrous oxide is created when bacteria digests plant matter. Nitrous oxides are part of the nitrogen cycle, which is vital to our planet's ability to support plant life, build soil and cycle nutrients.

Nitrous oxide is the third most damaging man-made natural gas, accounting for 7% of the warming we've seen thus far.

It is actually **298 times stronger** than carbon dioxide when it comes **to trapping heat**, and it stays **in atmosphere** for **120 years**

Nitrous Oxide (N_2O)

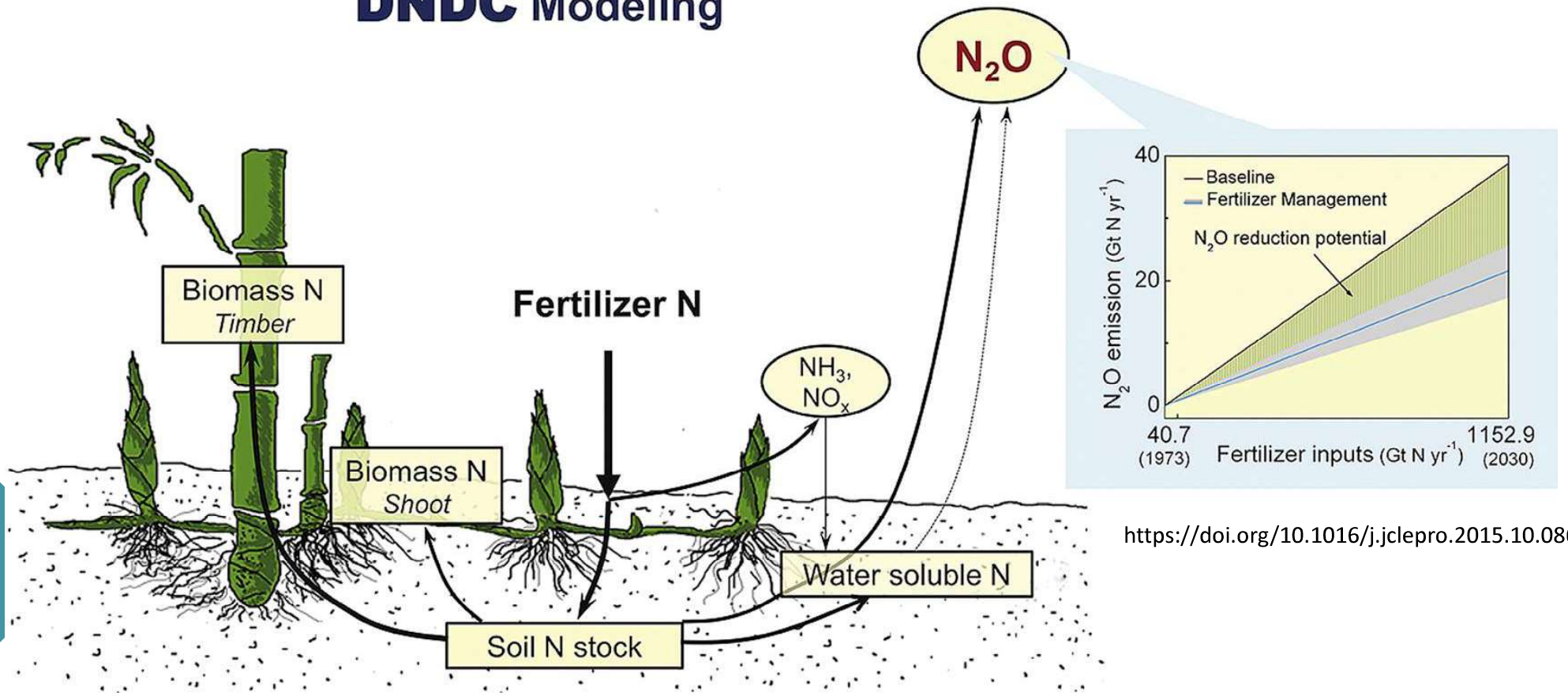
Human responsibility comes by **pumping more nitrogen into the soil since it increase yields.**

Human agricultural systems have been loading up on artificial nitrogen fertilizers to compensate for our degradation of soils, and spiking levels of nitrous oxide in the process.

Humans are pouring more than 70 million tons of chemical fertilizer on the land annually, drastically increasing nitrogen inputs and once again throwing a completely natural system way out of whack.

Fertilizer N —*Cleaner Production Audit*→ **Global warming mitigation**

DNDC Modeling



https://doi.org/10.1016/j.jclepro.2015.10.086

While we've largely eliminated nitrous oxide from human industrial and transportation emissions, **we now need to turn our focus to how, where and when we apply nitrogen fertilizers to our land.** As the human population grows and demand for food increases, this will be an **important challenge.**

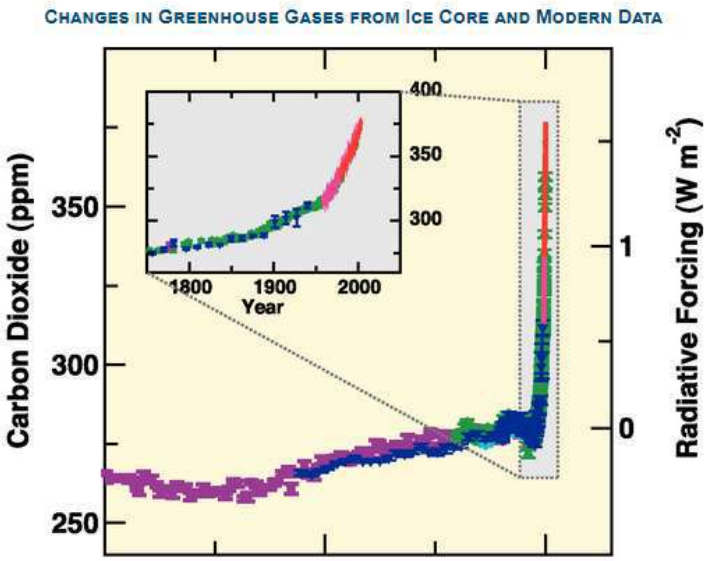
Fluorinated Gases or Halocarbons

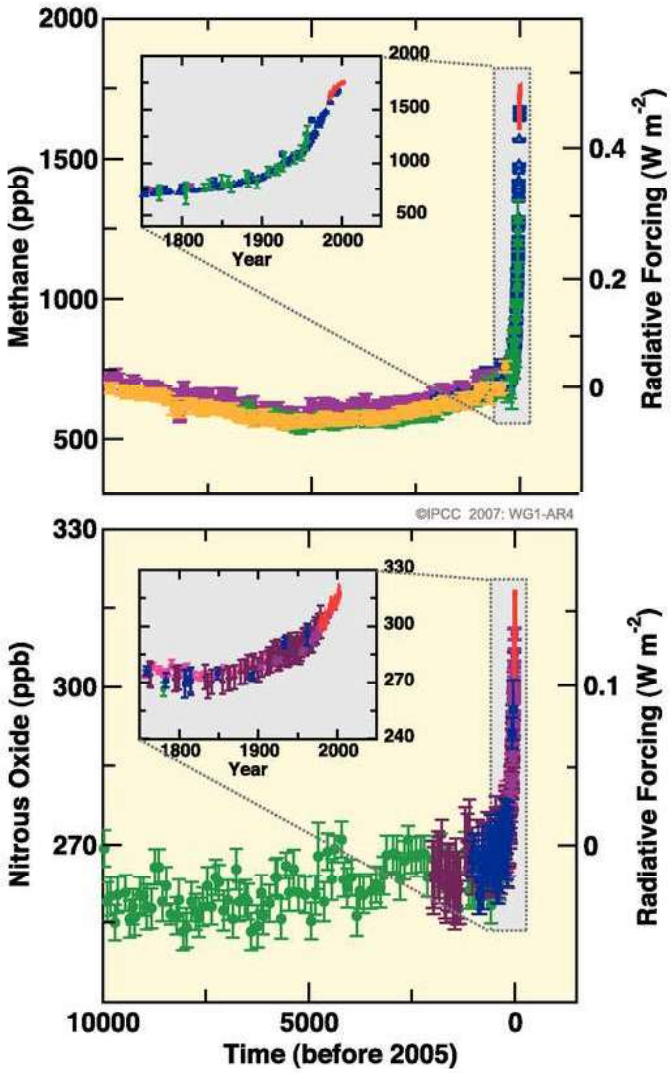
greenhouse gases created by humans that are not naturally occurring in the atmosphere.

Montreal Protocol in 1987 ➔ we progressively banned CFCs (chloroflurocarbons).

Halocarbons can contribute to greenhouse effect for 50,000 years

Now, we need to set our sights on some of the other fluorinated gases or halocarbons that are created and used for refrigeration, the manufacturing and operation of electronics and more.

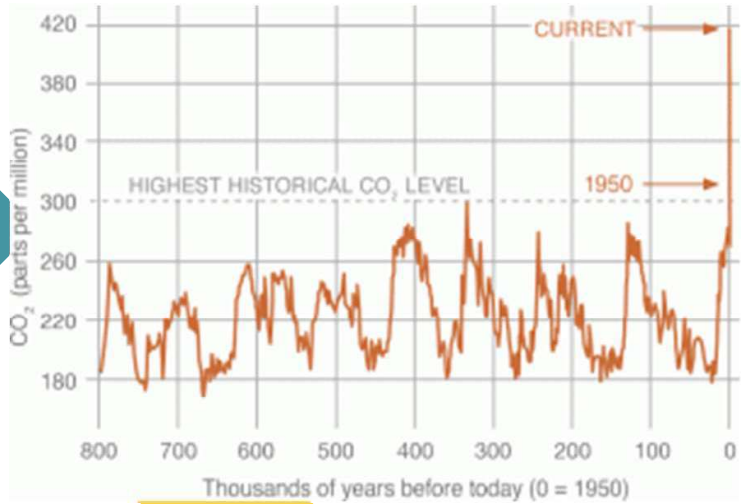


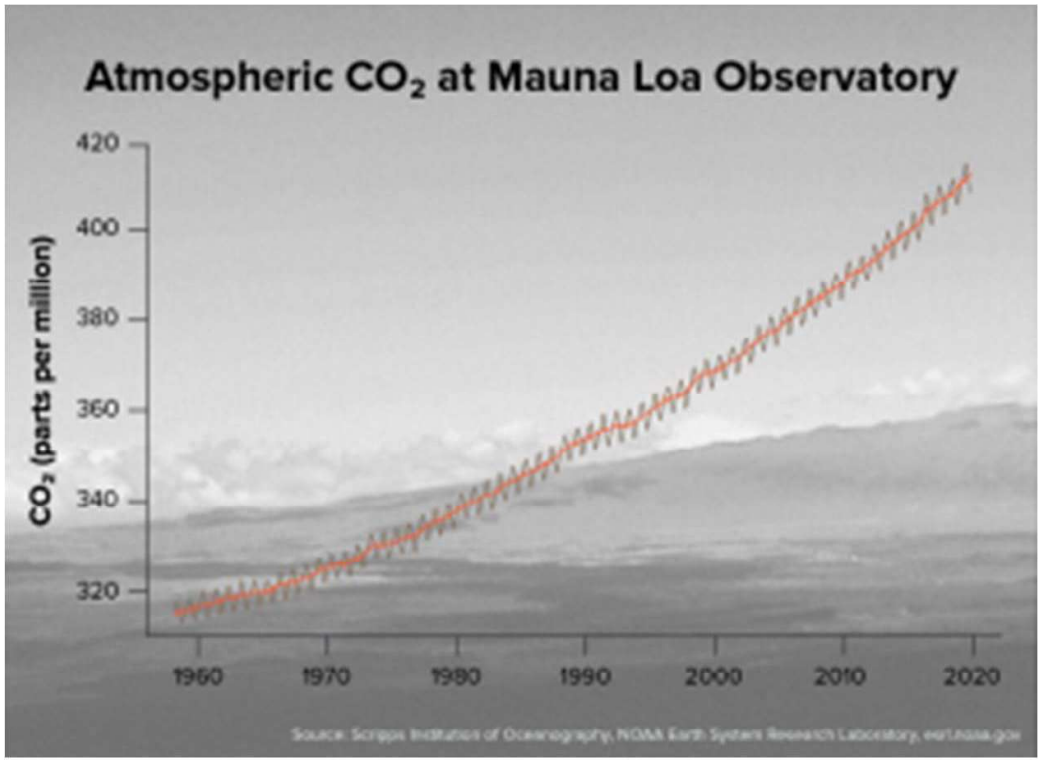


Atmospheric concentrations of carbon dioxide, methane and nitrous oxide **over the last 10,000 years** (large panels) and **since 1750** (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. Data available at: https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-1.html IPCC.ch

Anthropogenic climate drivers

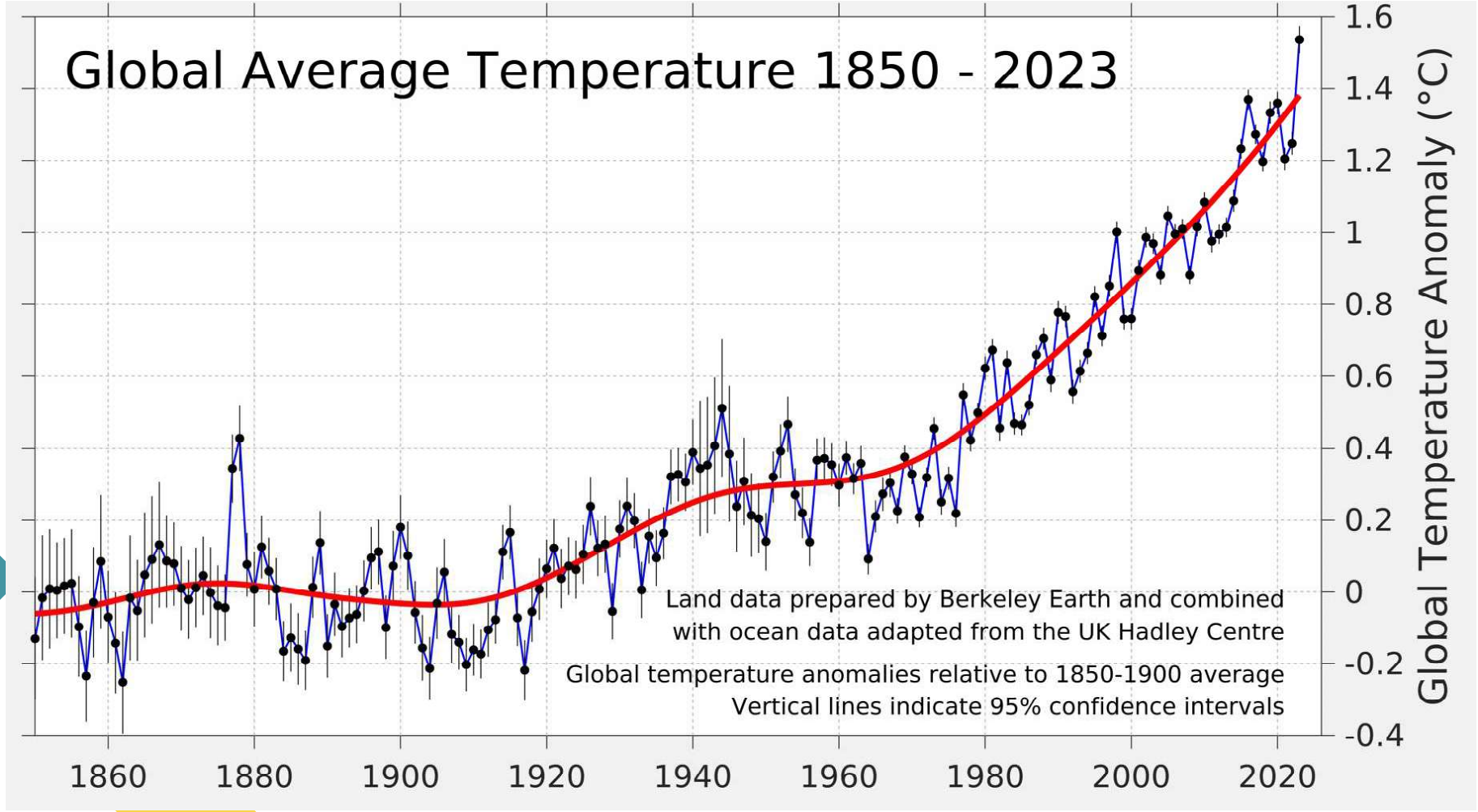
a **gradual warming** of the Earth caused by an unnatural (human-induced) increase of the greenhouse effect, as concentrations of greenhouse gases increase primarily from the burning of fossil fuels (coal, oil, and natural gas).





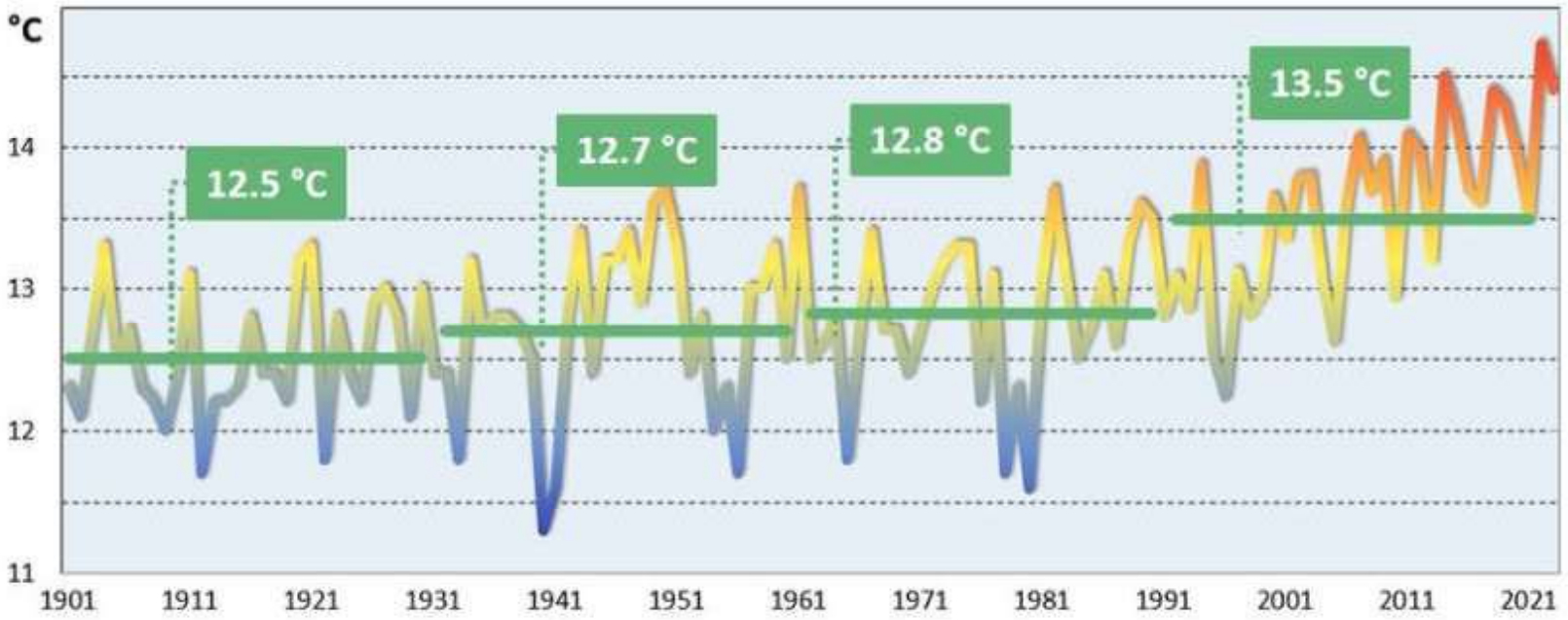
Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. (Source: NOAA and Scripps Institution of Oceanography)

Global temperature trends



https://berkeleyearth.org/

Local temperature trends (regional scale)



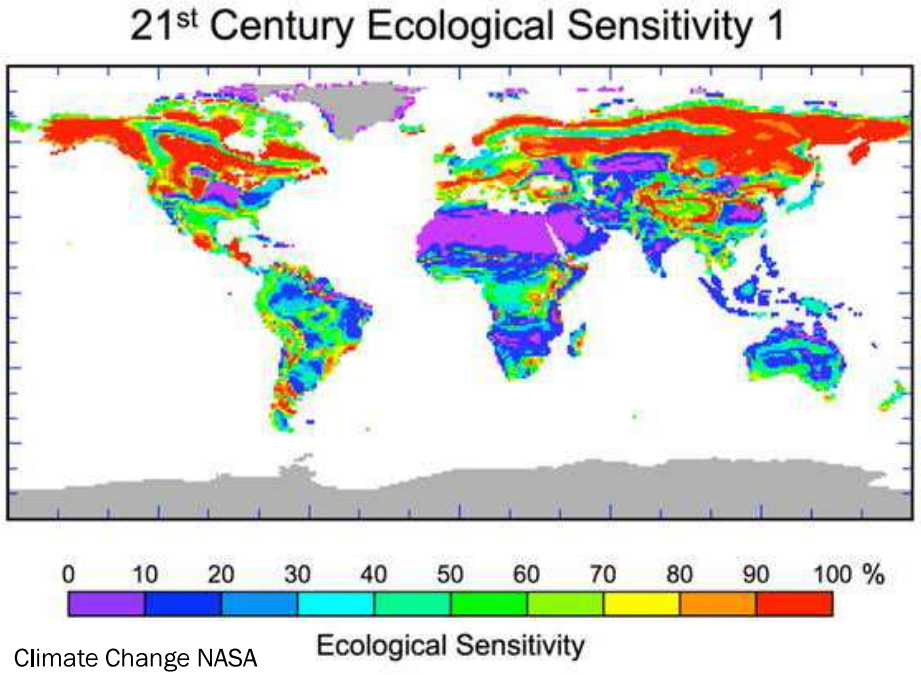
Andamento secolare della temperatura media annuale a Udine. Dati: serieHistAlp 1901-1991 Osmer-RAFVG 1992-2023. Le linee verdi orizzontali indicano le temperature medie trentennali. Temperatura media anno 2023: 14.4 °C. Temperatura media secolo scorso (1901-1999): 12.7 °C.

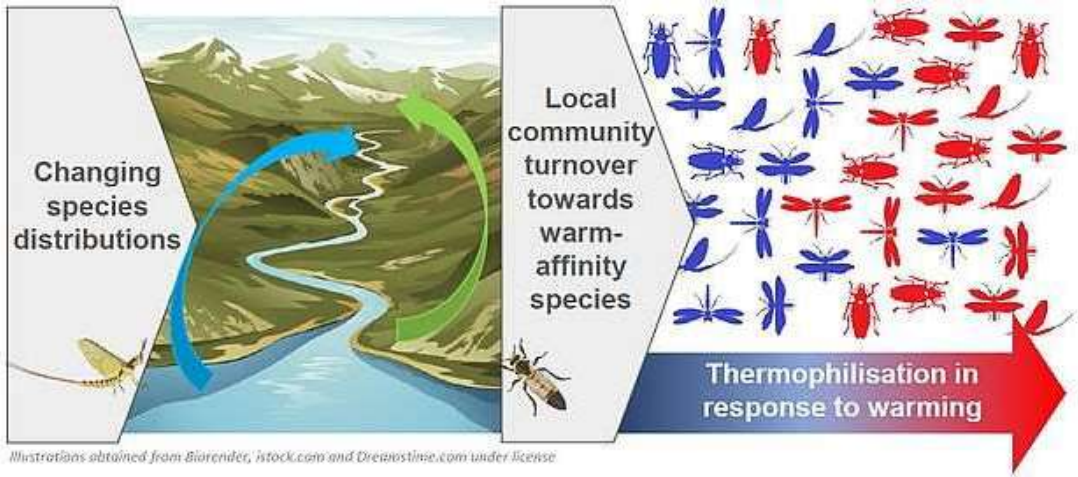
Average temperature year 2023: 14.4 °C.
Average temperature last century (1901-1999): 12.7 °C.

With these values, 2023 turns out to be the third warmest year since at least 1901, surpassed only by 2022 and 2014 (dati ARPA FVG).

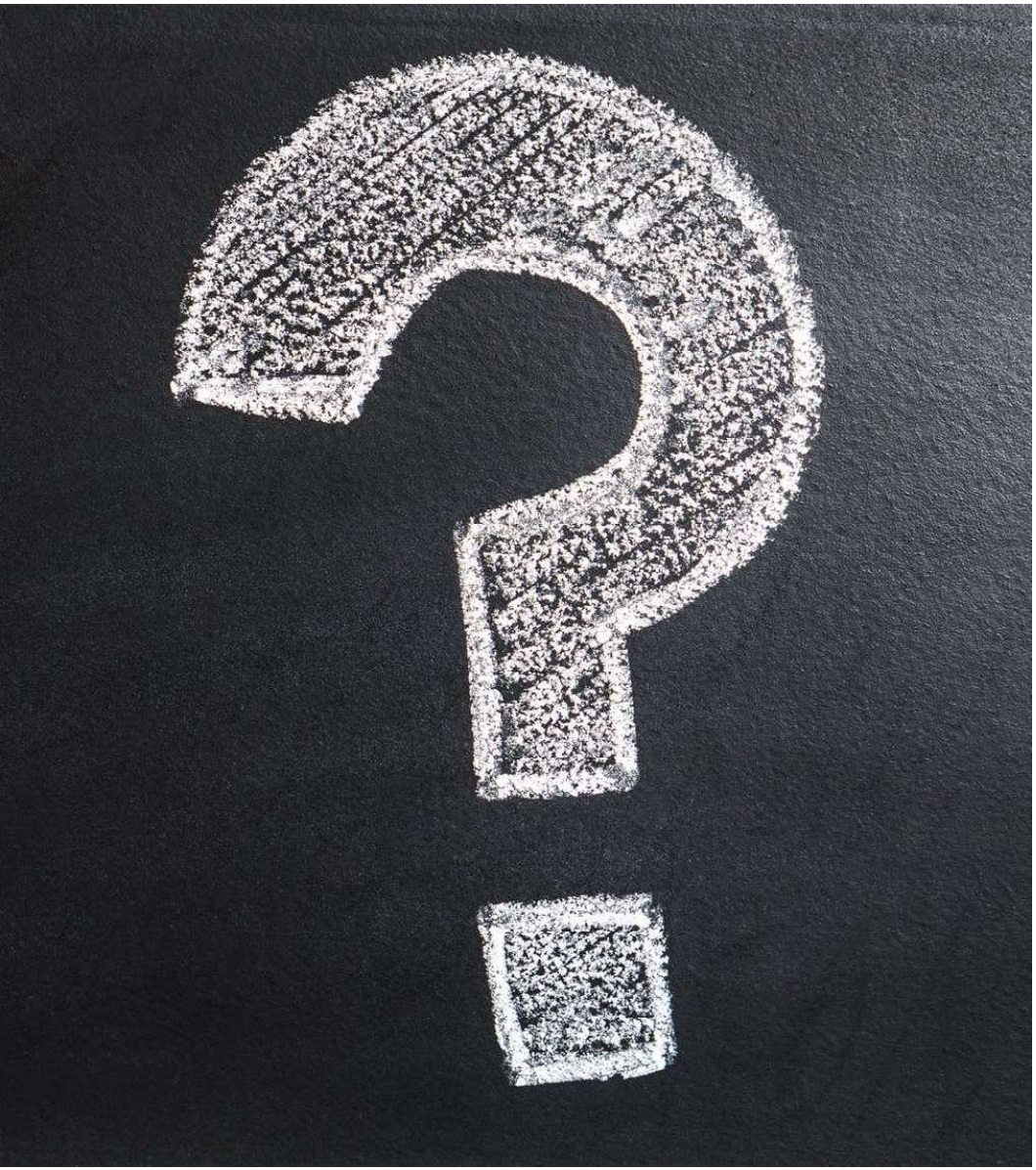
impacts on ecosystems and species distribution

The **higher** a species is in **latitude**, the **lower** its **tendency to live** in areas near the **equator** with temperatures they could tolerate





(Graphic: Eawag, illustrations obtained from Biorender, istock.com and dreamstime.com)



Questions

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