Understanding air quality and climate change science

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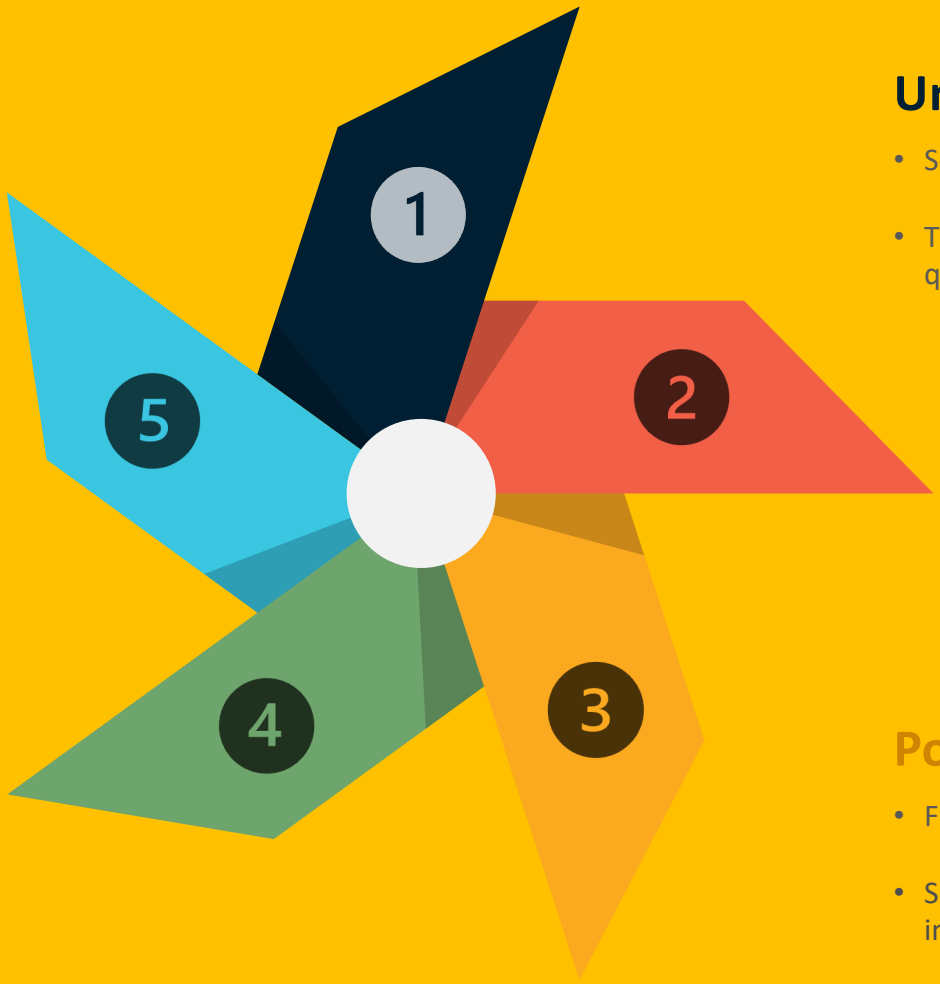
Science and policy

@ https://www.finestresullarte.info

Luigi Catani, In the presence of the Grand Duke, Galileo performs the experiment of the falling bodies from the Tower of Pisa

Our programme in this training



Understanding science

- Scientific principles of climate change
- The air we breathe: understanding air quality

Policy framework AQ

- A historical perspective and recent developments
- Modern scientific tools for policy support

Policy responses to CC

- From history to present
- Scientific methods to provide information to policy

Advocacy plan

- Promoting science as input to policy. An exercise

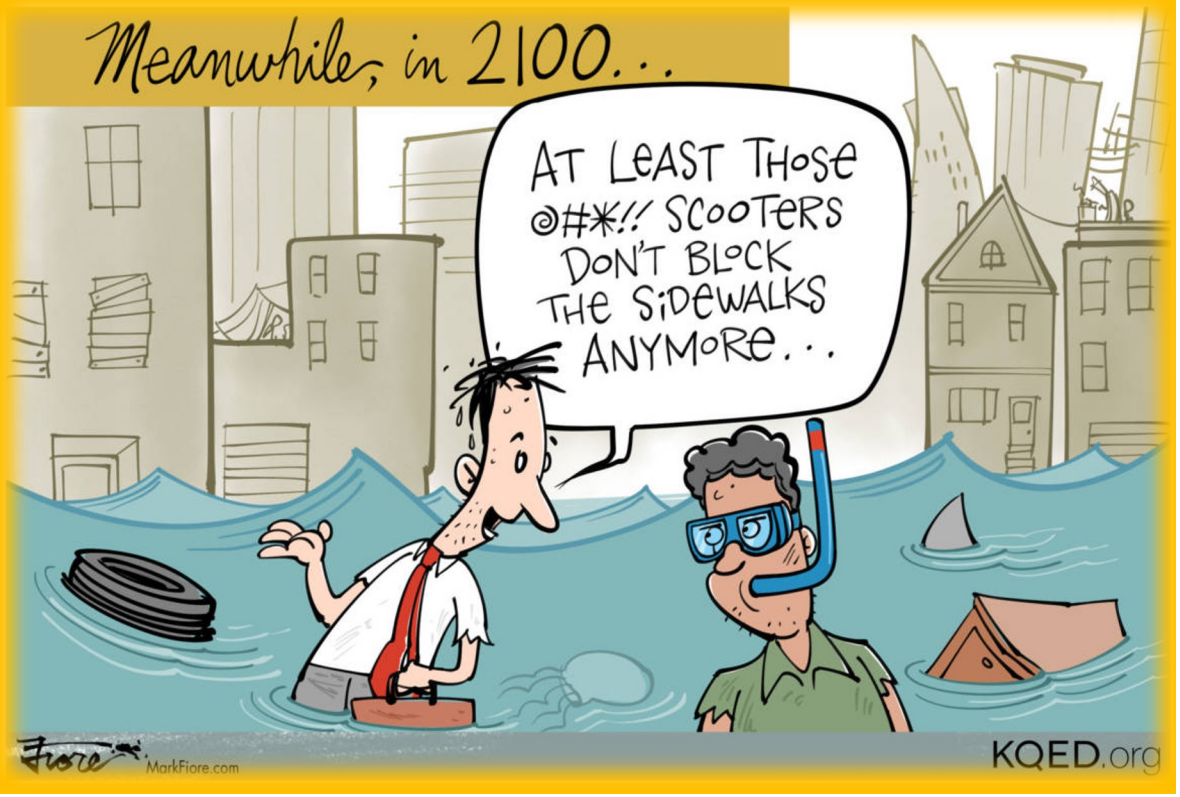
Future visions

- Shaping tomorrow: science in an uncertain world
- The power of connection

Outline

- Scientific principles of climate change
- The air we breathe: understanding air quality

- What is a recent news article or fact about climate change that caught your attention?



What is climate?

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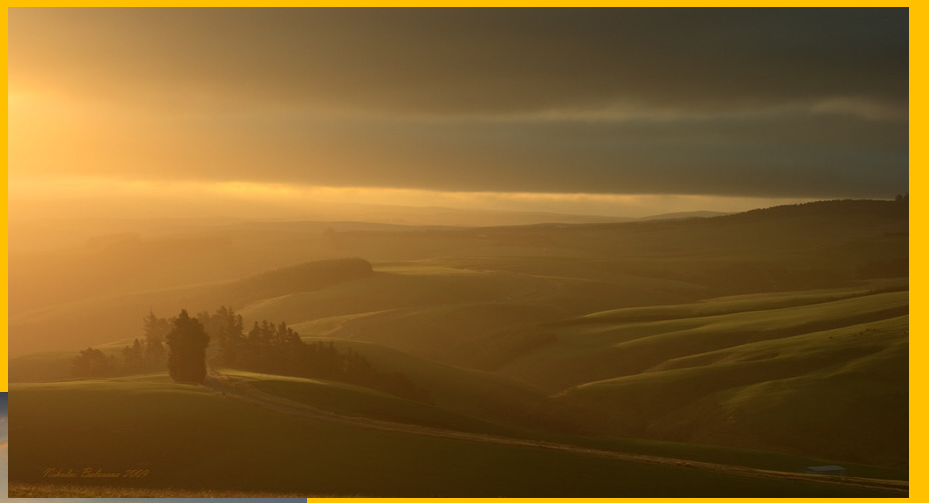

It is the long-term average of conditions of the atmosphere, oceans, and glaciers together, typically described over long-time intervals such as months, seasons, years, decades

Climate or weather change?

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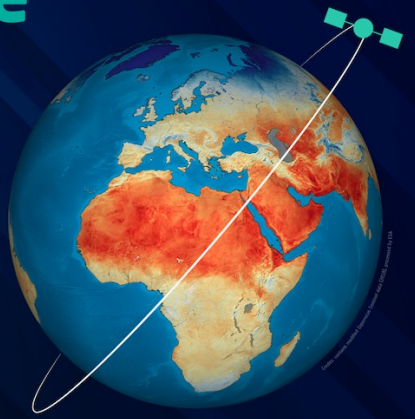
esa

Weather versus Climate

The difference between weather and climate is a matter of time

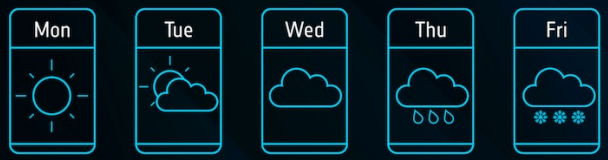


Weather

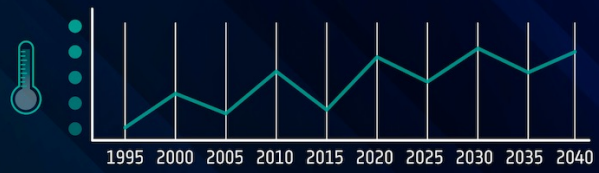
refers to short-term changes in the atmosphere.
It can change minute-to-minute, hour-to-hour and day-to-day

Climate

describes the average weather conditions in a specific area over a long period of time – 30 years or more



Satellites measure several aspects of Earth's weather as well as provide essential data over decades to monitor how our climate is changing



Climate is influenced by

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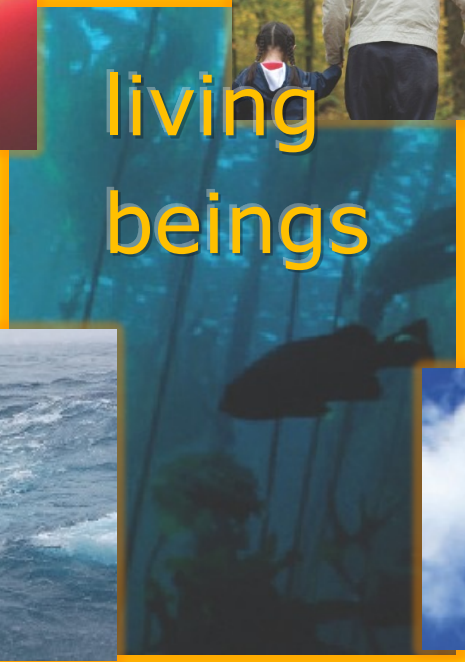
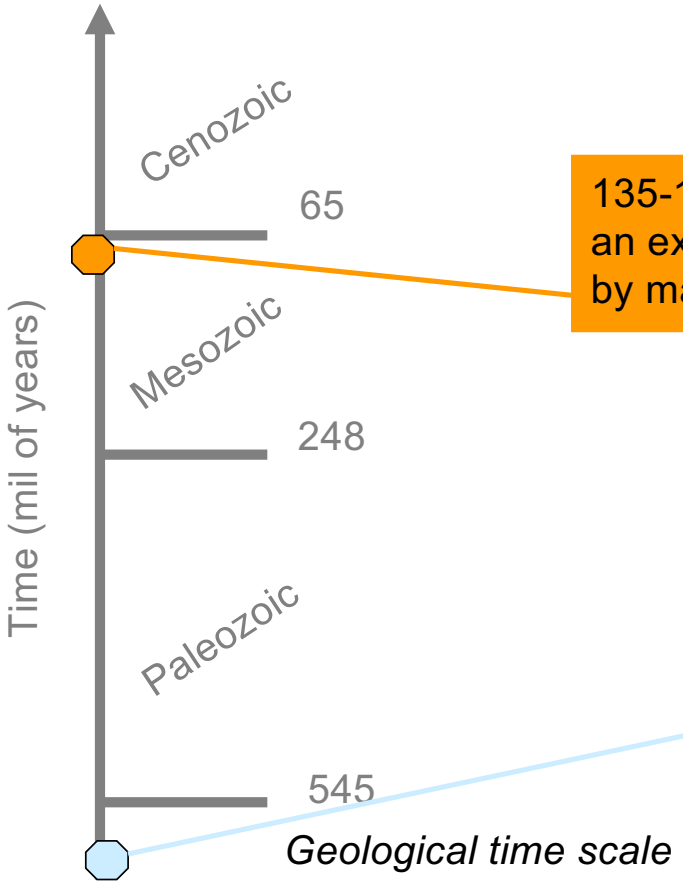
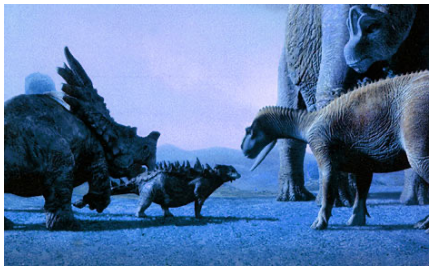


Climate has always changed



Geological time scale

135-115 mil. years ago, dinosaurs live on Earth: an extremely warm period, CO_2 is emitted by many volcanoes



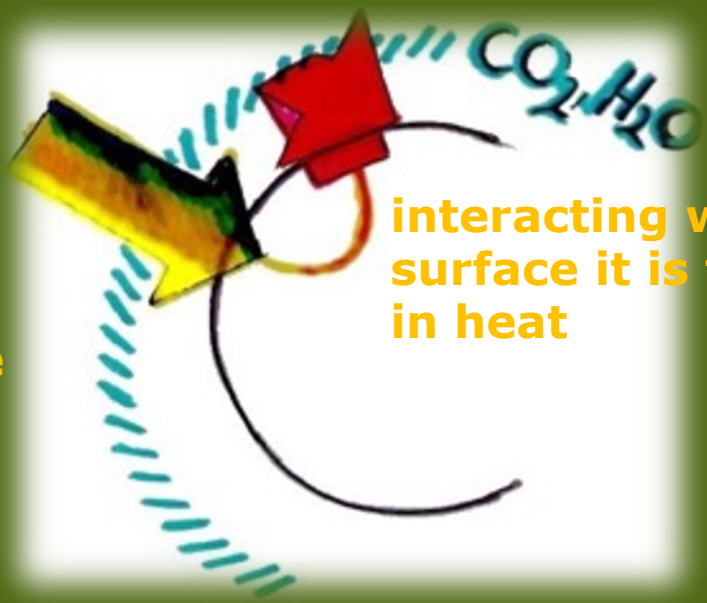
Temperature rises perhaps due to carbon dioxide (CO_2) emetted by volcanoes in the atmosphere

600-700 mil. years ago: Earth was covered by an ice layer of 1 km from tropics to the Poles

The Greenhouse effect

The visible solar radiation arrives

passes through the atmosphere



is absorbed by some of the gases and reemitted

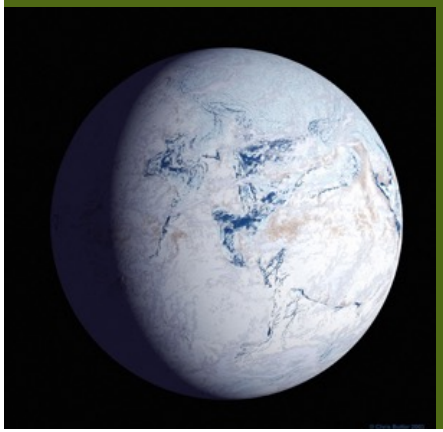
interacting with the surface it is transformed in heat

warming the Earth

The greenhouse gas effect is natural

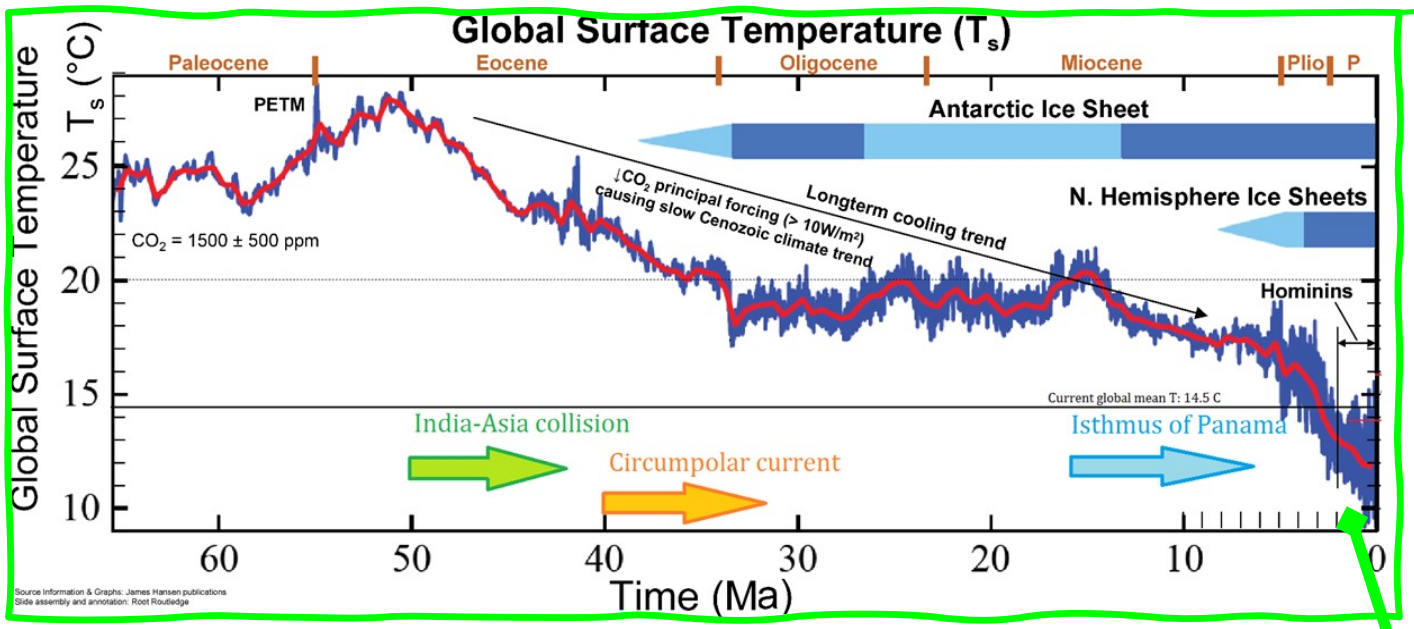
Since the beginning of the Earth its atmosphere contained CO_2 due to volcanic activity

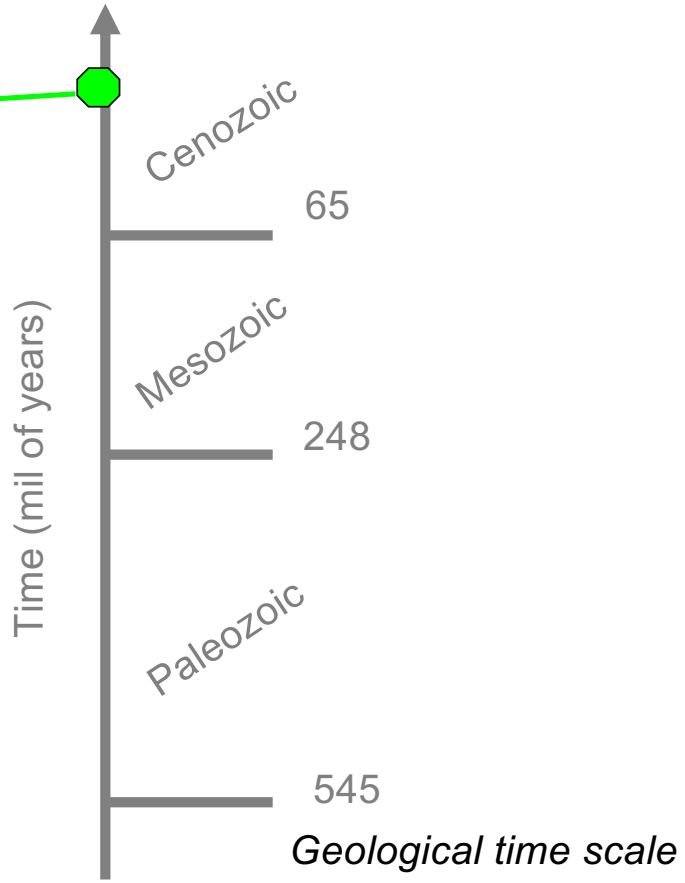
The existence of the atmosphere and of the natural greenhouse effect determined the origin of life



Without greenhouse gases, the global temperature would be around 18 degree below zero

Climate has always changed



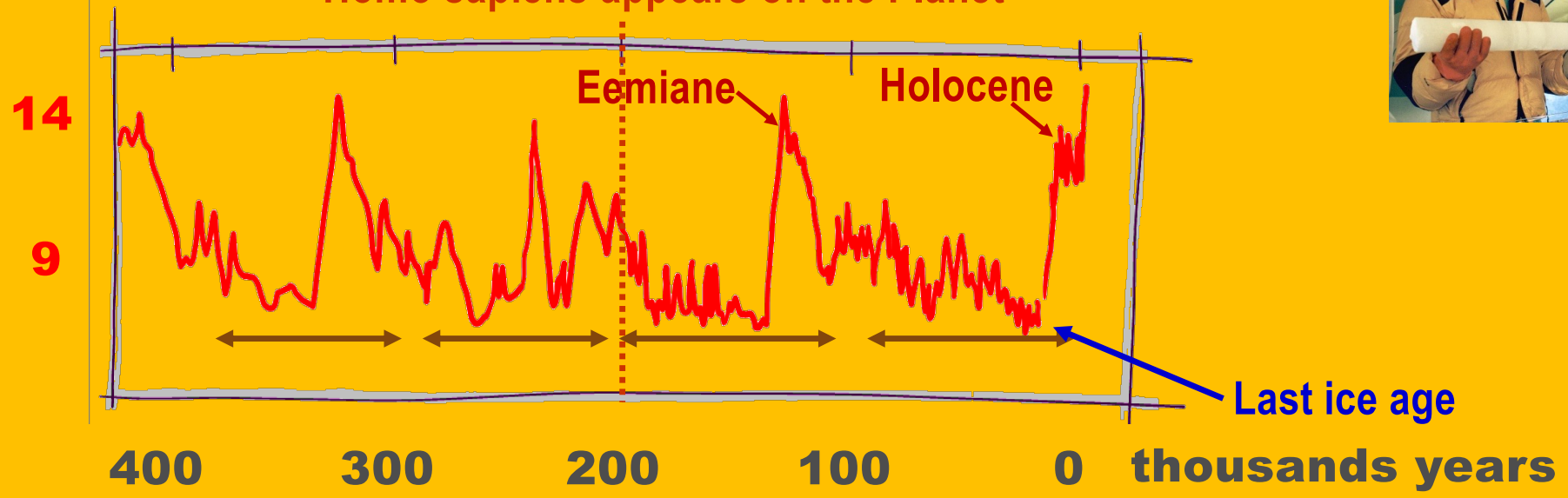


Geological time scale

from 3 mil. of years til now: cycles of warming and cooling with temperatures even higher than current

Temperature of last 450.000 years

In a more recent time…



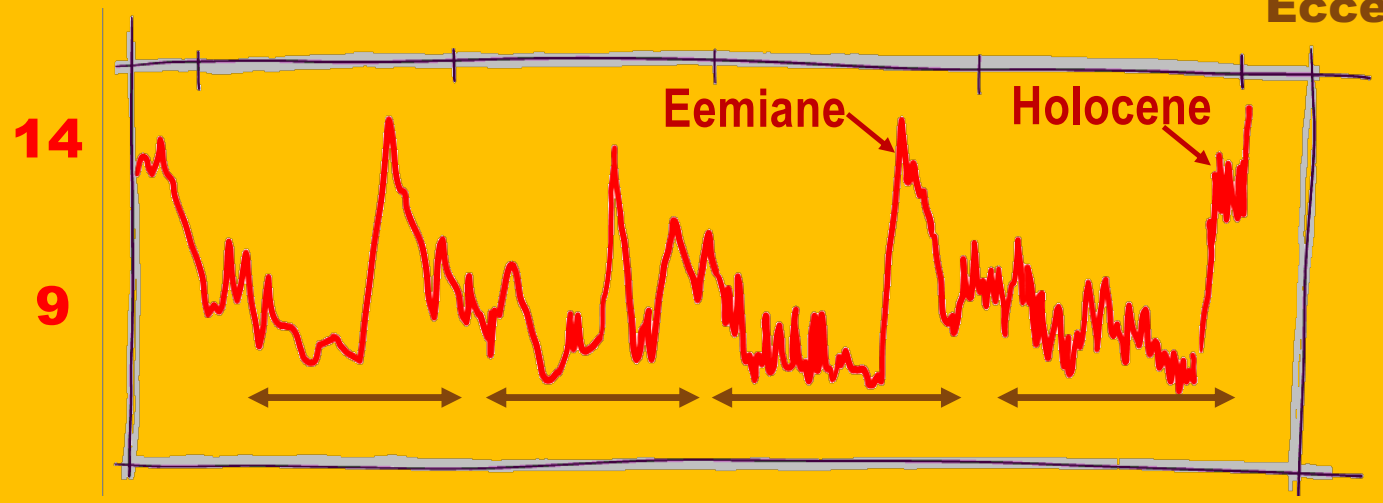
100.000 year cycles – Earth's orbital cycles

Petit et al, 1999

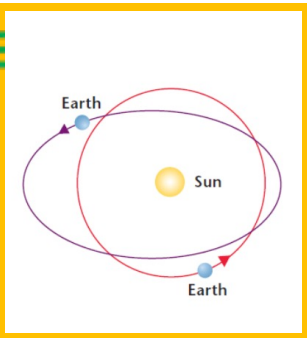
Temperature of last 450.000 years

In a more recent time…

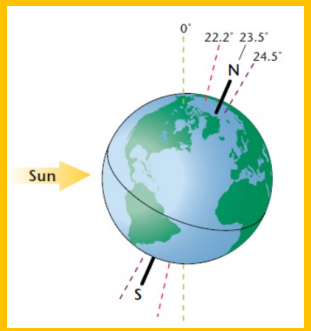
Average temperature of the Earth (ºC)



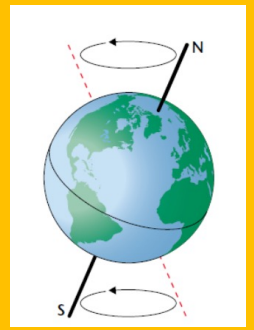
100.000 year cycles – Earth's orbital cycles



Eccentricity (100.000 years)



Tilt (41.000 years)

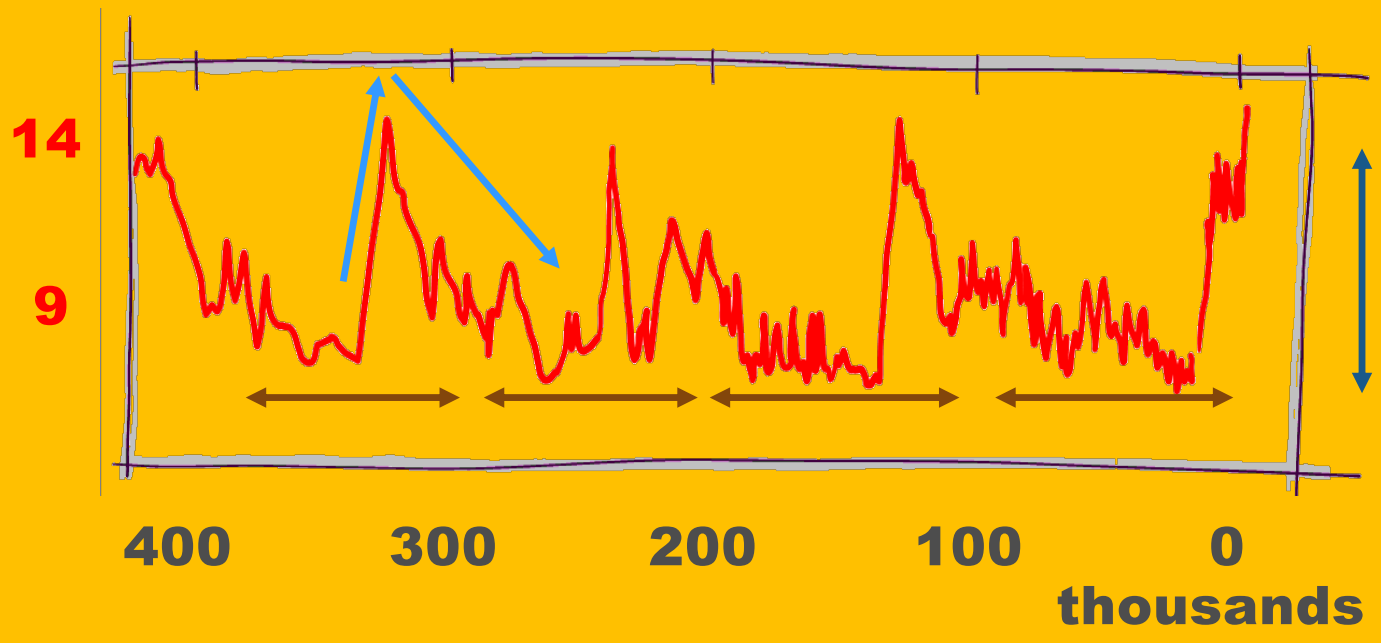


Precession (21.000 years)

Temperature of last 450.000 years

In a more recent time…

Average temperature of the Earth (ºC)

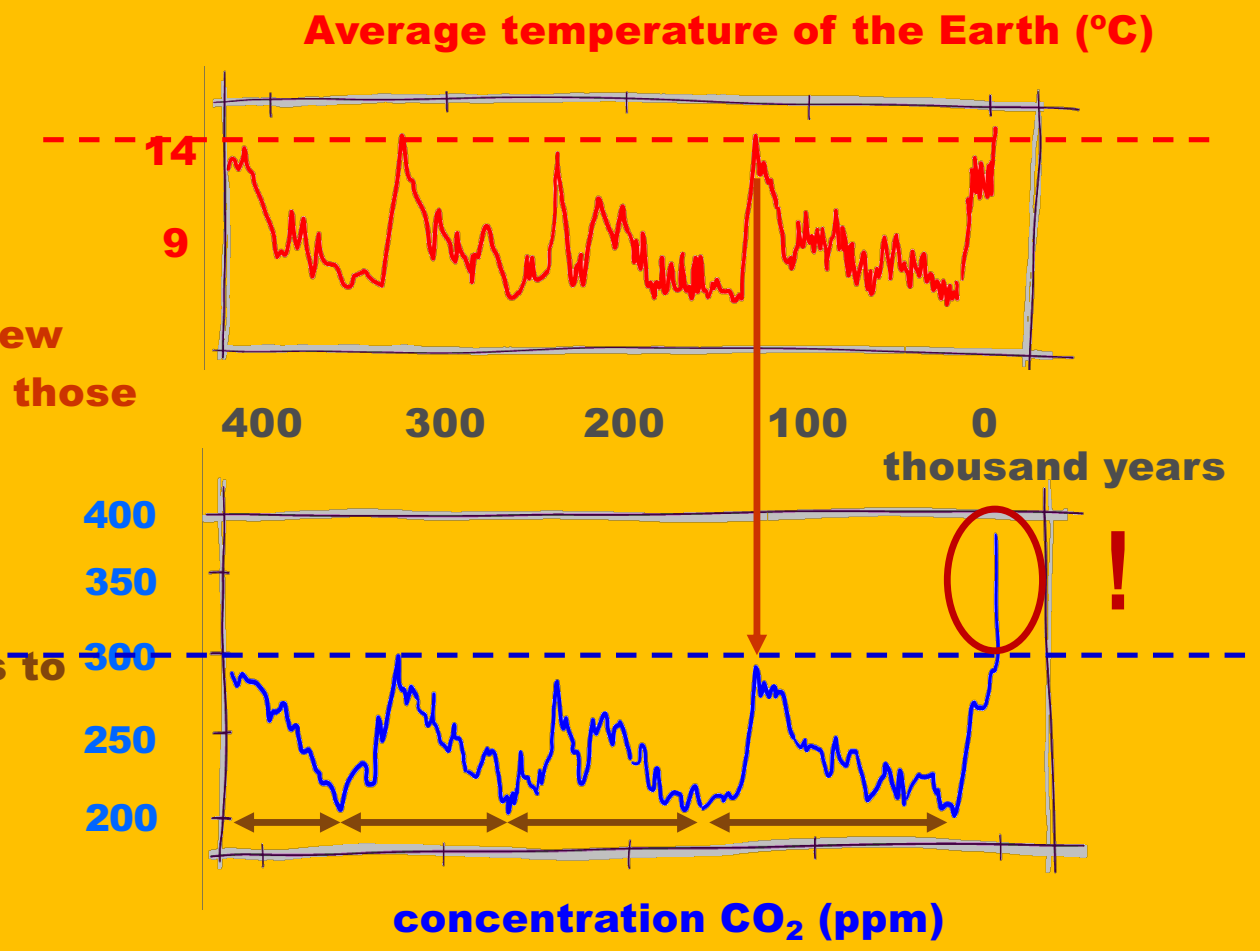


100.000 year cycles – Earth's orbital cycles

Warmings more rapid than coolings

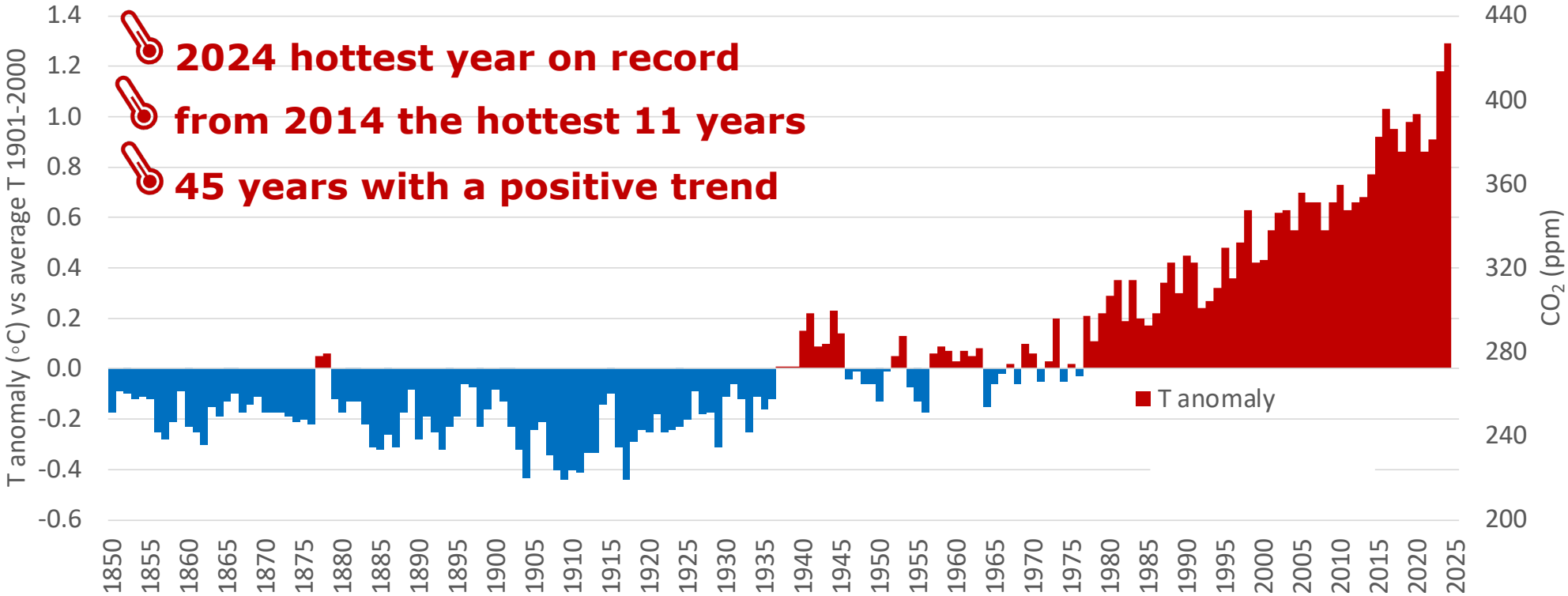
5 degree ˚C between ice and interglacial ages (in roughly 20.000 years)

CO_2 had a similar behaviour

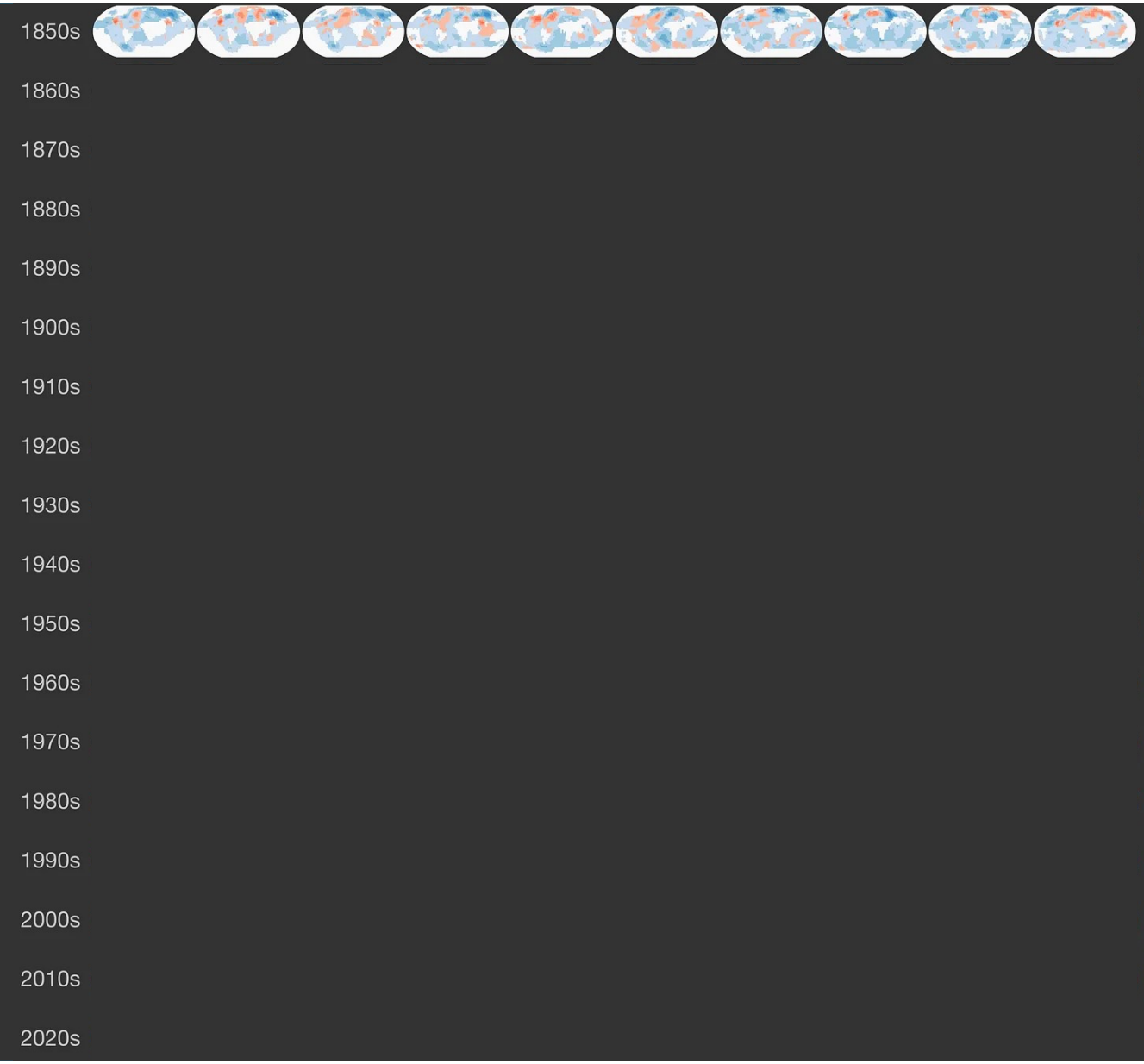


CO_2 rate of change is unprecedented over millenia

Change of temperature



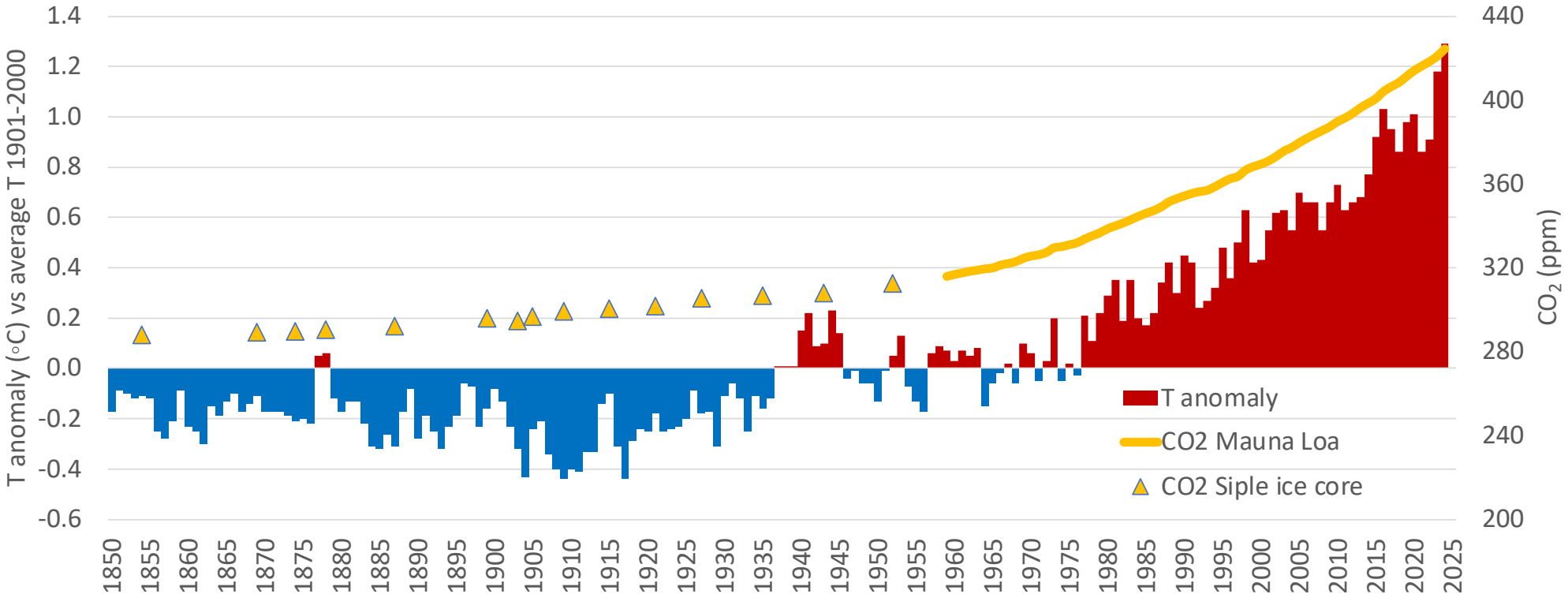
Mapping changes in temperature *from 1850 to 2024*



One for each year, showing cooler (blue) and warmer (red) regions.

The warming of the planet is obvious everywhere

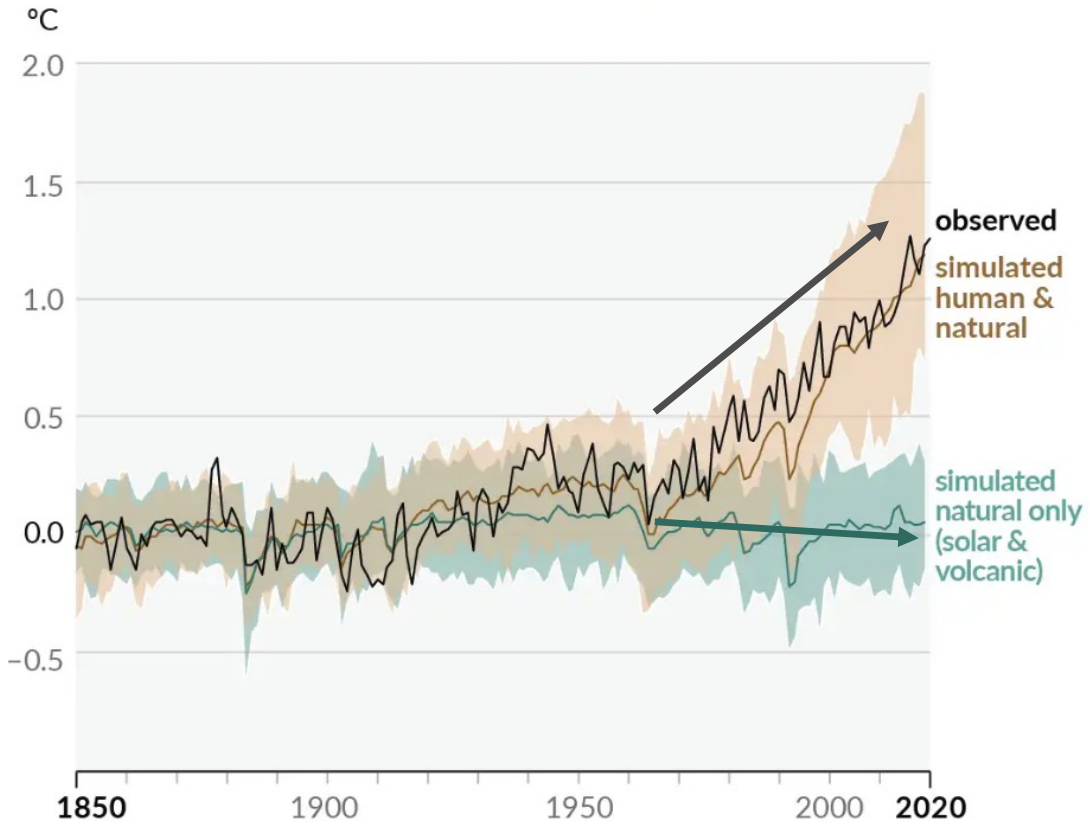
Change of greenhouse gases



1.46 degree °C in roughly 170 years

T increase coinciding with increase of CO_2

How do we know humans are the cause?



IPCC, Climate Change 2021: The Physical Science Basis, 2021

Major greenhouse gases

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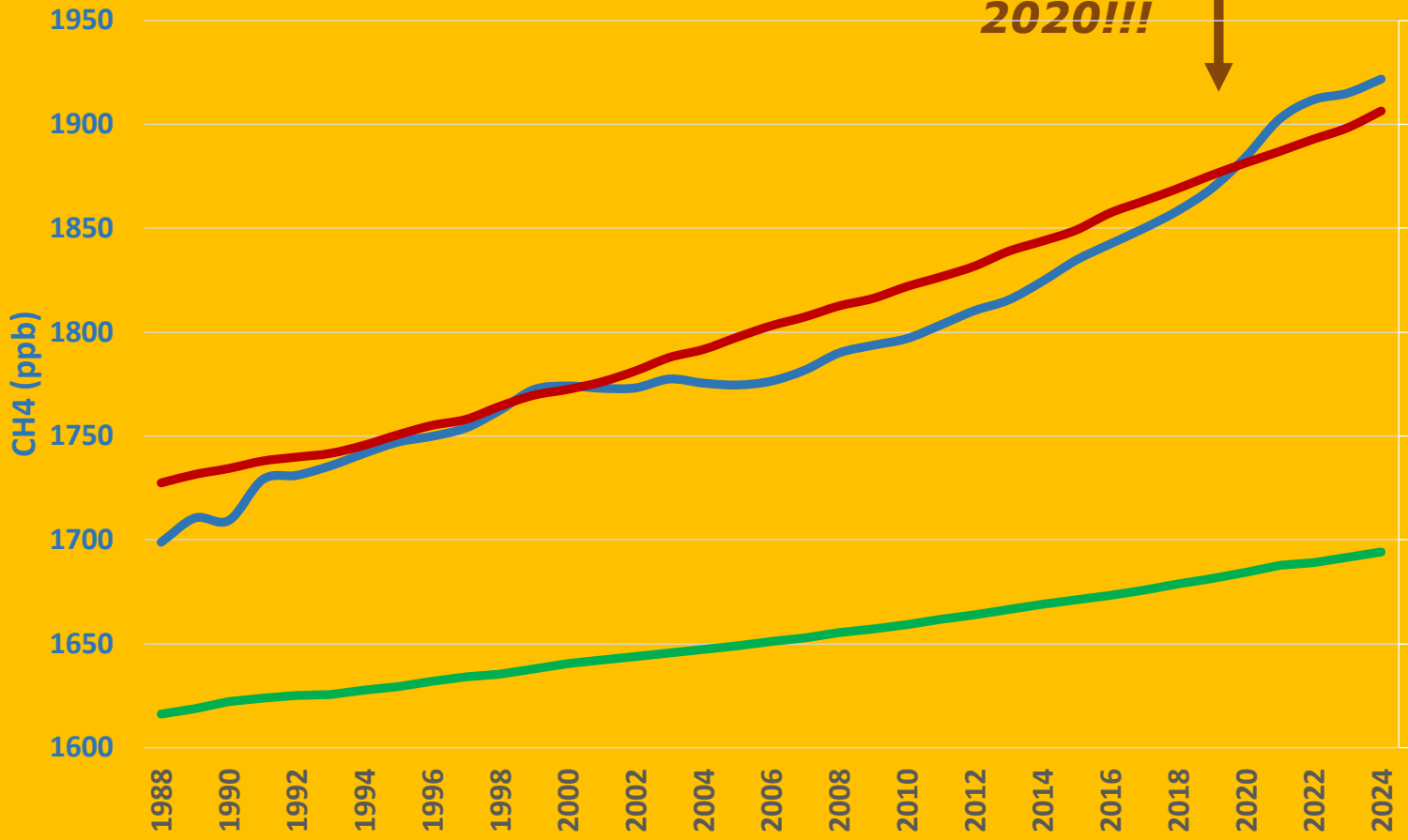
GHG concentrations

No decrease in 2020!!!



vs pre-industrial

+50%

>200%

+25%

capability to warm the atmosphere

1 time

28 times

273 times

National Oceanic and Atmospheric Administration (NOAA)

Greenhouse gasses from human activities

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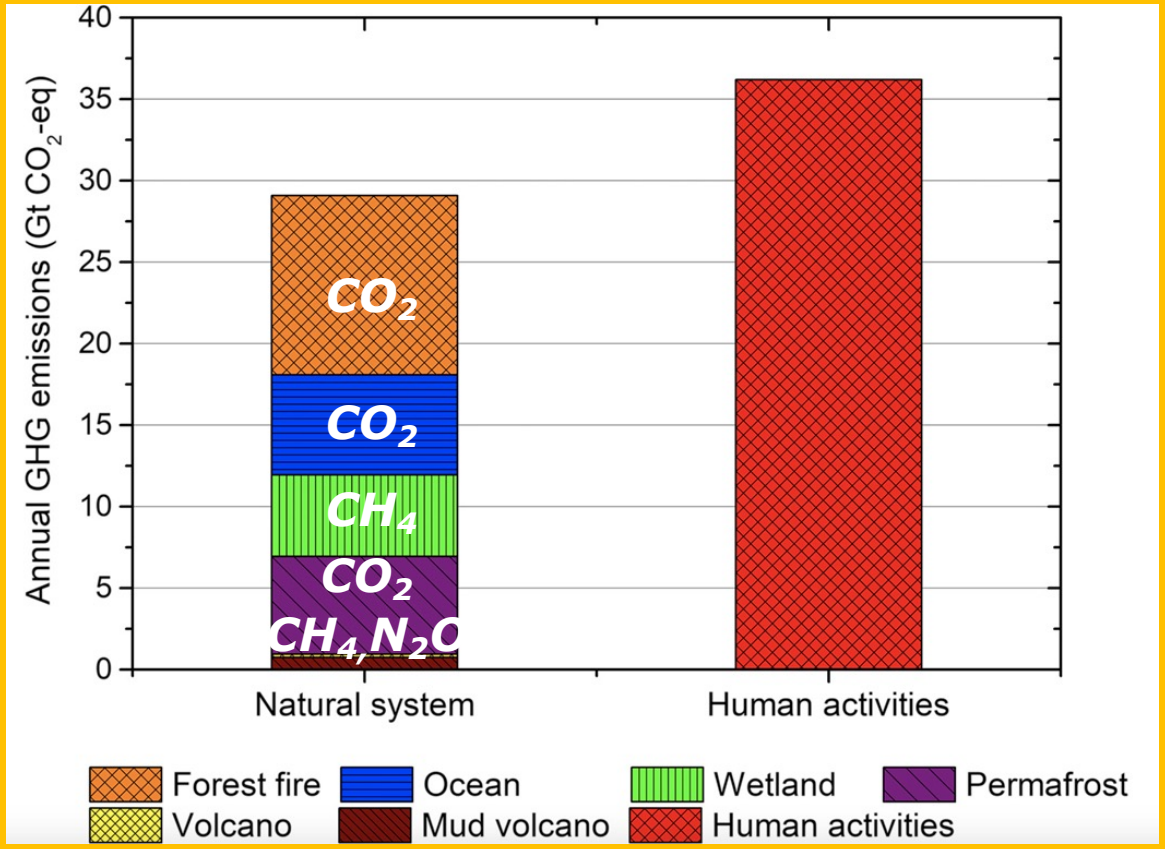
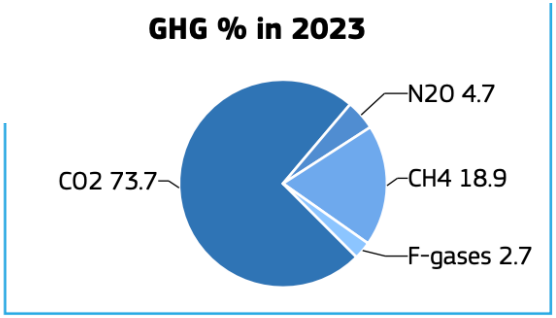
Natural and human GHG emissions



Yue and Gao, 2018

Global emissions of GHG
major sectors



Global financial crisis

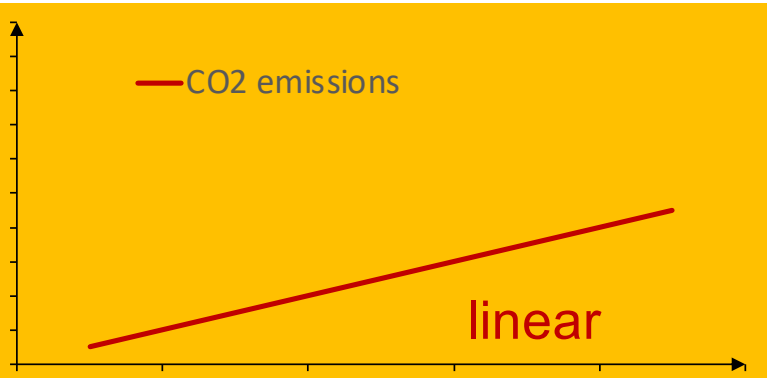
Paris Agreement

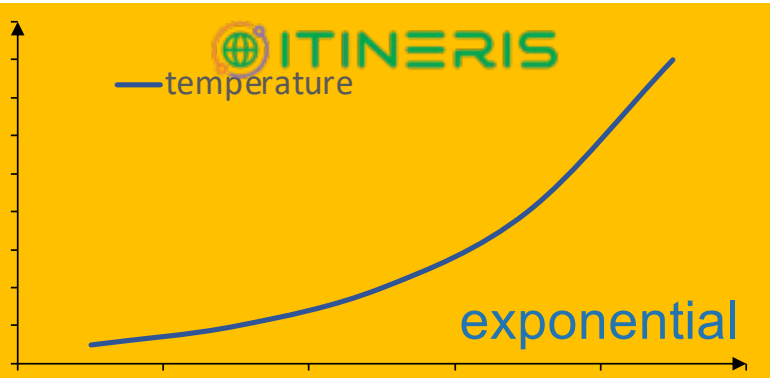
Sars-Cov2

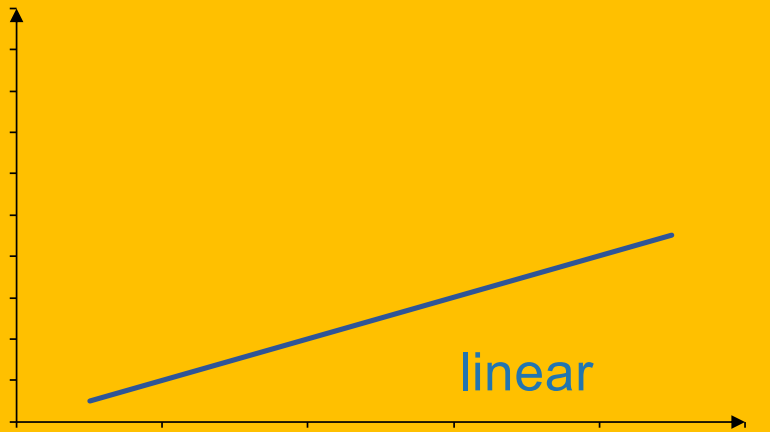
CO_2 residence time, trends, Temperature

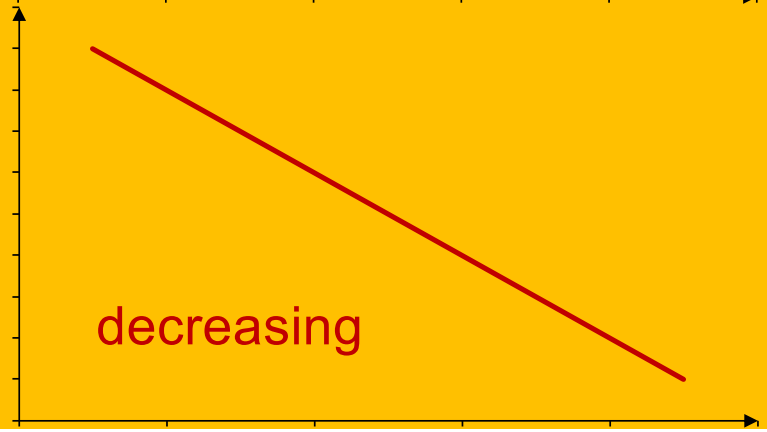
CO_2

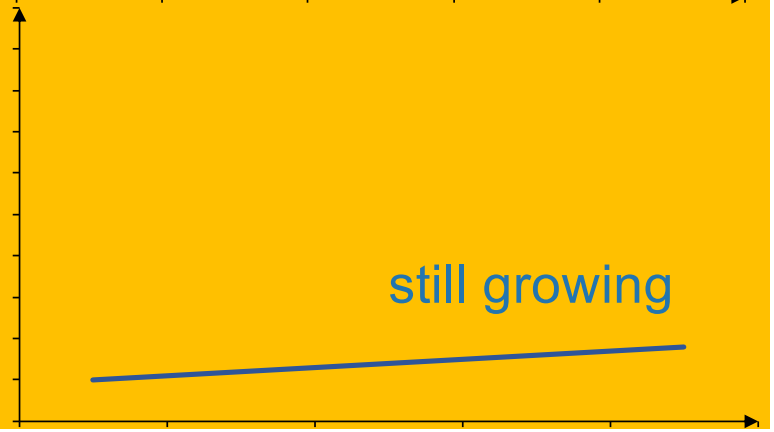
centuries to millennia











The evidence and effects are compelling

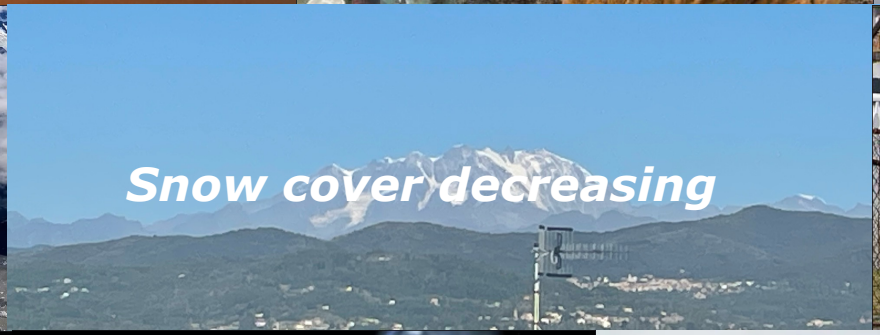
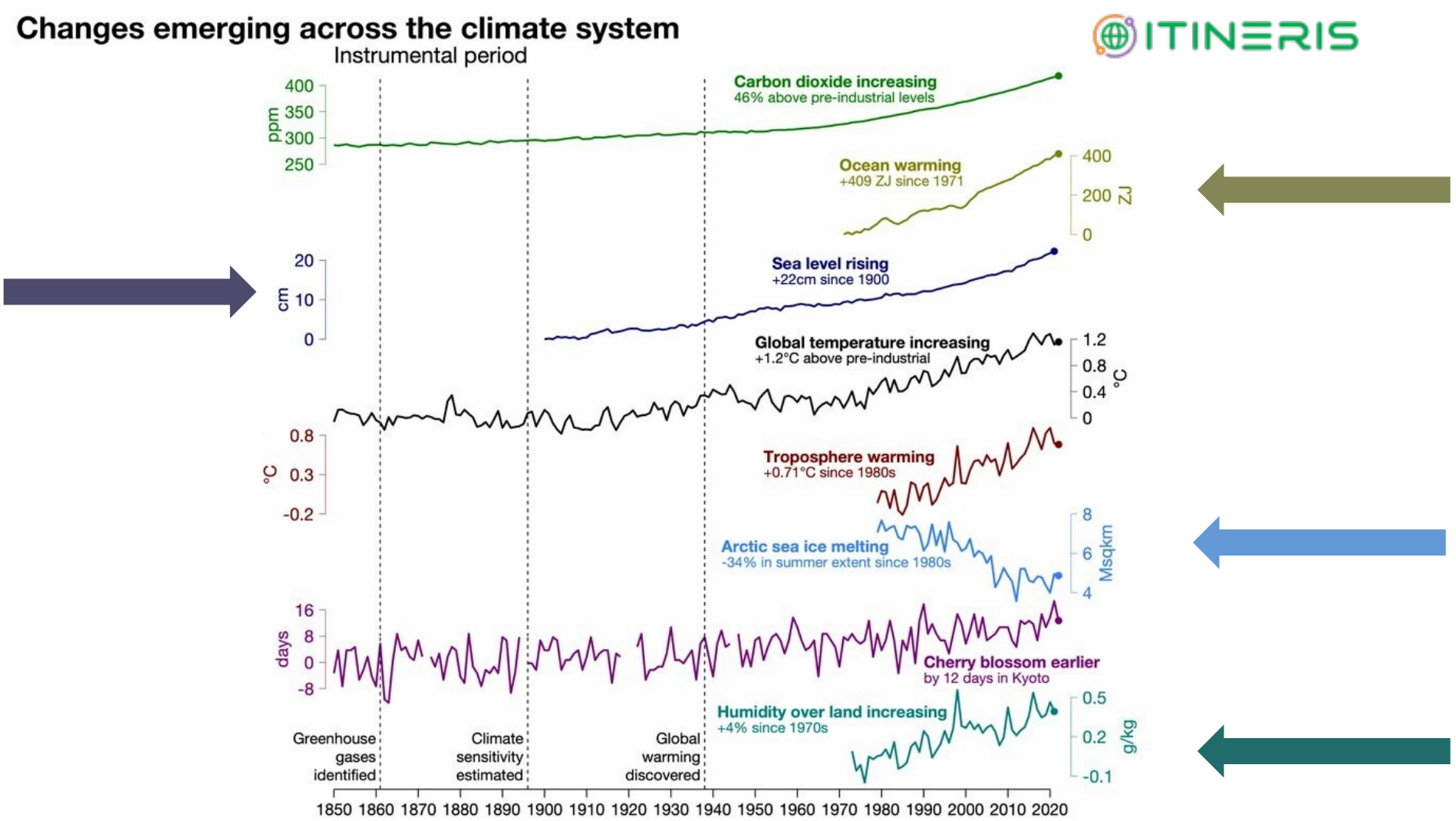
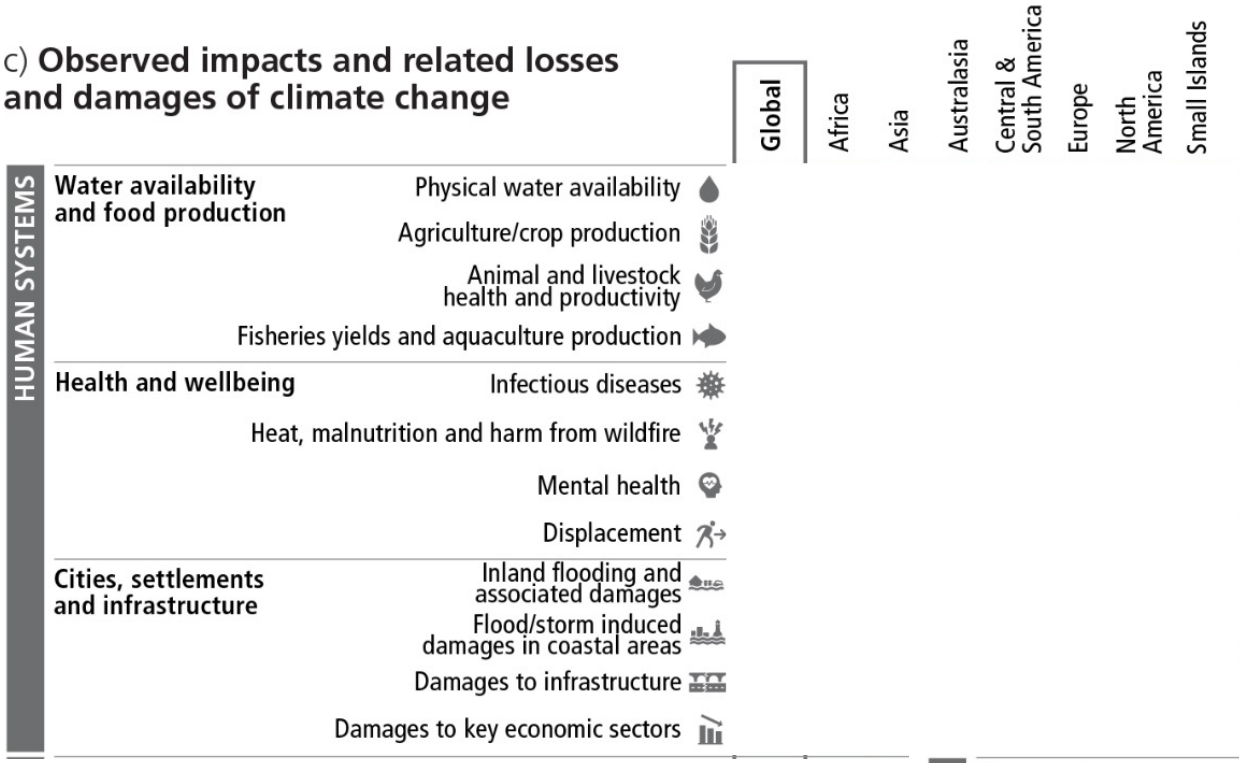


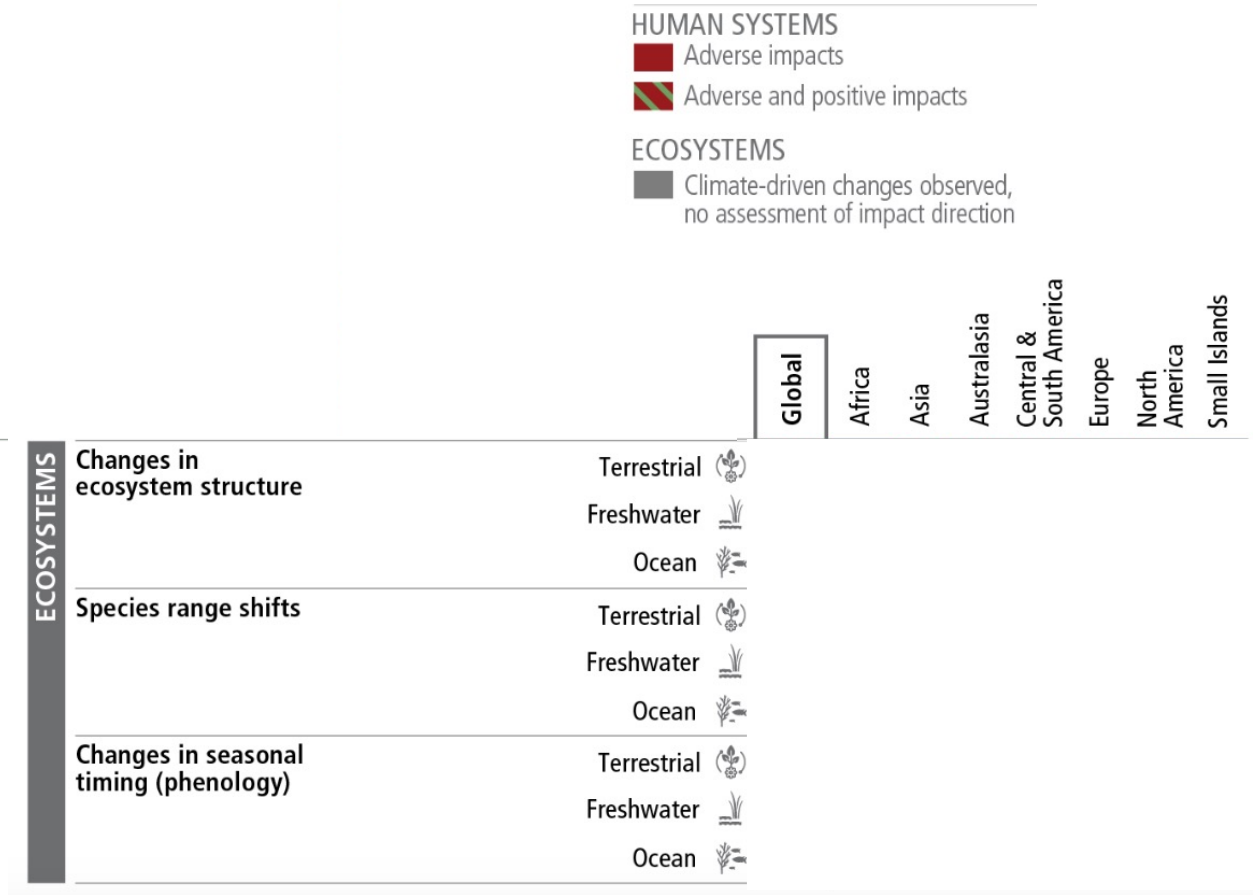
Photo credits @https://science.nasa.gov/climate-change/evidence/



Ed Hawkins, 2025
https://fediscience.org/@ed_hawkins/109710462146263953 2025

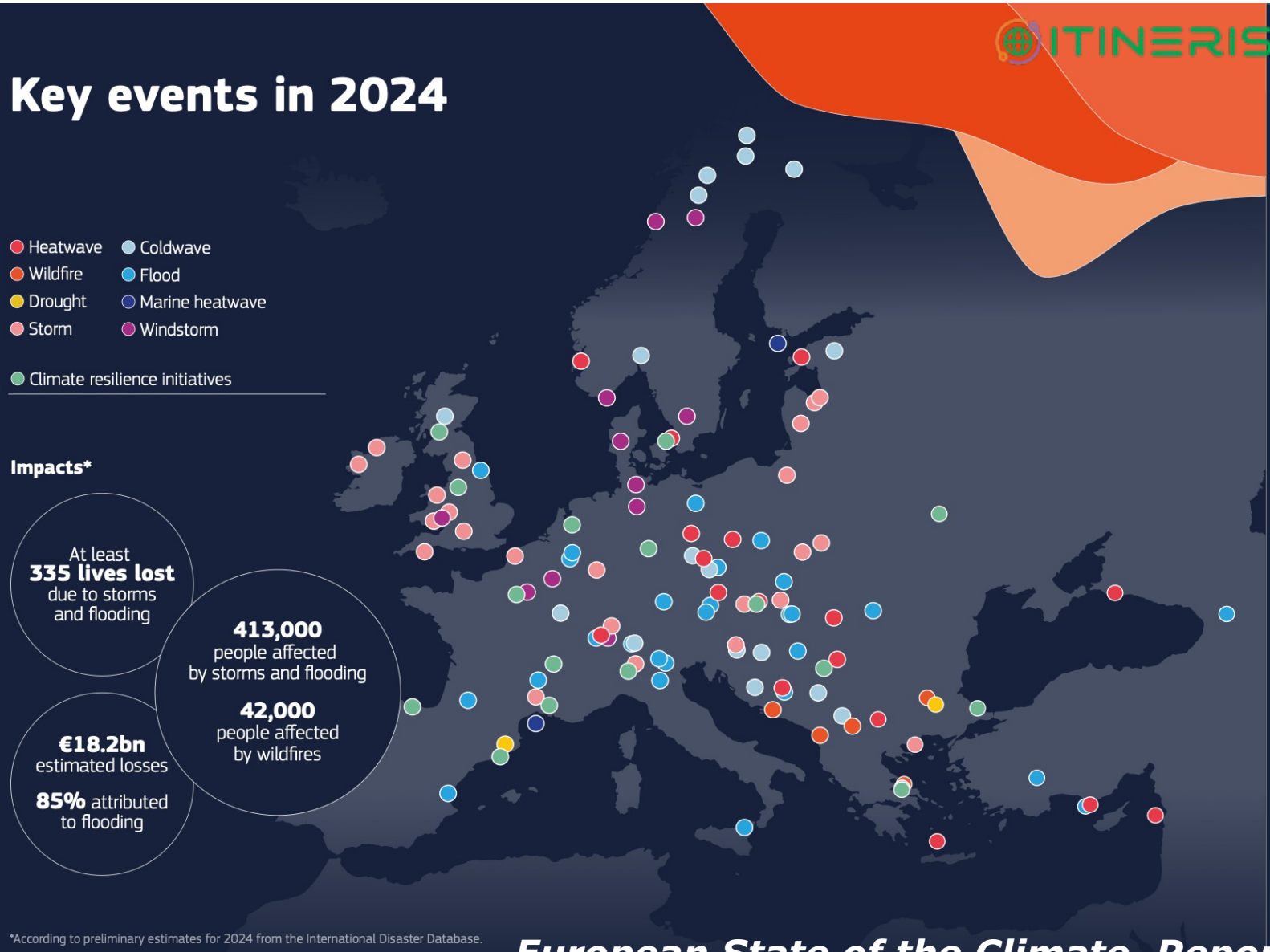
Environmental and societal impacts





IPCC, Climate Change 2023: Synthesis Report

Key events in 2024



Impacts*

At least **335 lives lost** due to storms and flooding

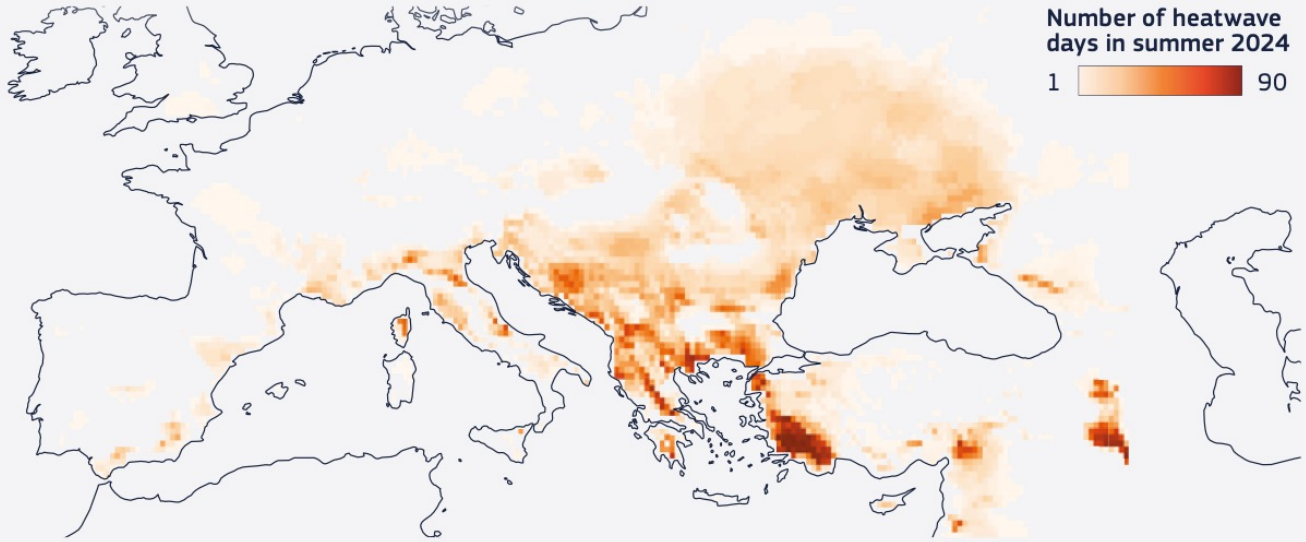
413,000 people affected by storms and flooding

42,000 people affected by wildfires

€18.2bn estimated losses

85% attributed to flooding

*According to preliminary estimates for 2024 from the International Disaster Database.



43 of 97 days had heatwaves

1 June to 5 September

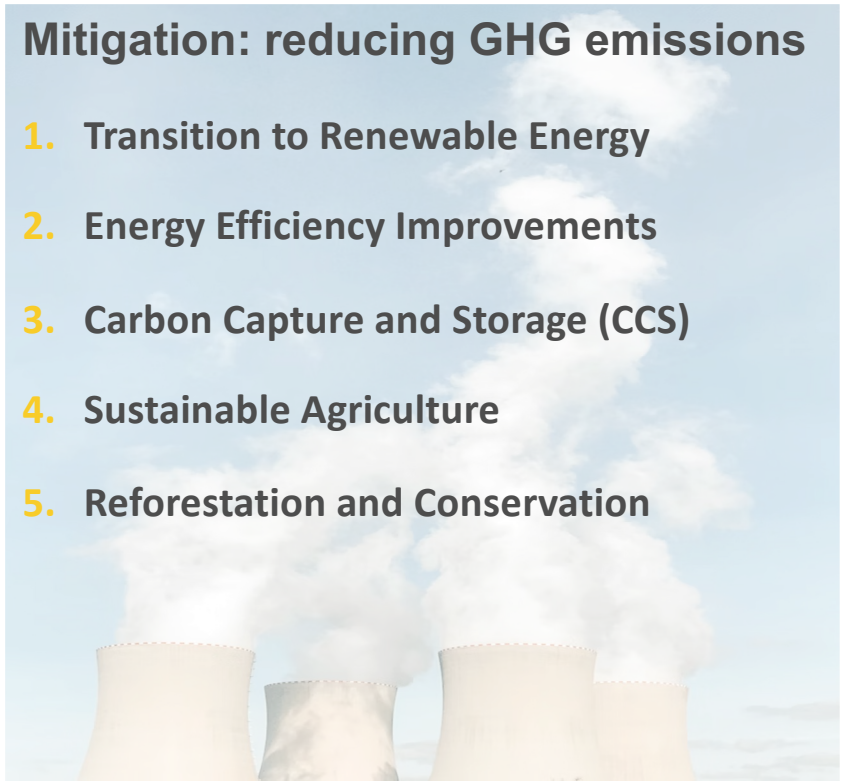
Average of 55000 heat-related deaths per year

European State of the Climate, Report 2024

Mitigation and adaptation strategies

Mitigation: reducing GHG emissions

1. Transition to Renewable Energy
2. Energy Efficiency Improvements
3. Carbon Capture and Storage (CCS)
4. Sustainable Agriculture
5. Reforestation and Conservation



Adaptation: preparing for climate impacts

1. Infrastructure Resilience
2. Water Management
3. Disaster Preparedness
4. Climate-Smart Agriculture
5. Policy and Governance

Questions?

- What are the limitations of current scientific evidence in informing climate change policies?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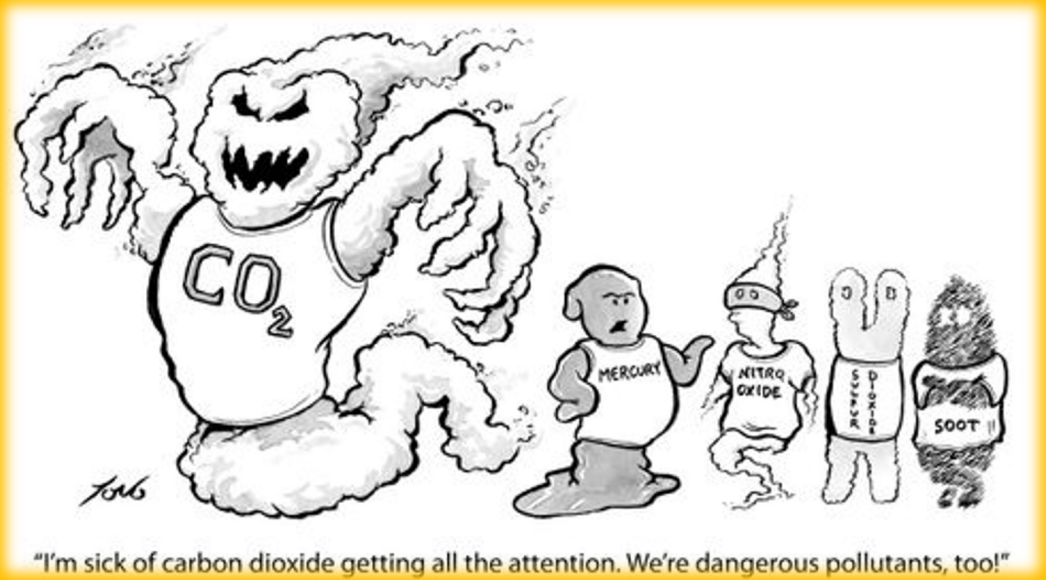
Let’s take a break

- Have you ever experienced a smoggy day or difficulty breathing in a polluted area?



"I'm sick of carbon dioxide getting all the attention. We're dangerous pollutants, too!"

Air quality

- Cleanliness of the air in our environment
- Presence and concentration of pollutants and other substances in the air that can affect human health, ecosystems, and the climate

Breathing Easy? Indoor & Outdoor Air Pollution

Air pollutants

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Particulate matter: $PM_{2.5}$ PM_{10}

Nitrogen oxides

Volatile Organic Compounds

Sulphur oxides

Methane

Ammonia

(surface) Ozone

From which sources?

- Quick Poll: What do you think is the biggest source of air pollution in your city?

From which sources?

From which sources?

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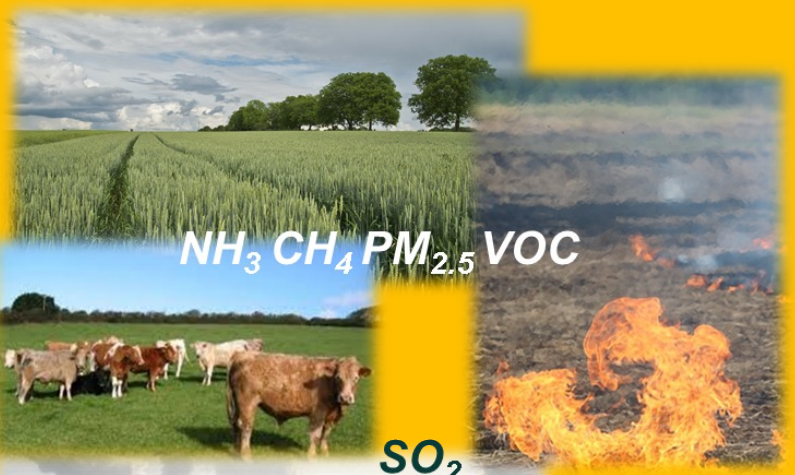
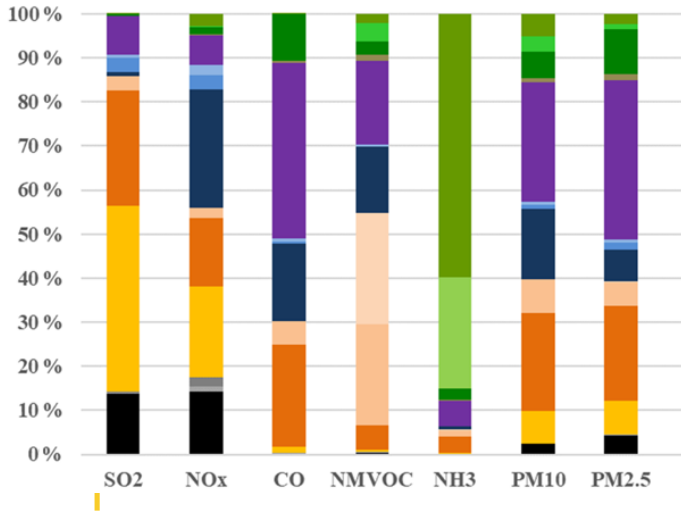
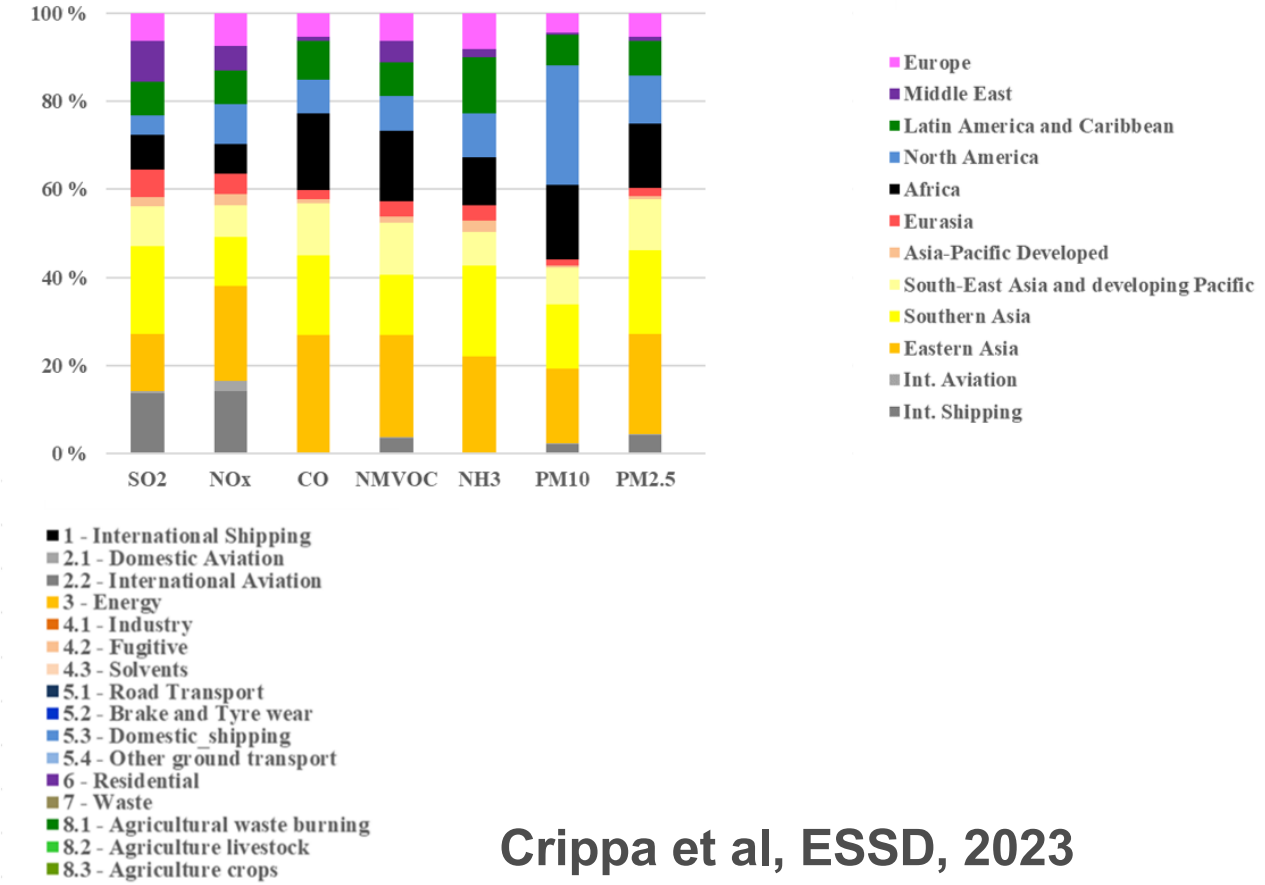


Where and in which proportion?

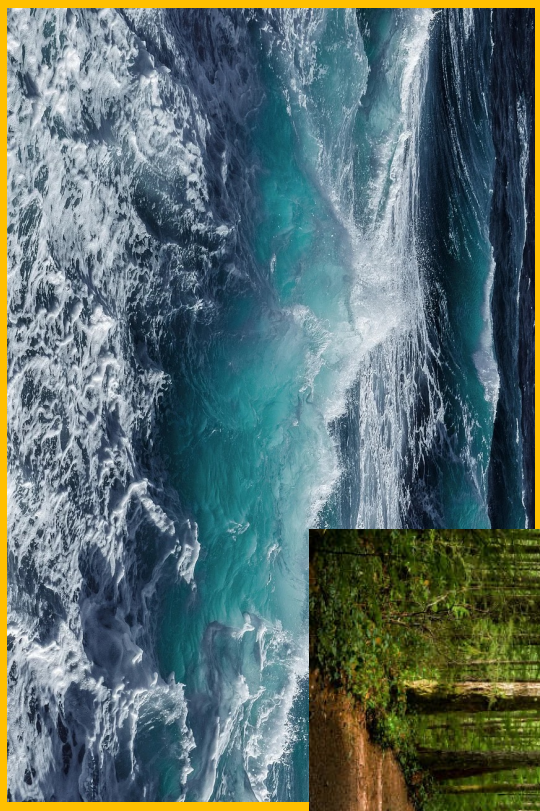
a global picture

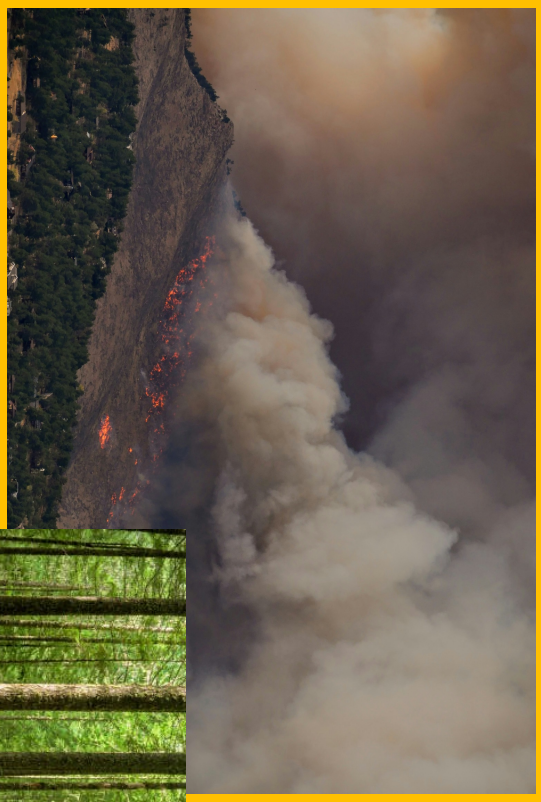


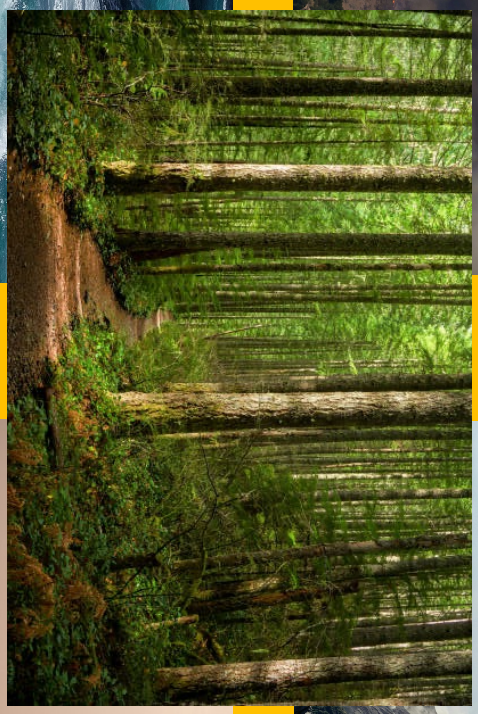


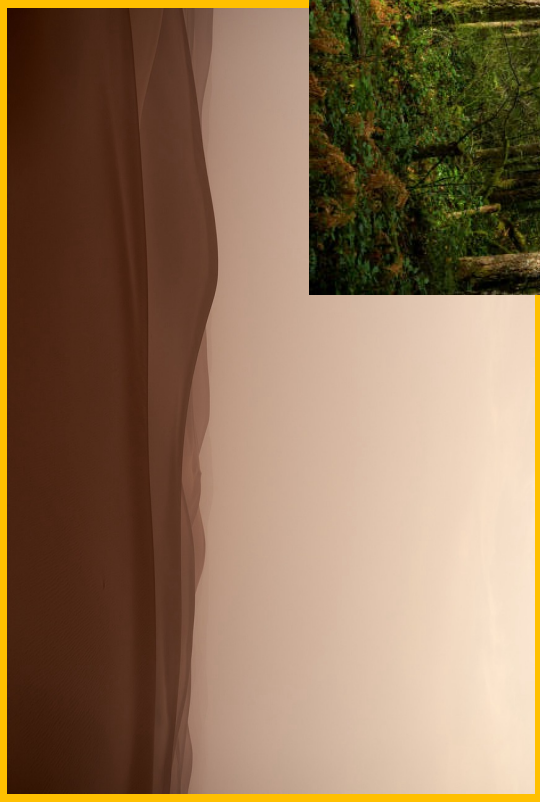
Crippa et al, ESSD, 2023

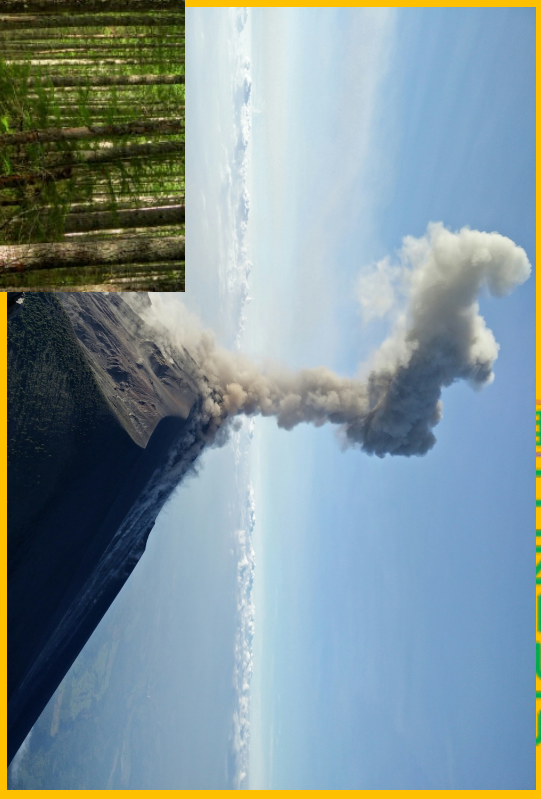
Natural sources as well



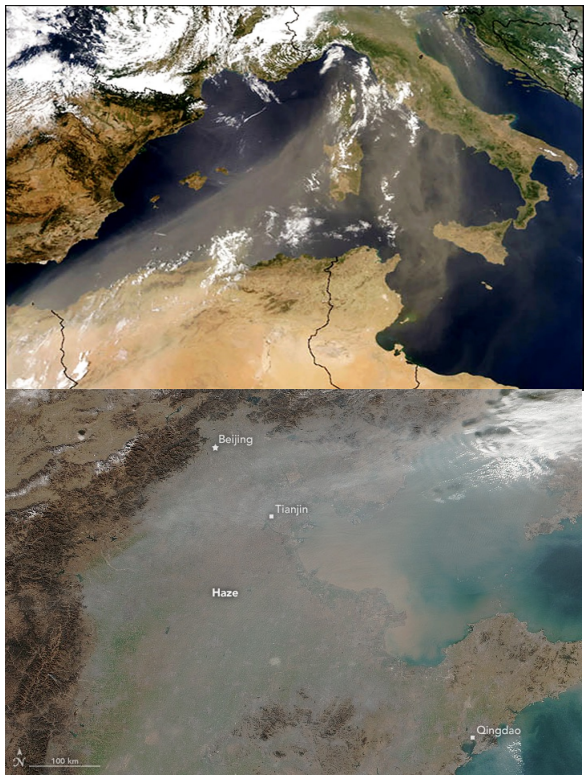


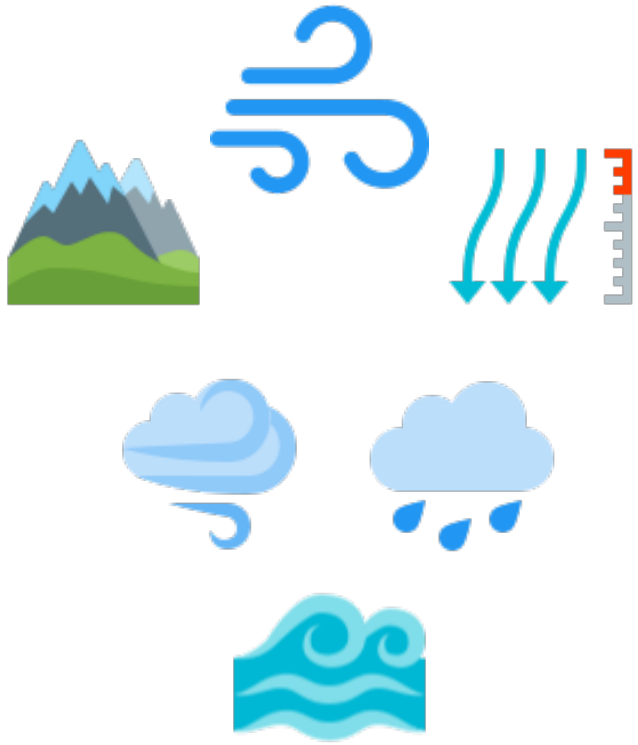




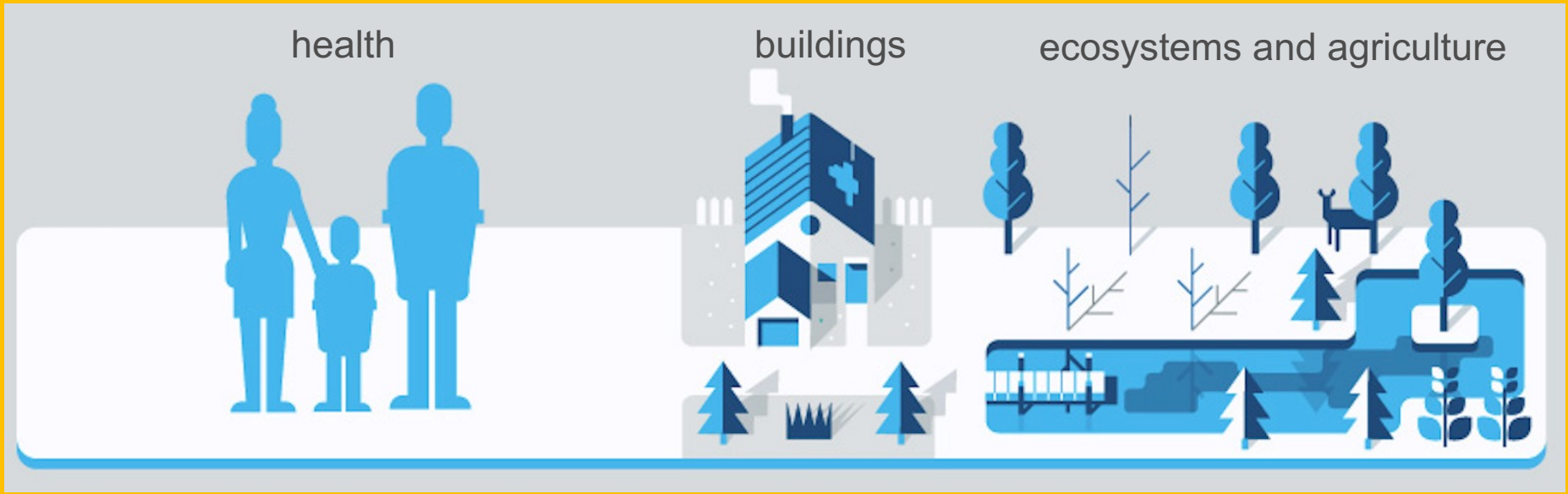


Weather, geography and the air we breathe



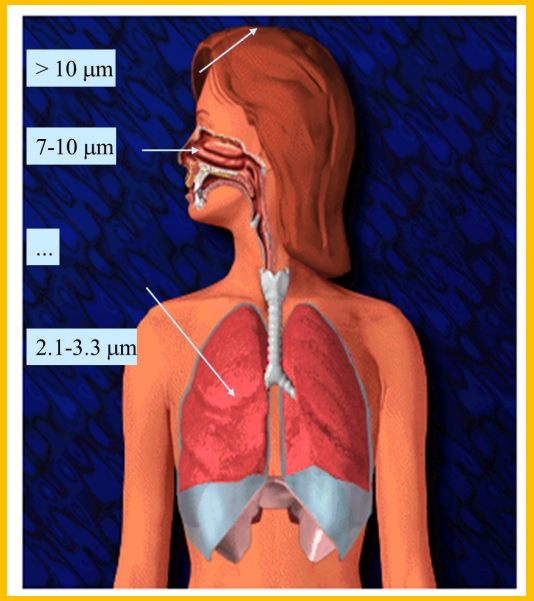


Effects



The invisible killer

Premature deaths:



World Health Organisation

21% due to pneumonia

19% due chronic obstructive pulmonary disease

7% from lung cancer

20% from stroke

34% from ischaemic heart disease

Effects on enviroment

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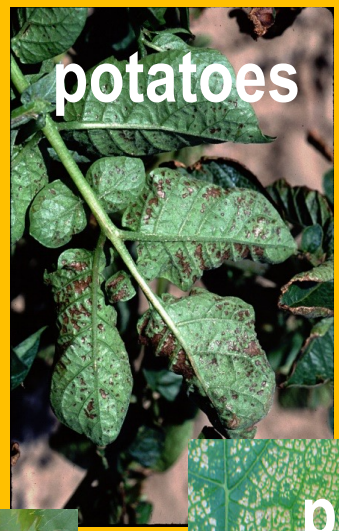
Ecosystem degradation

Food loss



Mapping pollutants and effects

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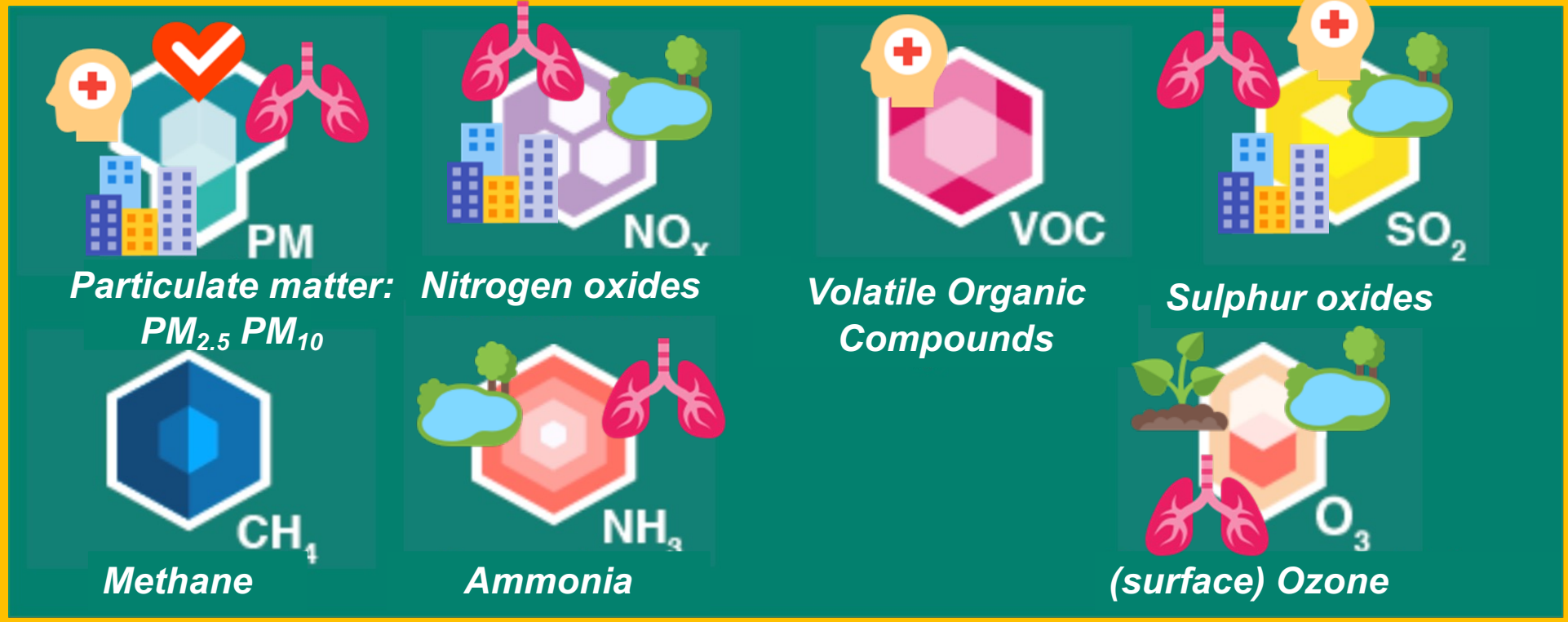


Particulate matter: $PM_{2.5}$ PM_{10}

Nitrogen oxides

Volatile Organic Compounds

Sulphur oxides

Methane

Ammonia

(surface) Ozone

Air pollution has a high cost

In Europe

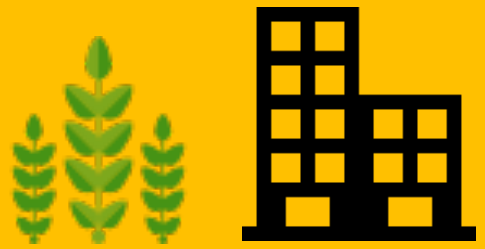
350.000 premature **deaths** each year

€4 billion in **healthcare**

€16 billion in **lost working days**

€3 billion in lost **crops**

€1 billion in building **damage**

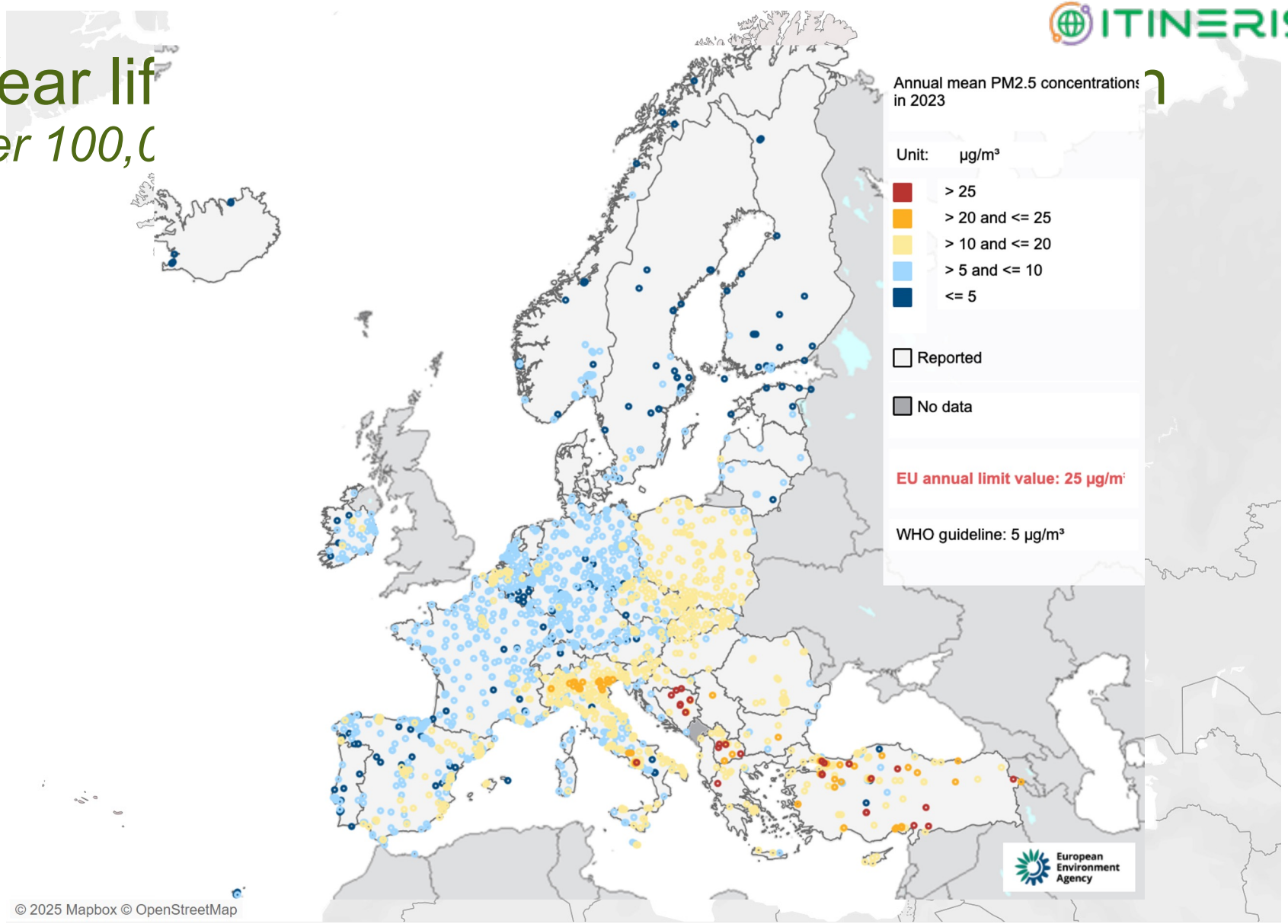


1nd environmental risk factor of death

European Environment Agency

Year lif

per 100,0



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ITINERIS

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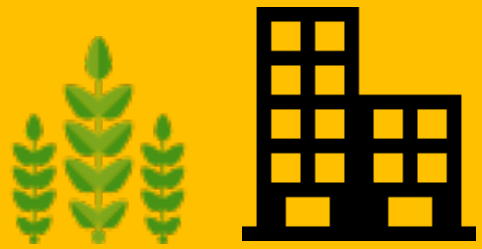


1nd environmental risk factor of death

European Environment Agency

Worldwide

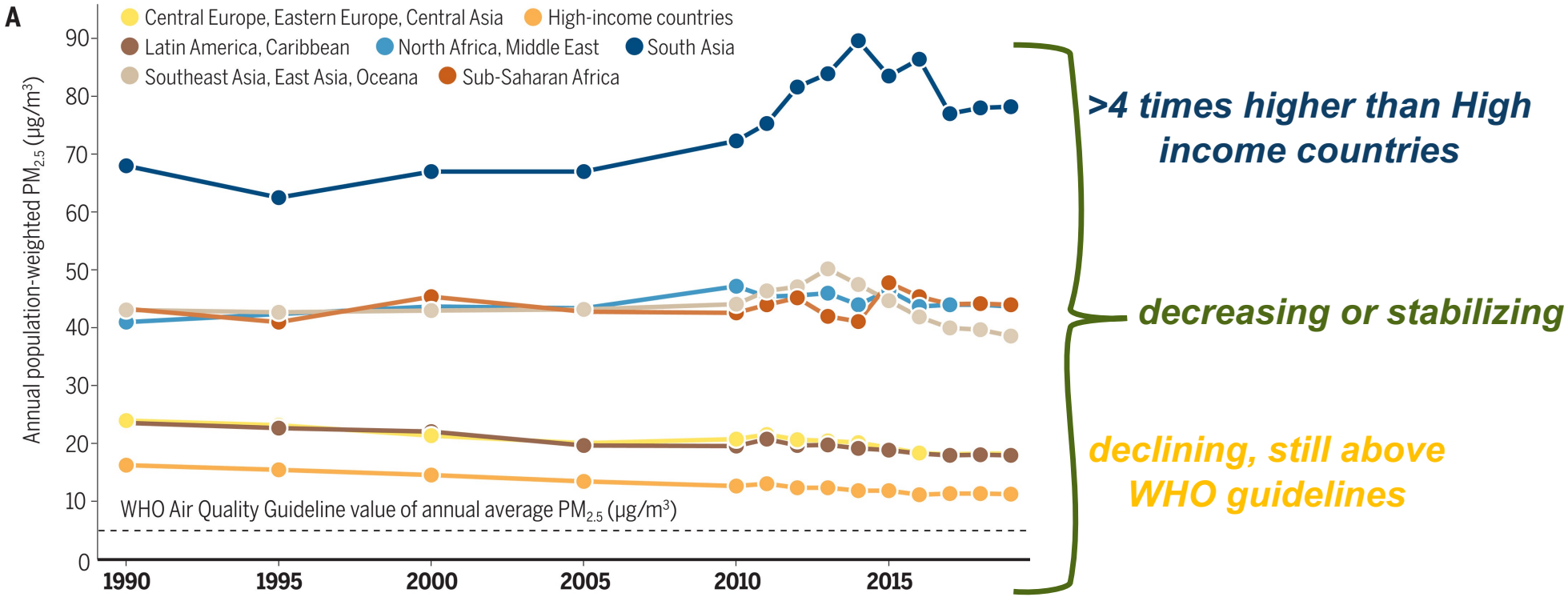
8.1 millions of premature **deaths** each year (including 3 millions due to indoor air pollution)

2nd largest risk factor of death

State of Global air, 2024

Where do we stand at global level?

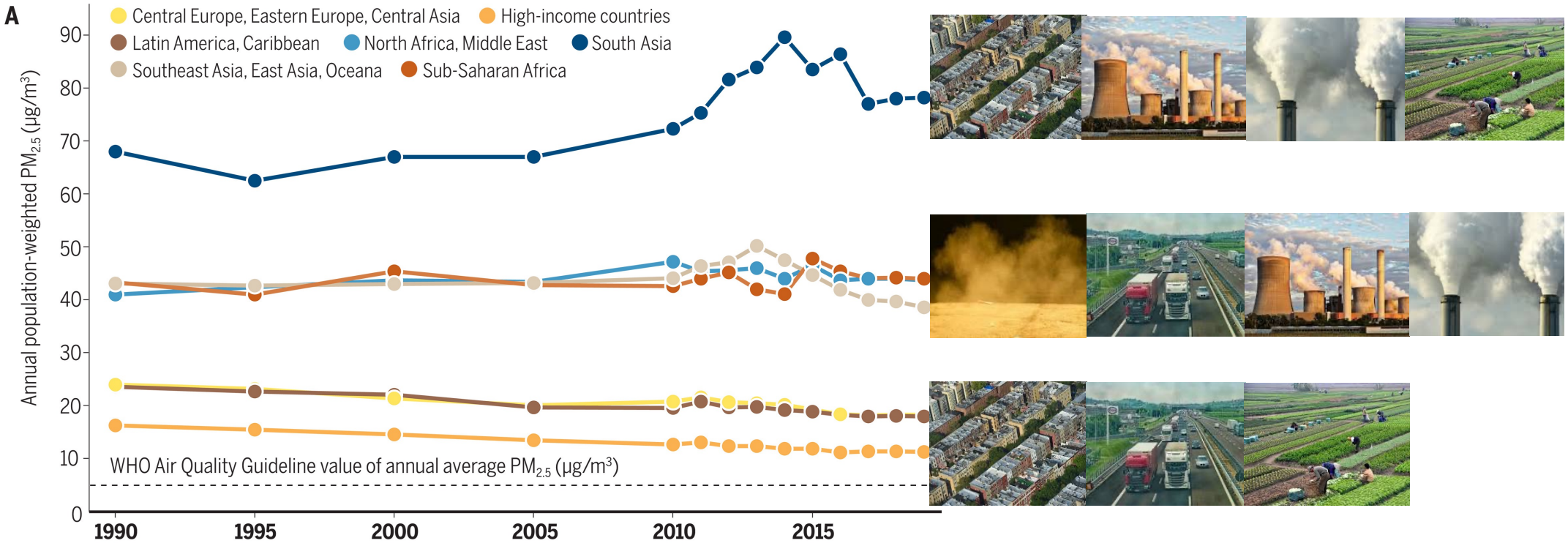
PM2.5 in world regions



Huang et al., Science, Air Pollution special issue, 2024

Where do we stand at global level?

PM2.5 in world regions and their sources



Health Effects Institute, State of Global Air 2024, Special Report

The two-way link between Air Pollution & Climate

- These two events are connected to both air quality and climate change. How?

Sharing sources and emissions

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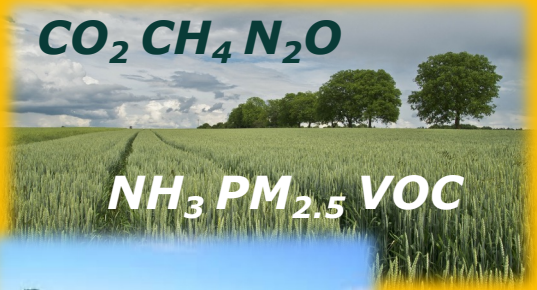


Climate and air quality impacts

Pollutant	Climate impact	Air quality impact
Carbon Dioxide (CO_2)	**Traps heat, main driver of climate change**	**Indirect—does not degrade air quality directly**
Methane (CH_4)	**Strong greenhouse gas, contributes to ozone**	**Contributes to ground-level ozone (harmful)**
Aerosols ($PM_{2.5}$ and Black Carbon)	**Absorbs or reflects sunlight (warming/cooling)**	**Major health hazard, reduces visibility**
Ozone (O_3)	**Greenhouse gas in troposphere**	**Respiratory health impacts, smog formation**
Sulphur dioxide (SO_2) and nitrogen oxides (NO_x)	**Forms aerosols that cool the atmosphere**	**Acid rain, worsens air pollution**

Feedback loops and interactions

climate change can exacerbate air quality issues

Heatwaves, increased solar radiation and summertime temperatures:

- Increased levels of tropospheric ozone
- More frequent occurrences of stagnant air, trapping pollutants near the ground

- More frequent and intense wildfires

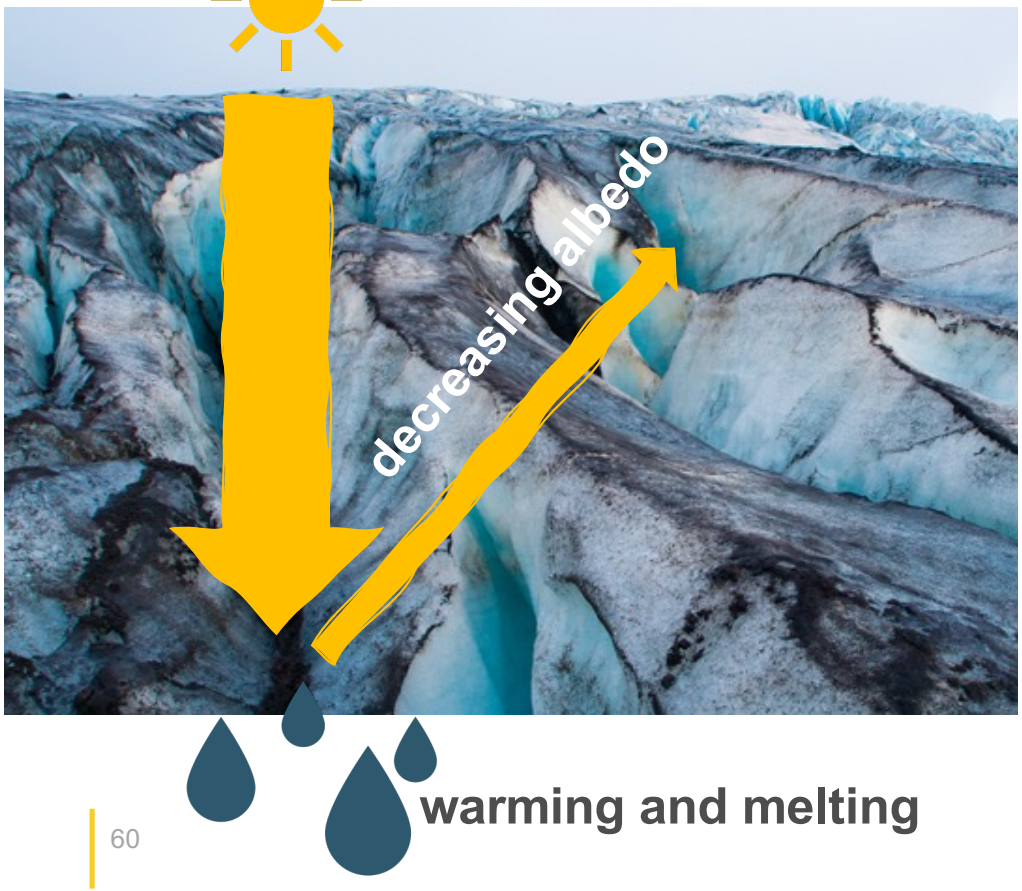
- Changes in precipitation and land use can lead to more frequent and intense dust storms

- Exacerbate pathologies related to bad air quality

Feedback loops and interactions

poor air quality can impact climate

Black carbon on ice and snow



and also

- Increasing ozone as potent greenhouse gas
- Some aerosols, like sulfate particles, reflect sunlight, causing a cooling effect
- Aerosols can change cloud properties, influencing precipitation patterns
- High concentrations of air pollutants in urban areas can exacerbate the urban heat island effect
- Ground-level ozone can damage plant tissues, reducing their ability to photosynthesize and sequester carbon dioxide
- …..

Air pollutants and GHG

similarities and differences

HUMAN CAUSE

Human activities contribute significantly to the emission of both

ENVIRONMENTAL AND HEALTH IMPACTS

Both can have **detrimental effects**, although in different ways

REGULATION

Governments and international bodies **regulate both** to mitigate their negative impacts

LIFETIME IN THE ATMOSPHERE

GHG have a **long** atmospheric lifespan, (CO_2 lasting hundreds to thousands of years); many APs have a **shorter** lifetime, ranging from hours to weeks

(IN)DIRECT EFFECTS

GHG's effects are mainly indirect through the mechanism of **climate change**; APs can have direct harmful effects on **human health and the environment** upon exposure

REGULATORY PURPOSE

GHGs Regulation often focuses on **reducing emissions**: APs Regulation typically focuses on **improving air quality**

Policy dilemma

fixing one problem can worsen another

- Reducing SO_2 emissions **helps air quality** but reduces aerosol cooling, which temporarily **accelerates warming**.
- Transition from diesel to natural gas, while **reducing** NO_x and PM, methane from extraction and transport of gas **can offset CO_2 reduction**.
- Using biomass instead of fossil fuel can **reduce CO_2 emissions**, but it **releases** $PM_{2.5}$, NO_x and VOCs.
- Transitioning to electric vehicles **reduces tailpipe emissions**, without cleaning the electricity production emissions of air pollutant **may increase**; **increased** brake and tire wear from heavier cars

Questions?

- Clean air is not a privilege; it’s a right. How can we ensure future generations breathe safely?

THANKS!

Icons from https://icons8.com; https://www.flaticon.com; rodrigocartoon.com. Parts of the graphics By PresentationGO.com. Handmade drawings courtesy Frank Raes

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