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Climate Change and Arctic Warming

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About myself

eerl.epfl.ch

EERL

- Environmental Engineer
- PhD in Atmospheric Science
- Worked at the Science-Policy interface
- Big passion for polar environments

Associate Campus Sion
Alpine and Polar Environmental Research Center (ALPOLE)

I find climate change an important topic.

A. Agree.
B. Partially agree.
C. Neutral
D. Partially don‘t agree.
E. Don‘t agree.
F. I don‘t know.

Go to: **responseware.eu**
Login: **enter as guest**
Session-ID: **susclim**

I am interested in what is happening in polar environments.

A. Agree.
B. Partially agree.
C. Neutral
D. Partially don‘t agree.
E. Don‘t agree.
F. I don‘t know.

After this lecture you will be able to answer the following questions

- Why is there a climate change emergency?
- How do greenhouse gases work?
- Why are aerosols and clouds important in the climate system?

- Why is the Arctic warming faster than the global average?
- What are important Arctic atmospheric processes?
- What are the global consequences of Arctic warming?

April: Heat waves in India, Bangladesh, Thailand and Philippines


April - May: Record flooding in Brasil - up to half of the annual predicted rain fell in just 10 days
April : UAE flooding
March - May : Kenya flooding

May: Cyclone Remal – Bangladesh

Fires – April through August

October – Floods in Spain

All these events have become more likely because of climate change.

Impacts are current reality.
Not a problem of the future. They come thicker and faster than anticpated.

Climate Emergency in a nutshell

1. We are extremely close to our global temperature target of 1.5/2.0°C for 2100.

We're late.

2. Drastic emission reductions are needed now and net-zero needs to be achieved by 2050.

We need to hurry up.

3. Humanity is faced with a technological, political and behavioral challenge never encountered before.

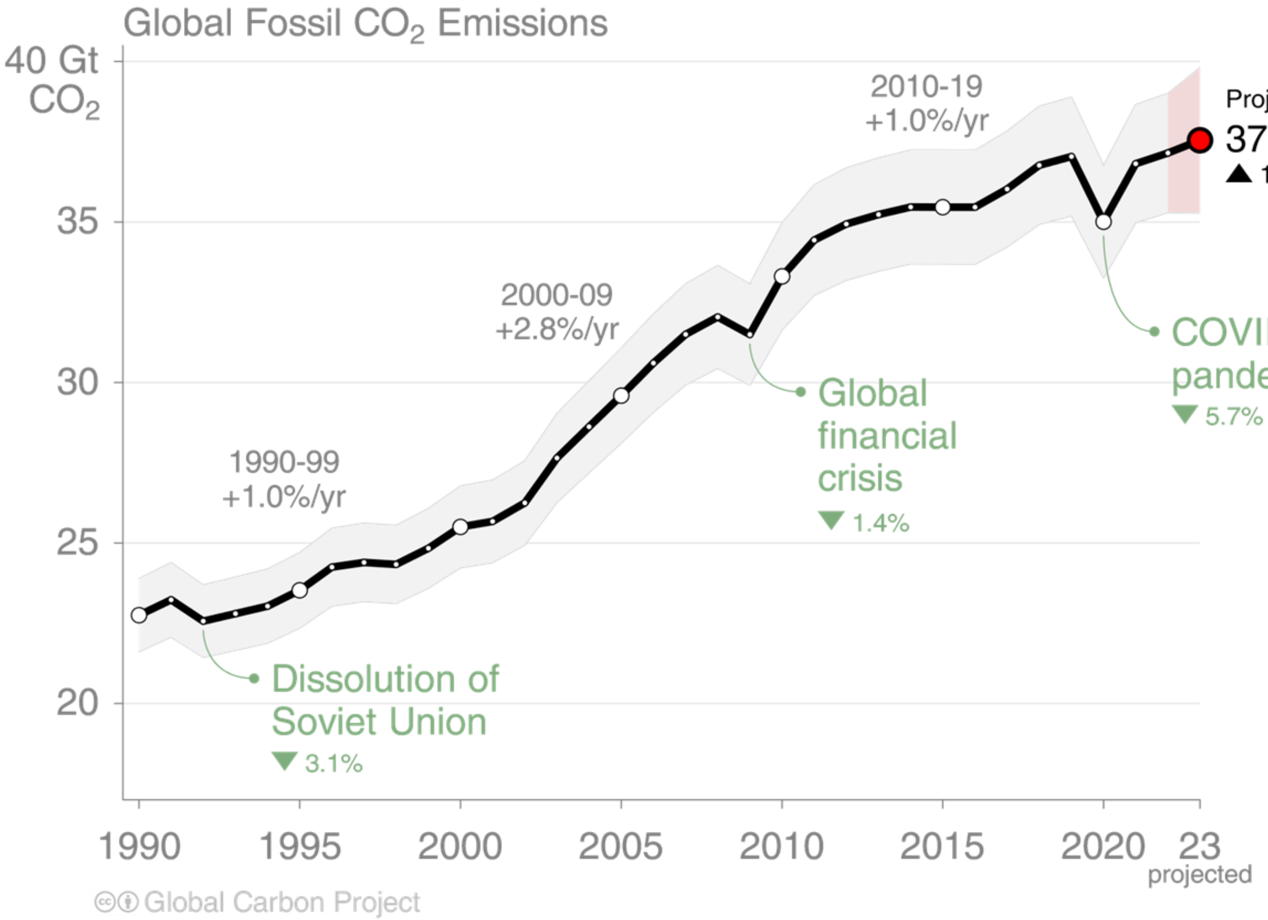
We need to run faster than ever before.

Global Fossil CO_2 Emissions

Global fossil CO_2 emissions: 37.1 ± 2 $GtCO_2$ in 2022, 63% over 1990

Projection for 2023: 37.5 ± 2 $GtCO_2$, 1.1% [0.0% to +2.1%] higher than 2022

Covid was a tiny dent.



Uncertainty is ±5% for one standard deviation (IPCC “likely” range)

When including cement carbonation, the 2022 and 2023 estimates amount to 36.4 ± 2 $GtCO_2$ and 36.8 ± 2 $GtCO_2$ respectively

The 2023 projection is based on preliminary data and modelling.

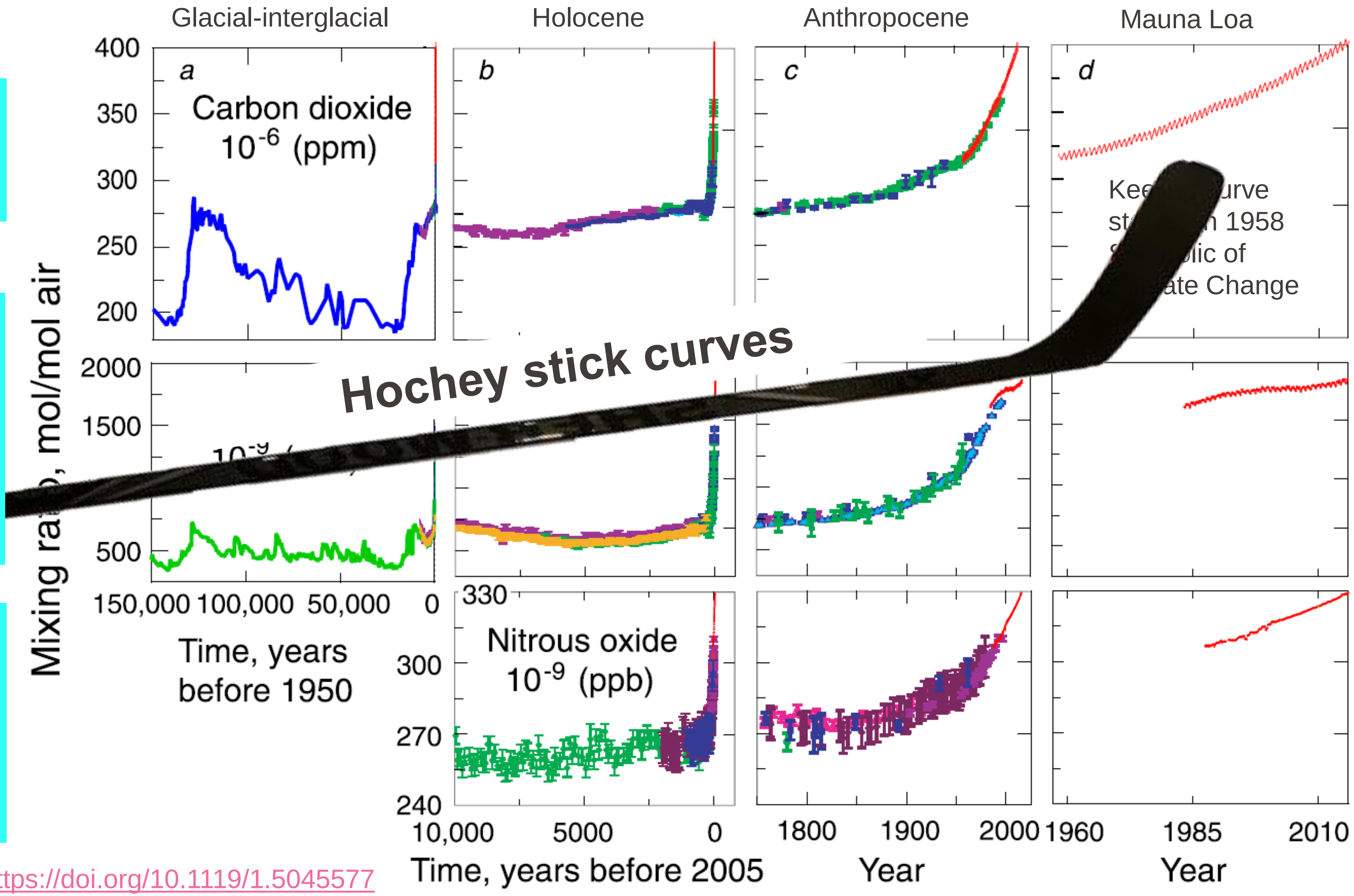
Source: Friedlingstein et al 2023; Global Carbon Project 2023

Increase in greenhouse gases due to anthropogenic activity

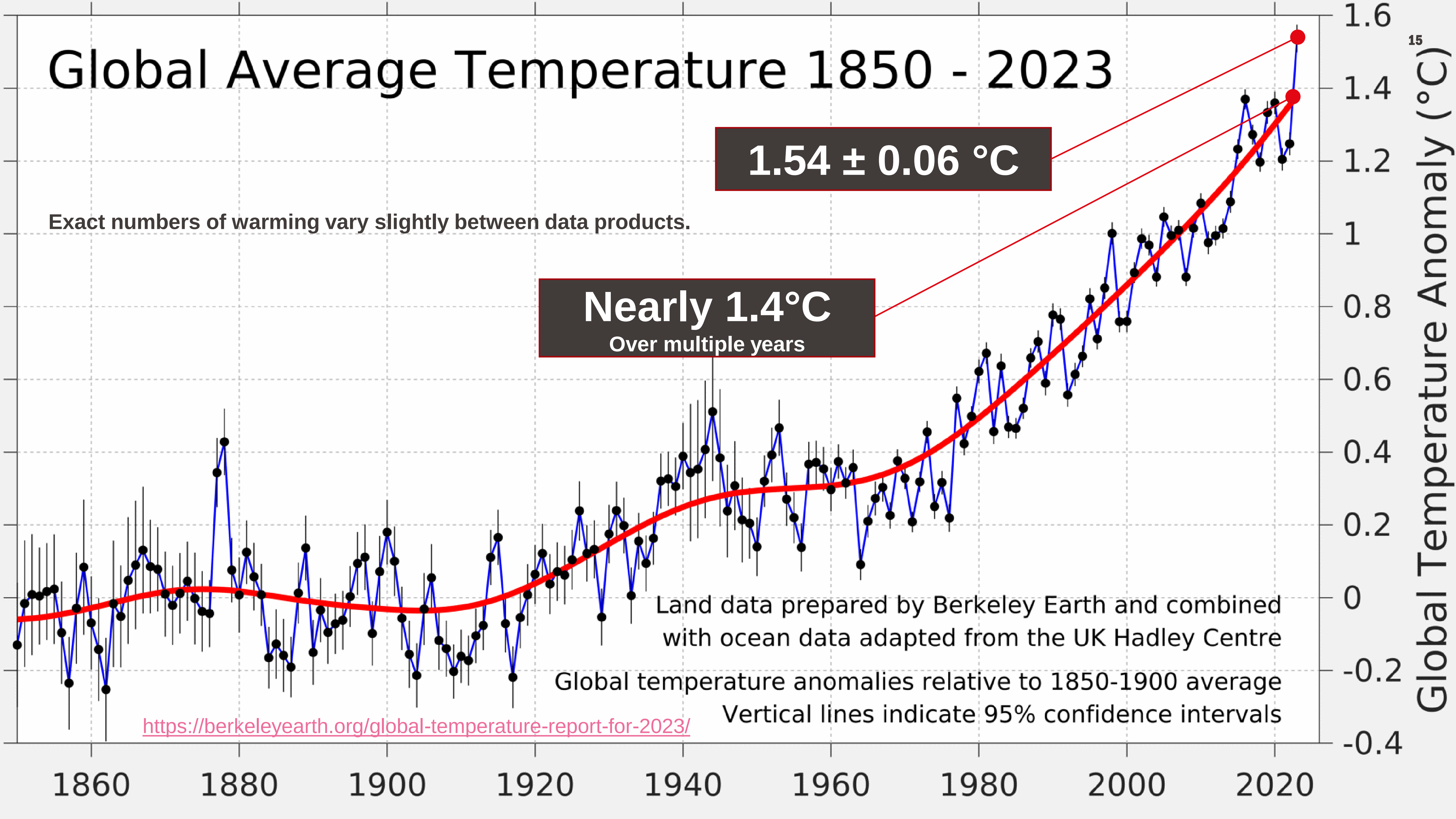
CO_2
Most important
Source: combustion
Lifetime: ~100 years

CH_4
2nd most important
Source: agriculture, energy, waste
Lifetime: ~12 years
84 times more potent than CO_2 within 20 years

N_2O
Source: agriculture, waste
Lifetime: >100 years
273 times more potent than CO_2 within 20 years



- Schwartz, 2018, https://doi.org/10.1119/1.5045577


Global Average Temperature 1850 - 2023
1.54 ± 0.06 °C
Exact numbers of warming vary slightly between data products.
Nearly 1.4°C
Over multiple years
Land data prepared by Berkeley Earth and combined
with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals
https://berkeleyearth.org/global-temperature-report-for-2023/
Global Temperature Anomaly (°C)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1860
1880
1900
1920
1940
1960
1980
2000
2020

Paris Agreement 2015

*“The **Paris Agreement** central aim is to [...] keep global temperature rise [...] well below 2°C above pre-industrial levels and to pursue efforts to limit the [...] increase [...] to 1.5 °C.”*

https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

In 2021, at the Conference of the Parties (COP) in Glasgow, the international community agreed to strive for a maximum warming of 1.5 °C.

https://unfccc.int/process-and-meetings/the-paris-agreement/the-glasgow-climate-pact-key-outcomes-from-cop26

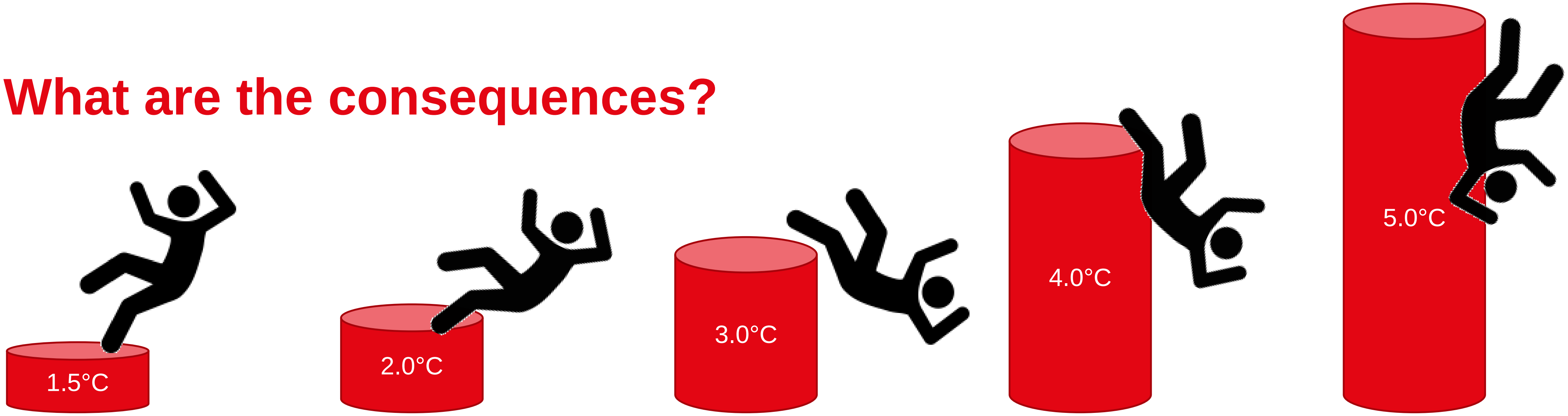
Why 1.5°C?
And what if we go beyond?

1.5°C versus warmer

- Limitation of global warming to 1.5°C compared to more than 2°C allows to avoid substantial additional changes in living conditions, in extremes and (irreversible) impacts.
- Living conditions
  - Sea level rise requires evacuation of neighborhoods / entire islands
  - Crops might not grow anymore where they used to, or new crops can be planted
  - Some regions will get too hot to live
  - …
- Extremes
  - Increase in hot extremes in most inhabited regions of the world
  - Heavier precipitation accompanied by cyclones in several regions
  - Increased droughts in some regions
  - …
- Irreversible impacts
  - Sea level rise,
  - Loss of glaciers and sea ice
  - Biodiversity loss: e.g., extinction of animals, plants, corals
  - …

1.5°C versus warmer

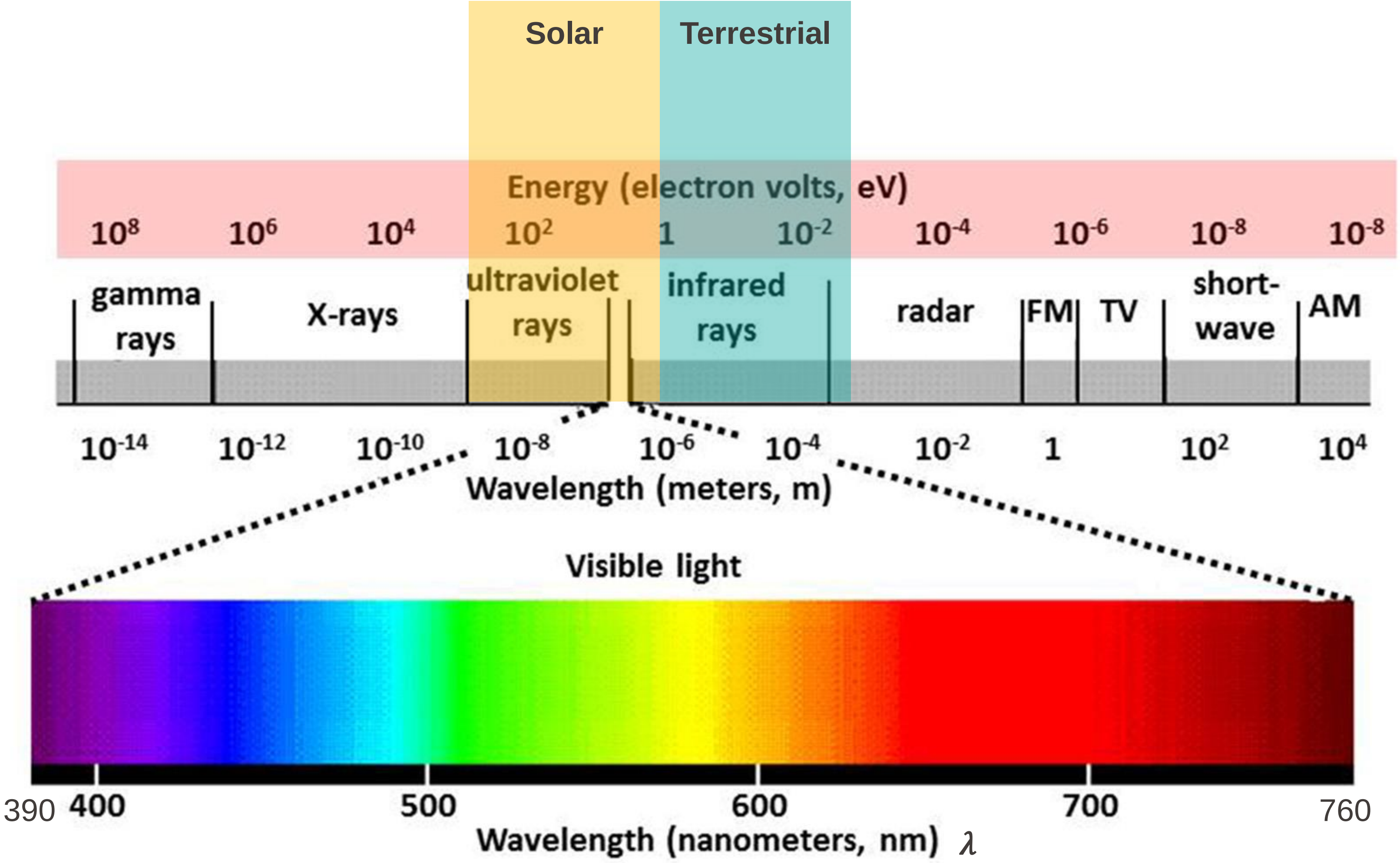
What are the consequences?



How greenhouse gases, aerosols and clouds affect climate

Spectrum of electromagnetic radiation

High energy,
short wavelength



Low energy
long wavelength

Some definitions

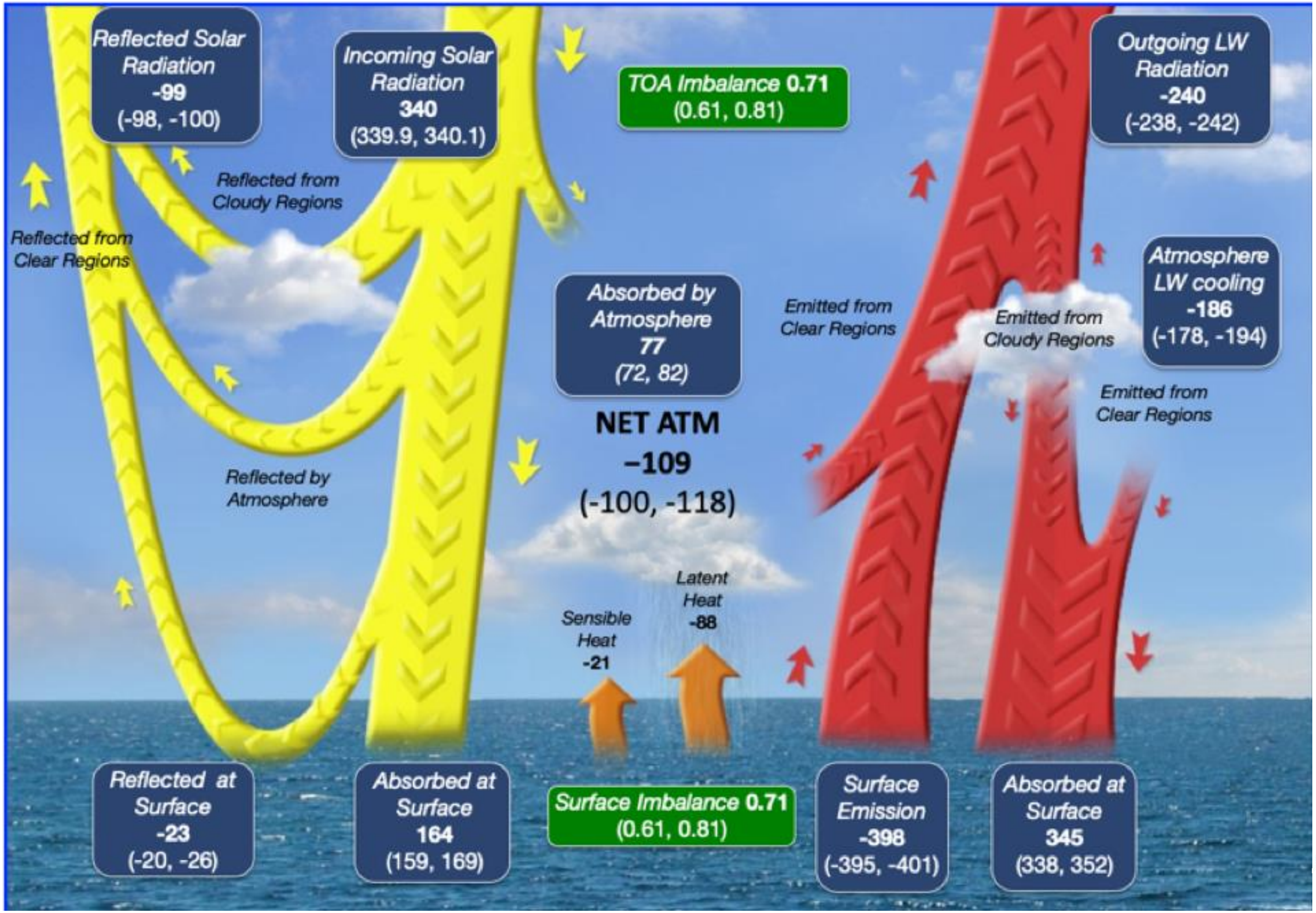
Visible:
0.39 – 0.76 µm, colors
Solar radiation:
< 4 µm, shortwave
Terrestrial radiation:
> 4 µm, longwave
Near infrared:
0.76 – 4.0 µm (solar radiation)
Thermal Infrared:
> 4 µm, terrestrial radiation

- https://ozonedepletiontheory.info/what-is-radiation.html

Earth's Energy Balance

- Some of the solar radiation is reflected back to space before it reaches the ground
- Sun heats Earth's surface

Units: W/m^2



- Earth radiates because it has a temperature (black body radiation)
- Some of the longwave radiation escapes to space
- Much of the longwave radiation interacts with greenhouse gases and clouds that re-emit the longwave radiation in all directions

https://ceres.larc.nasa.gov/science/

Natural greenhouse effect

- At the surface, temperatures would be 33ºC cooler without the **natural greenhouse effect** driven by water vapor, CO_2, O_3 and clouds. These absorb surface infrared radiation and re-emit most of it back to the surface.
- That means global average surface temperature is roughly 15 °C.
- Water vapor is the most abundant natural greenhouse gas.

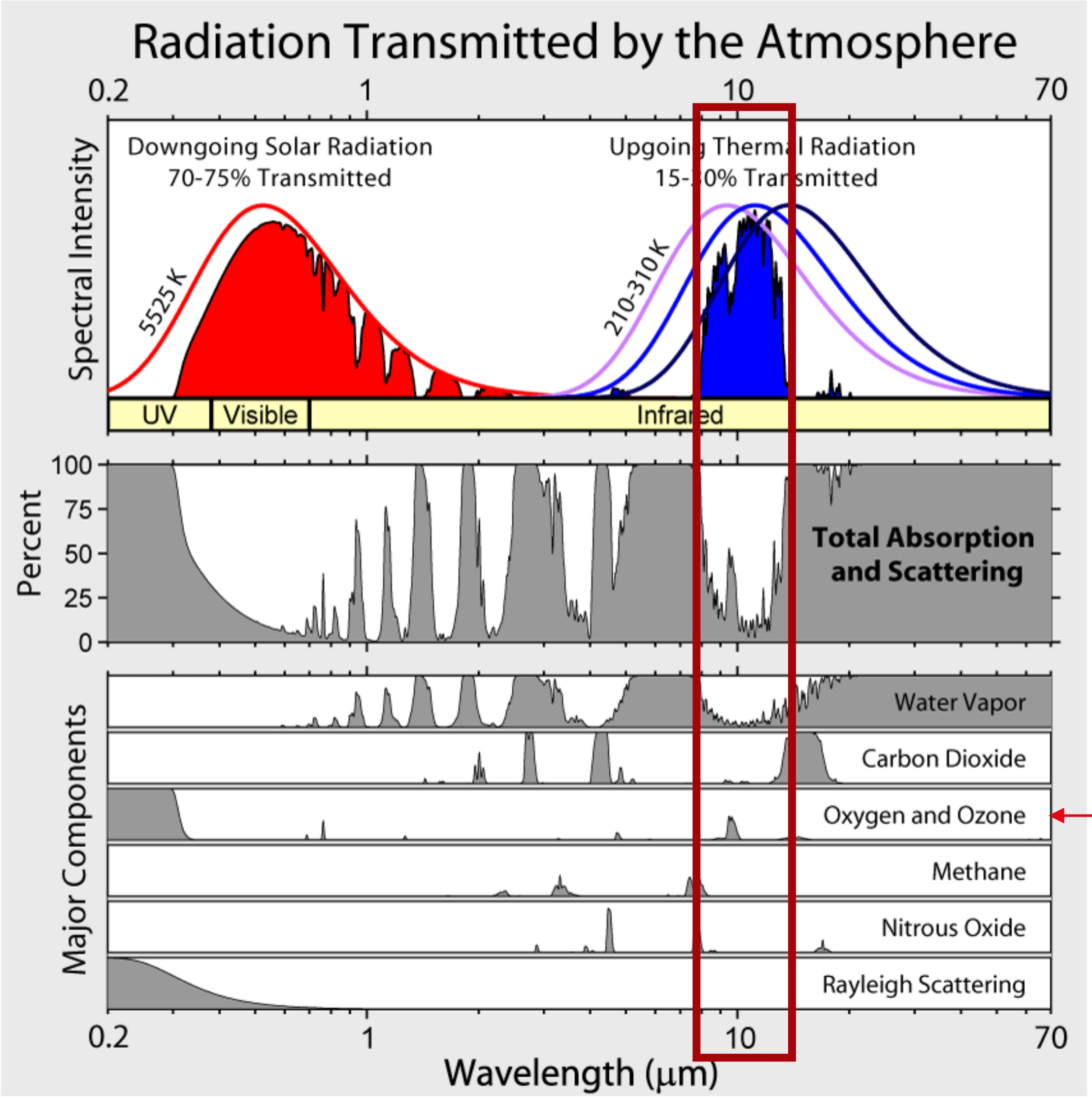
Greenhouse gases

1. **Interact with infrared radiation** because of their molecular structure. They must have at least 3 atoms and a dipole (the centers of the postive and negative partial charges do not overlap).
2. The absorbed infrared radiation creates **vibrational and rotational energy** in the molecules. They collide with other molecules and thereby **create heat**.

- https://www.acs.org/content/acs/en/climatescience/greenhousegases/properties.html

Atmospheric «windows»

In the shortwave radiation range, Earth's atmosphere is nearly transparent. The atmospheric window is very large.



The longwave radiation window is between 8-9 and 10 - 12 µm, roughly. The atmospheric window is small.

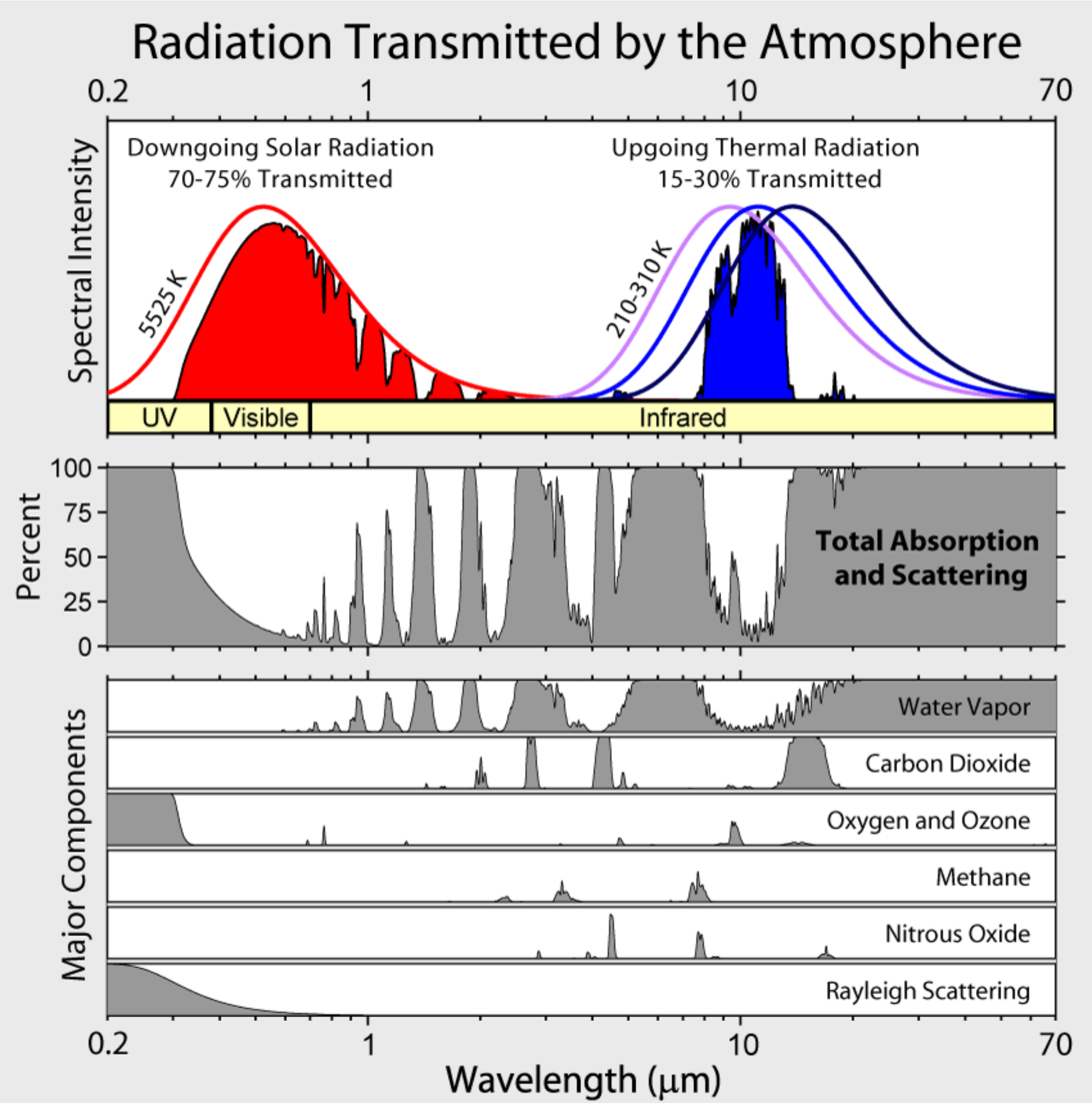
The result of the presence of greenhouse gases is that only a small part of the longwave surface emission makes it to space.

Different greenhouse gases work together to close "atmospheric windows" in the longwave part of the spectrum. They are located at the window edges.

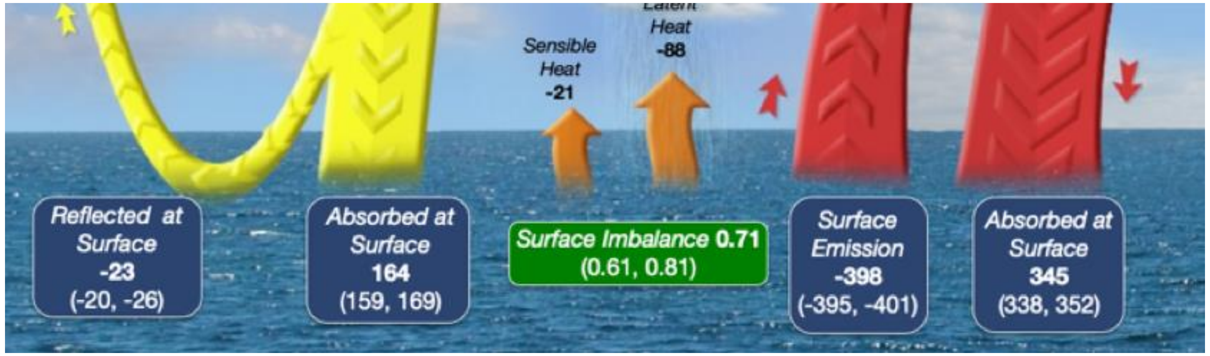
Ozone absorbs at 9.6 µm.

Source: Wikipedia

Greenhouse effect

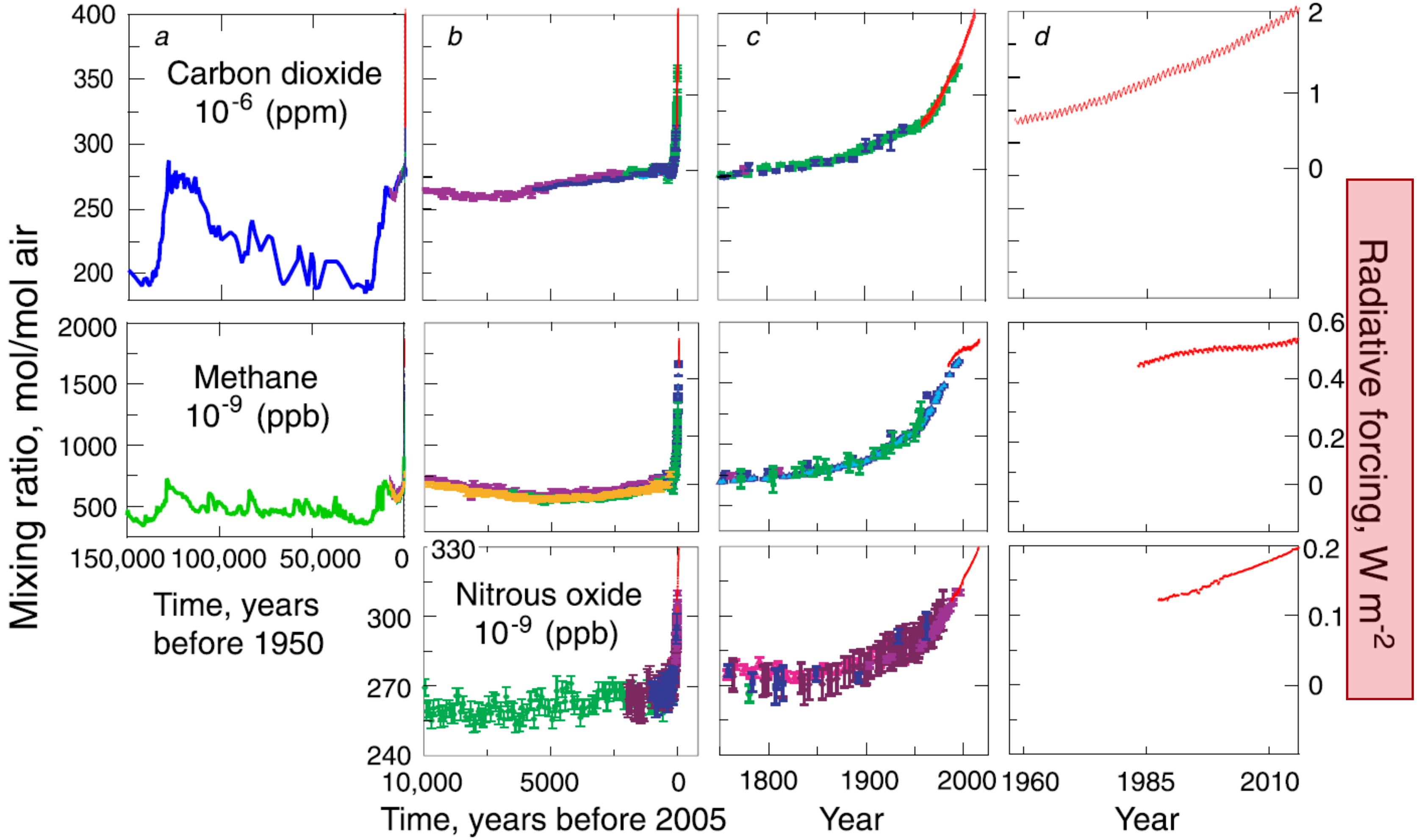


1. Solar radiation is transmitted through Earth's nearly transparent atmosphere (transparent to shortwave radiation).
2. Earth's surface absorbs the solar radiation and warms.
3. The Earth emits thermal IR radiation (blackbody radiation).
4. The atmosphere is much less transparent to thermal infrared radiation and absorbs it.
5. The absorbed radiation leads to warming of the atmosphere, which in turn emits thermal IR radiation in all directions, and importantly partly downwards.
6. So the net thermal IR flux from the Earth (as blackbody) to space is greatly recuded. This diminishes the radiative cooling of the Earth's surface and leads to surface warming.



Greenhouse gases exert a radiative forcing (RF)

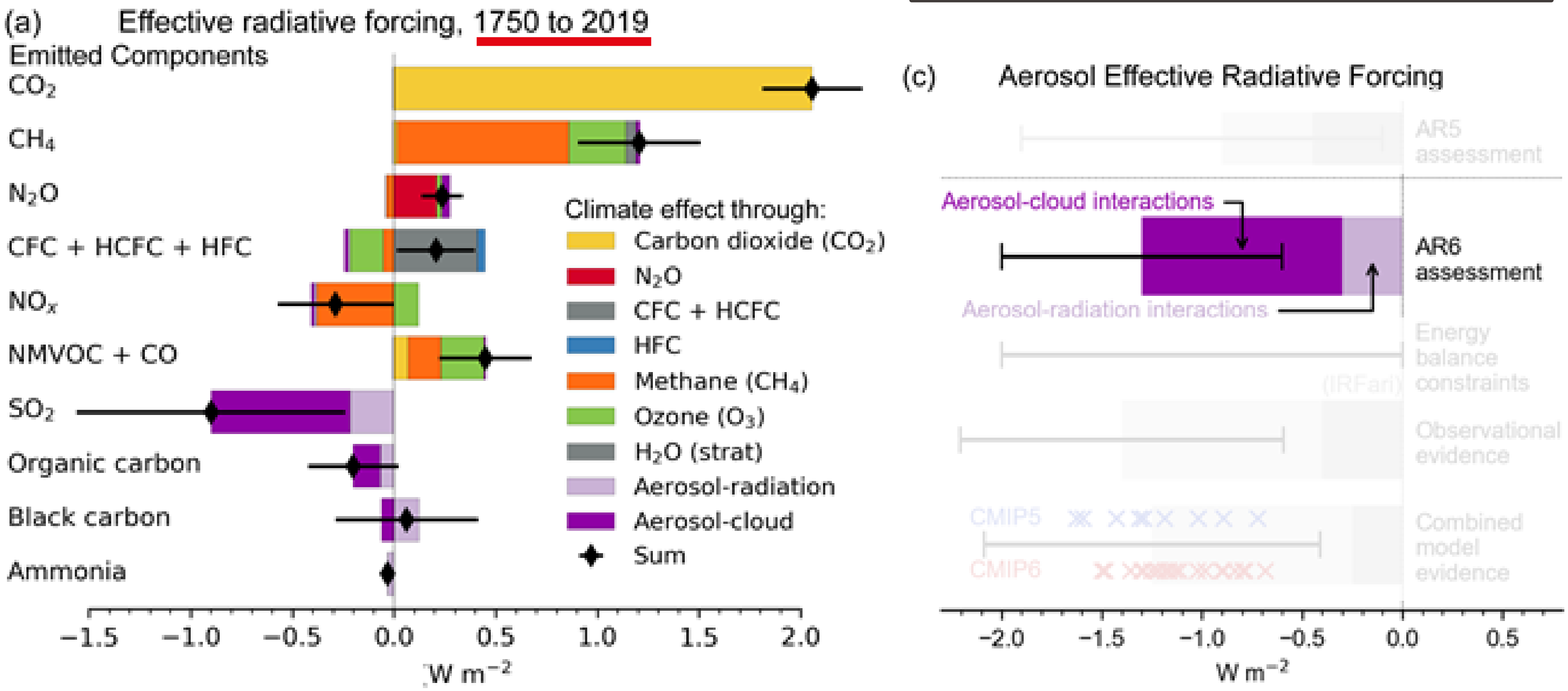
- Radiative forcing is a forcing that changes the radiation balance of Earth.
- Radiative forcing in climate science is commonly compared against the preindustrial time, when humans did not emit many greenhouse (GHG) gases.



- Schwartz, 2018, https://doi.org/10.1119/1.5045577

Radiative forcing by chemical component

- Effects of most important GHG are well understood.
- The largest uncertainties are with aerosols and clouds.



Negative leads to temperature decrease

Positive forcing leads to temperature increase

- IPCC AR6, Fig. TS.15

Sources of aerosols

Forest fires

Sea spray

Dust

Volcanic eruptions

Traffic / Transport

Domestic activities

Industry

Agriculture

Sources of aerosols

Mixed

Forest fires

Natural

Sea spray

Dust

Volcanic eruptions

Traffic / Transport

Domestic activities

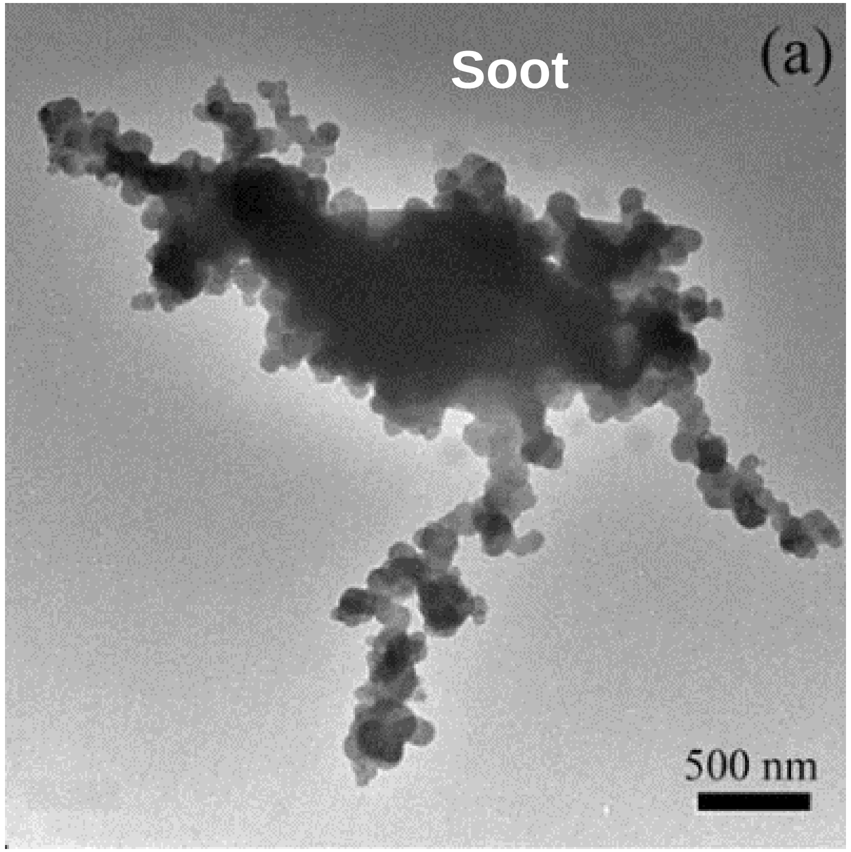
Industry

Agriculture

Anthropogenic

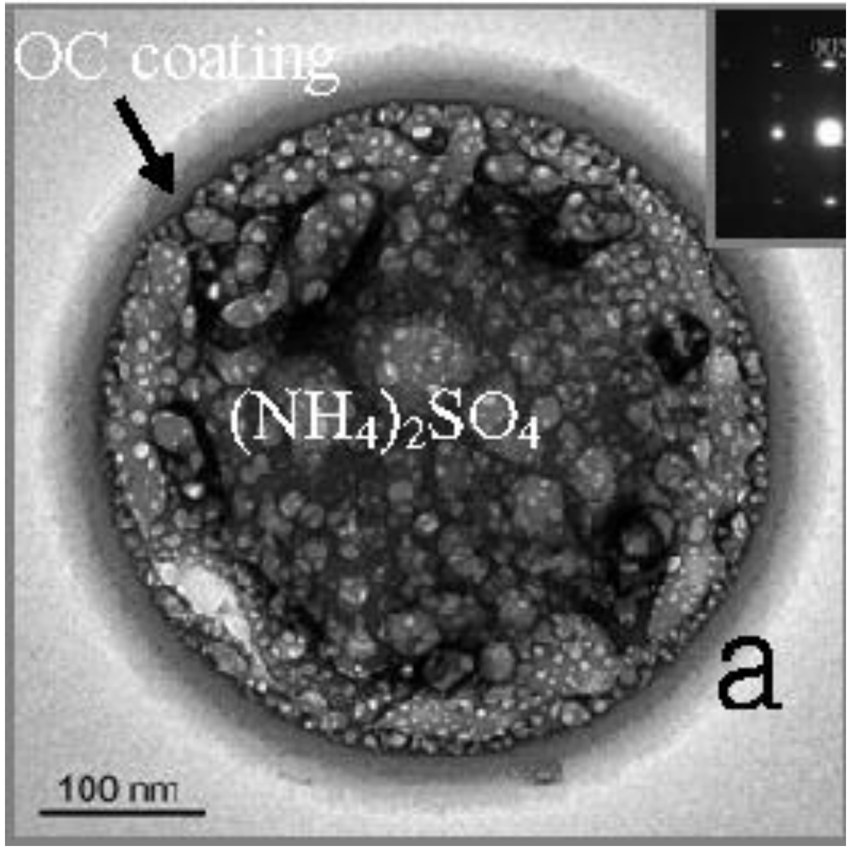
Types of aerosols

Primary



Primary particles are emitted from their source as particles. Examples: soot for combustion, mineral dust from soil.

Secondary

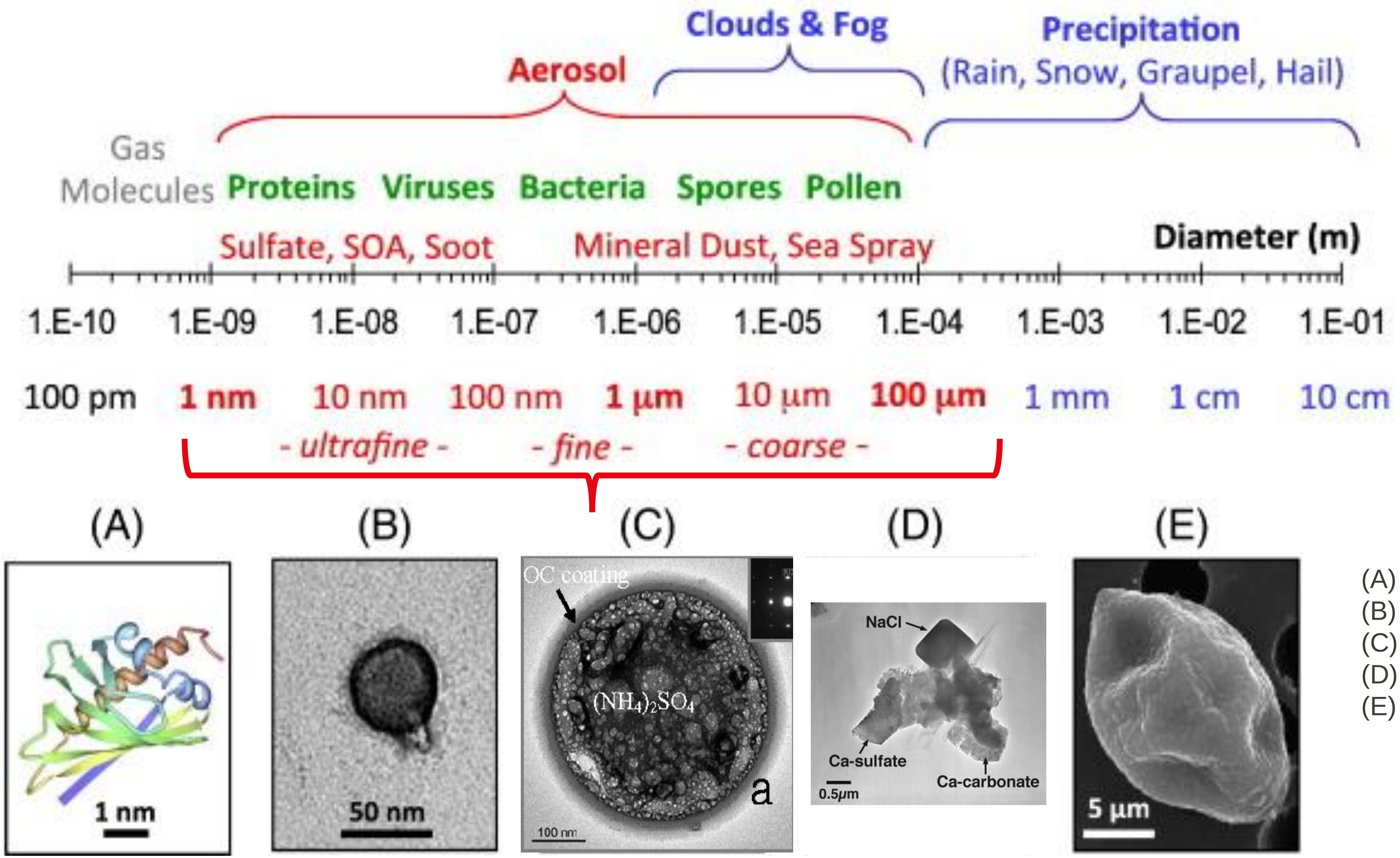


Secondary particles are NOT emitted as particles, but they are formed from gases in the atmosphere through condensation or chemical reactions (in clouds). Examples: Ammoniumsulfate, ammoniumnitrate, secondary organic aerosol

Images are from a Transmission Electron Microscope (TEM).

Links to papers: right, left

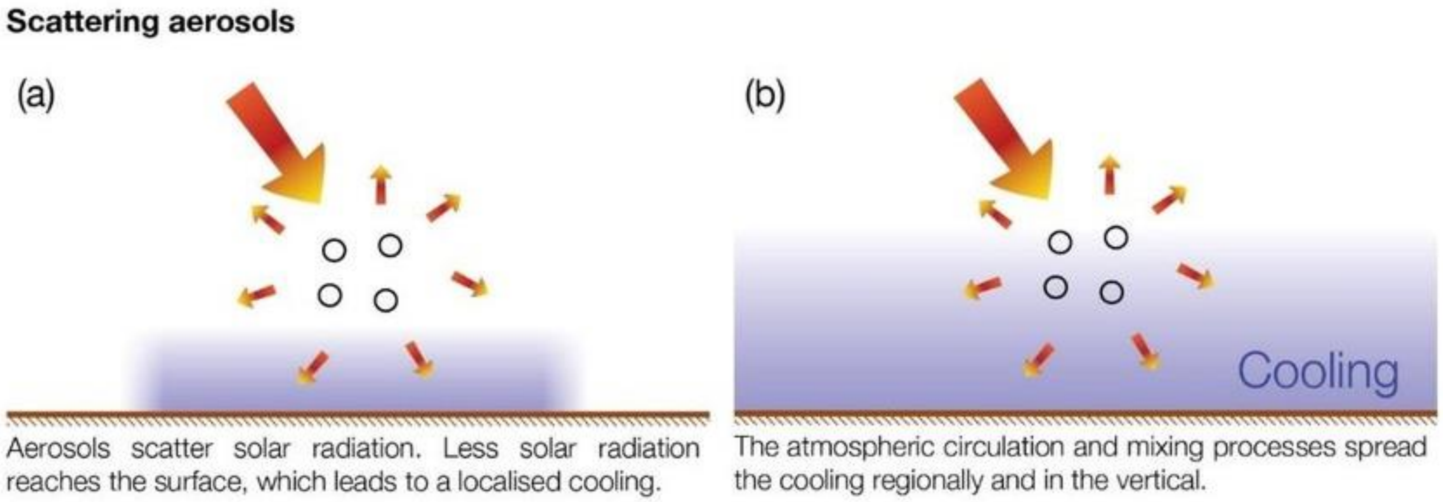
Size of aerosols



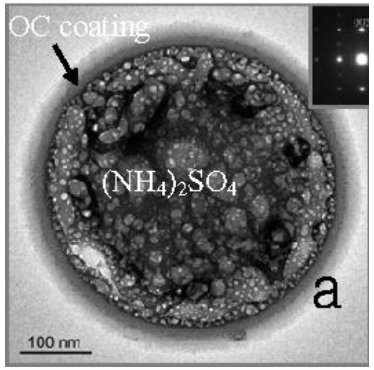
(A) protein,
(B) virus
(C) Urban particle
(D) Mineral dust
(E) pollen grain

- Fröhlich-Nowoisky et al. (2016), https://doi.org/10.1016/j.atmosres.2016.07.018

Aerosol-radiation interaction



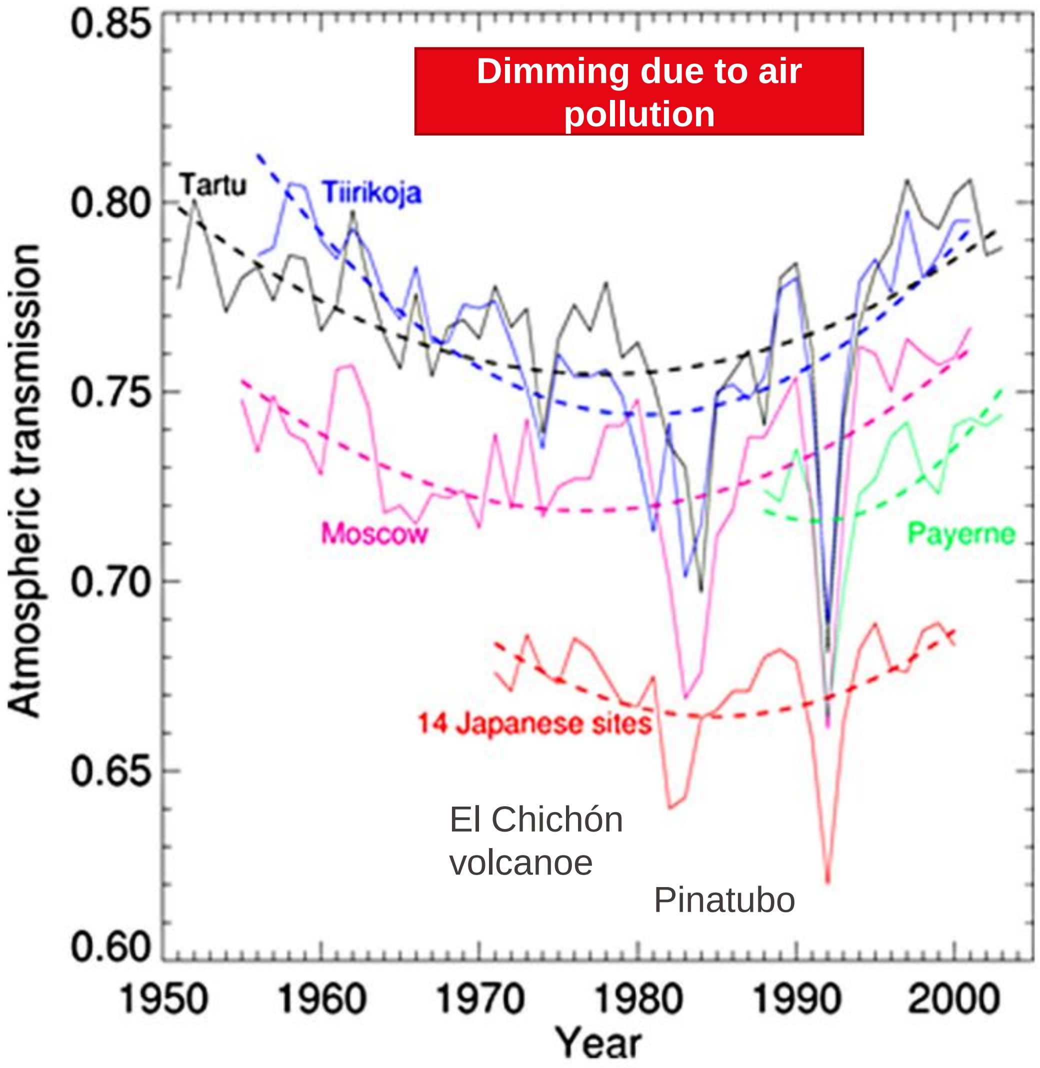
Aerosols reflect solar radiation, thereby shielding (masking) the Earth’s surface from radiation



Ammonium, sulfate, nitrate, some organics

- http://www.climatechange2013.org/report/reports-graphic/ch7-graphics/

Aerosol-radiation interaction



Aerosols prevent solar radiation from reaching the Earth's surface, they have a «dimming» effect → surface cooling.

Observed tendencies in surface solar radiation

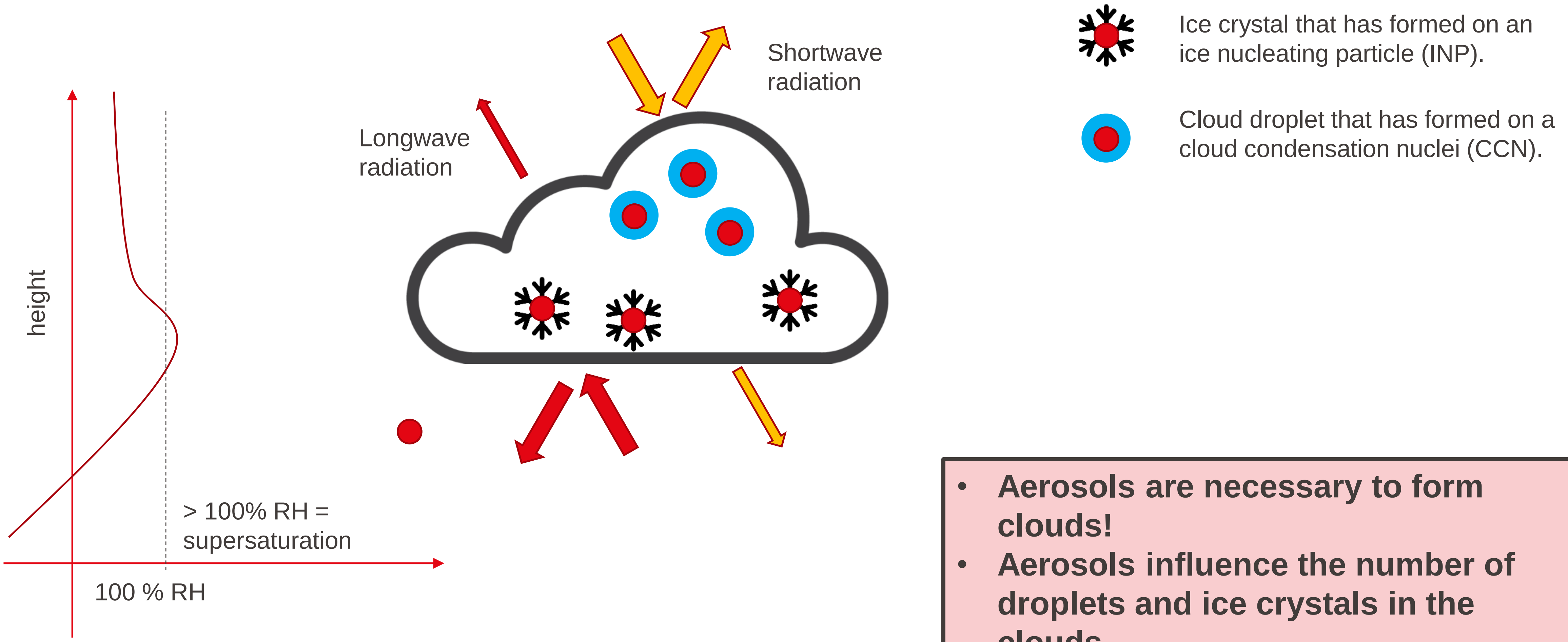
	1950s-1980s	1980s-2000	after 2000
USA	-6 ↘	5 ↗	8 ↗
Europe	-3 ↘	2 ↗	3 ↗
China/Mongolia	-7 ↘	3 ↗	-4 ↘
Japan	-5 ↘	8 ↗	0 →
India	-3 ↘	-8 ↘	-10 ↘

Units in W m^{-2}

- Fuzzi et al., 2015, doi:10.5194/acp-15-8217-2015

Wild, 2021, https://doi.org/10.1175/BAMS-D-11-00074.1

Aerosol-cloud interactions

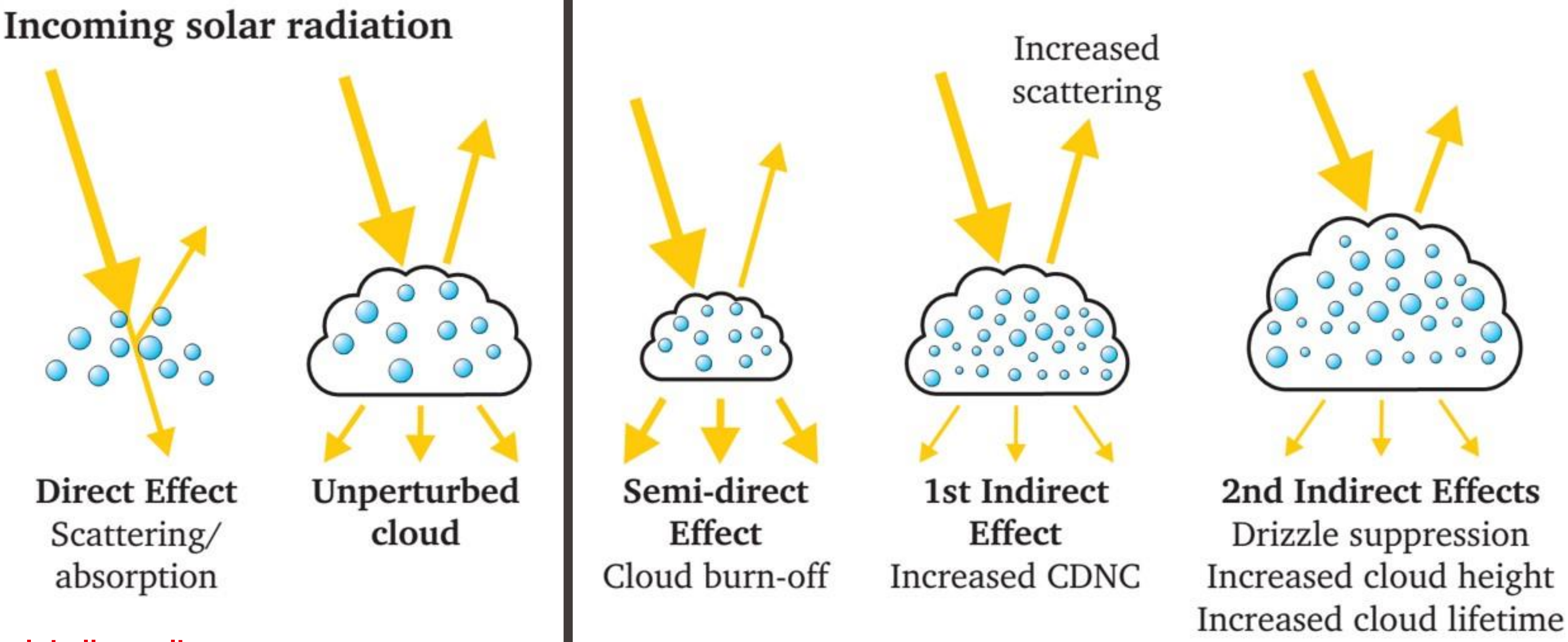


- **Aerosols are necessary to form clouds!**
- **Aerosols influence the number of droplets and ice crystals in the clouds.**
- **The number of droplets and crystals determinse the radiative properties of clouds.**

Aerosol-cloud interactions

Pristine cloud

Polluted atmosphere and clouds



globally cooling

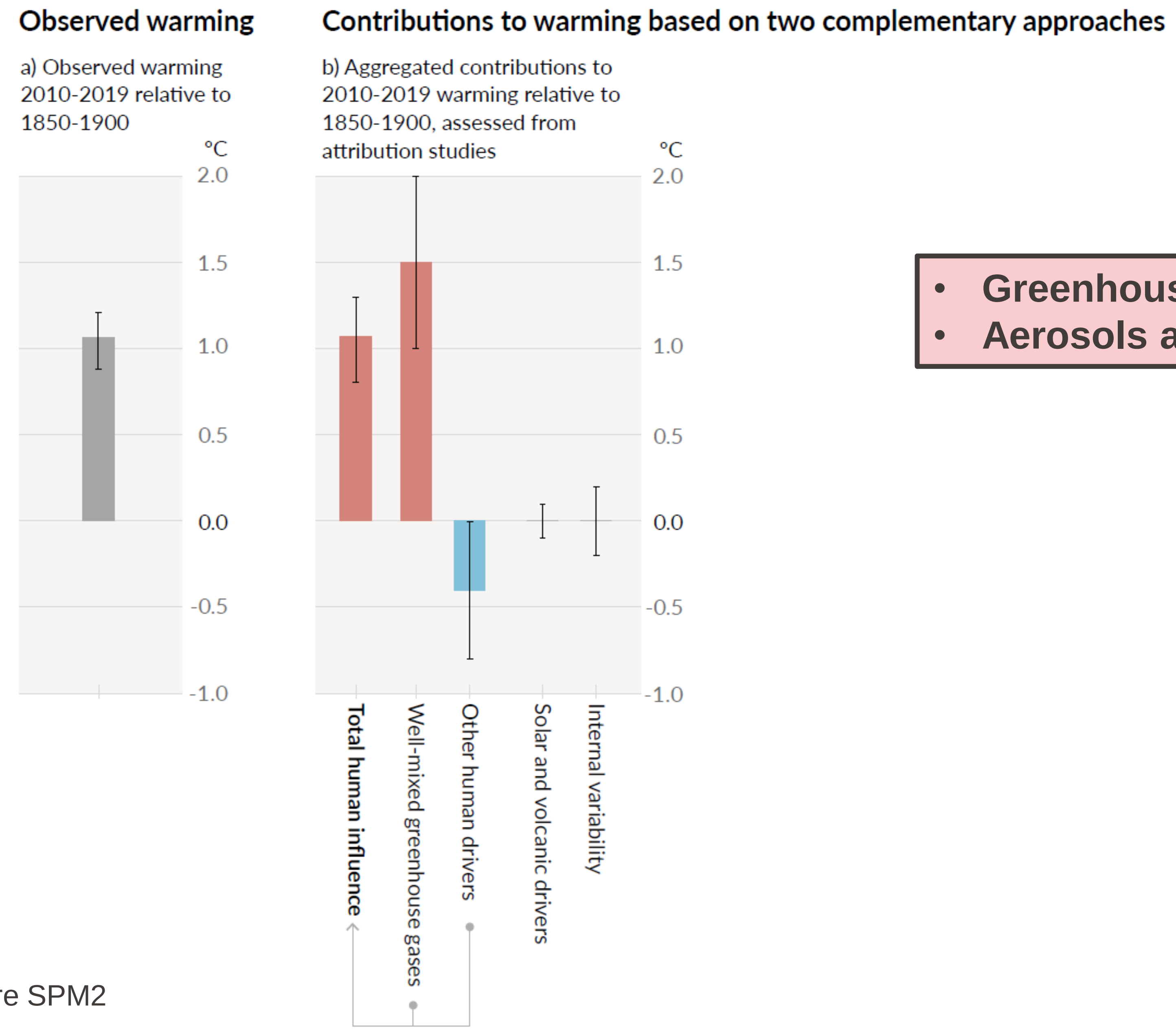
Air becomes warmer and clouds do not form or evaporate, globally warming

Higher albedo, globally cooling

No big drops, less rain, globally cooling

- CDNC – cloud droplet number concentration

Attribution of today's global warming

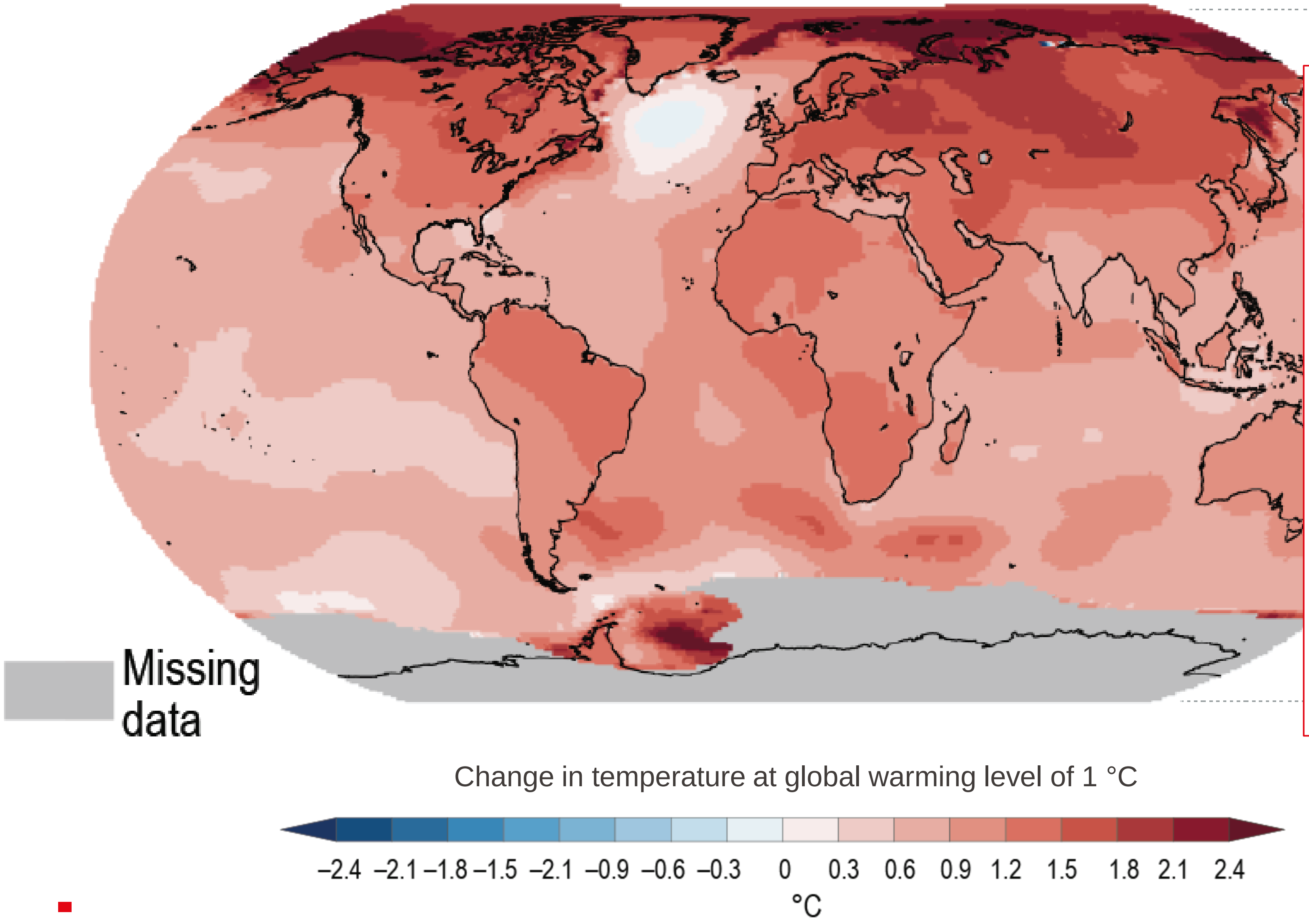


- Greenhouse gases warm
- Aerosols and clouds cool

- Figure SPM2

Does Earth warm uniformly?

Regional warming differences



- **Not all regions warm at the same speed.**
- **Land warms roughly two times faster than the ocean.**
  - **Average warming on land was > 2°C in 2023.**
  - **Average warming of the ocean was > 1.0°C in 2023.**
- **The Arctic warms up to 4 times faster than the global average!**

Contributions to Arctic warming

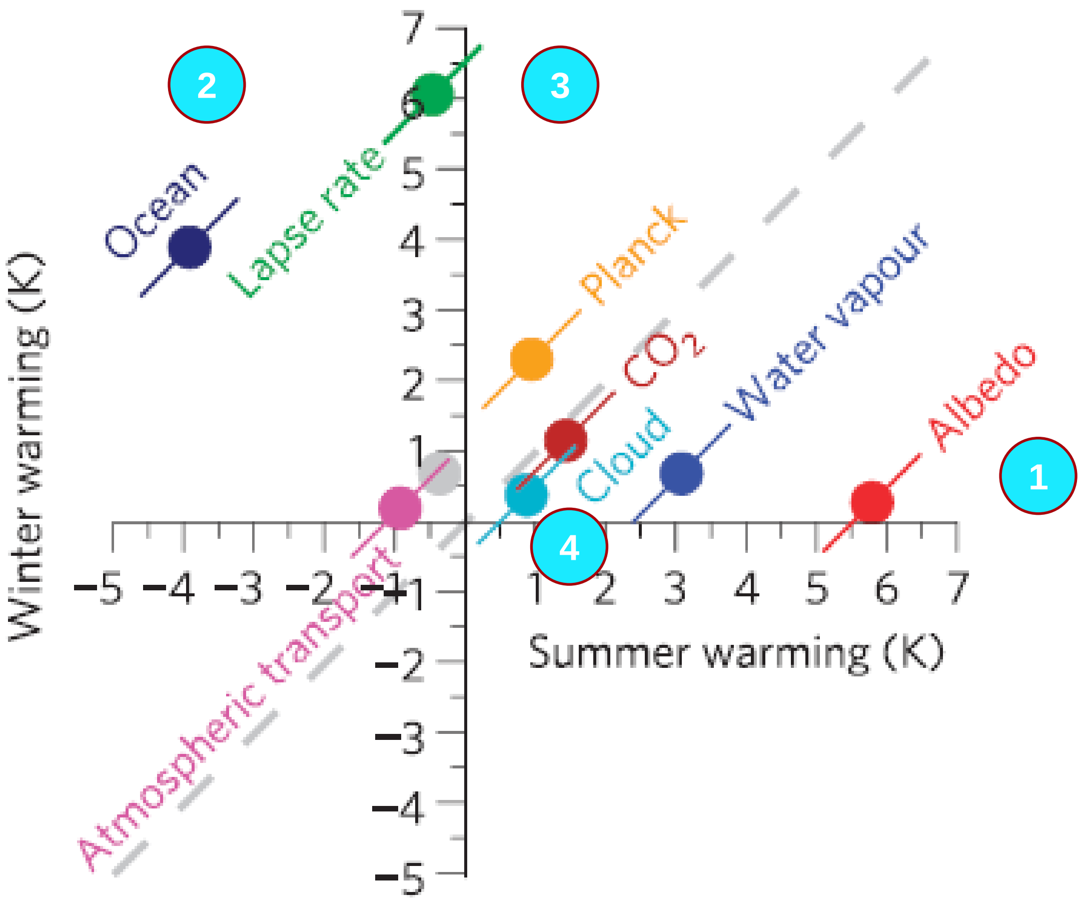
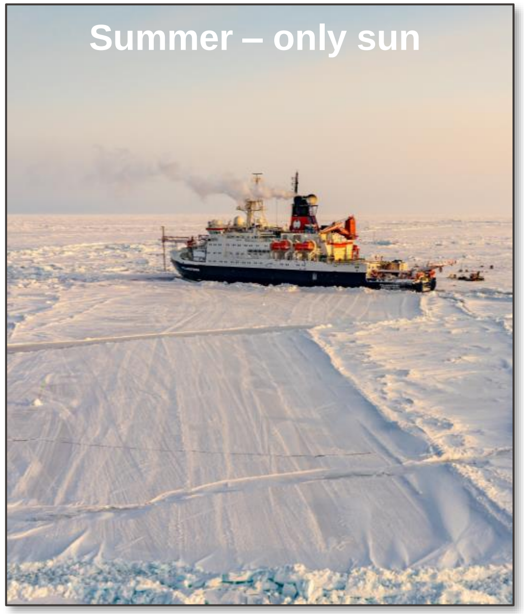


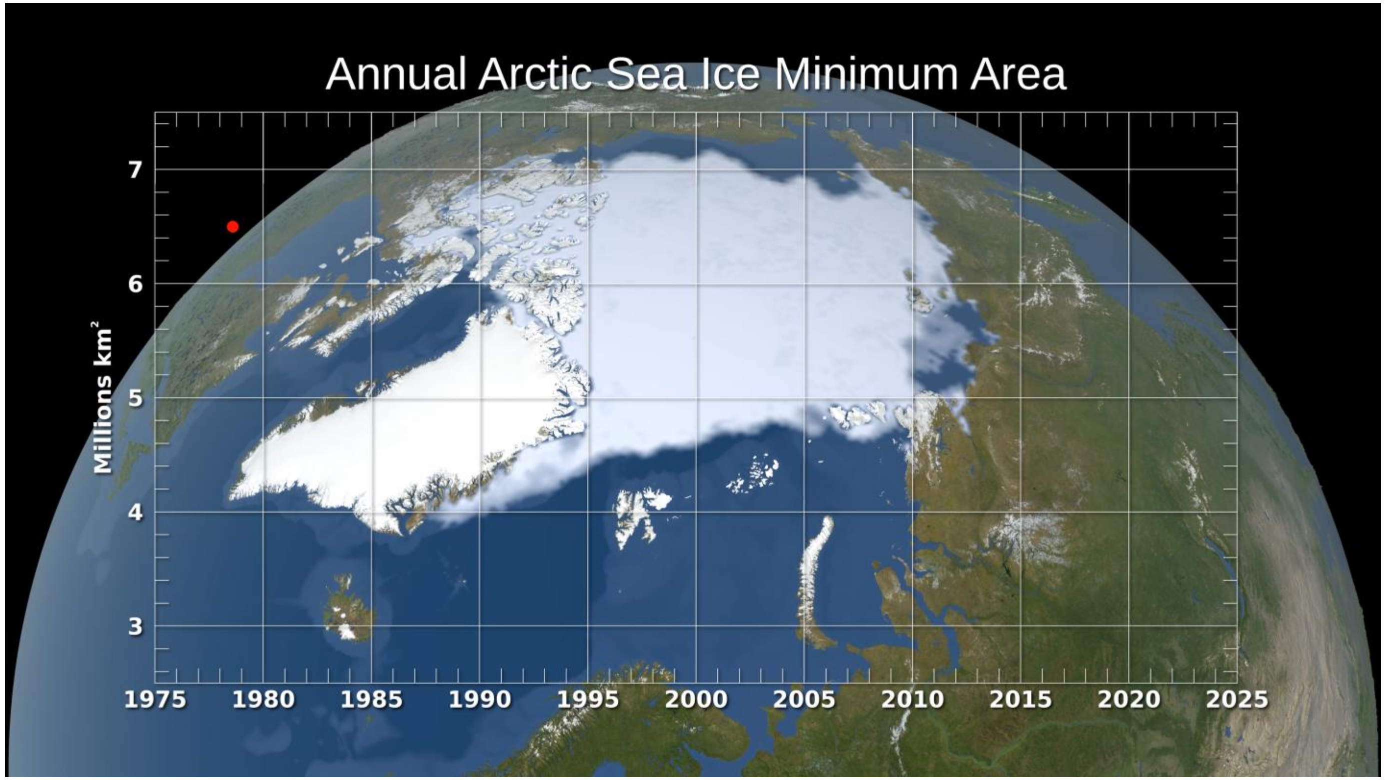
Figure 2 | Warming contributions of individual feedback mechanisms. **b**, Arctic winter versus summer warming. Grey is the residual error of the decomposition.

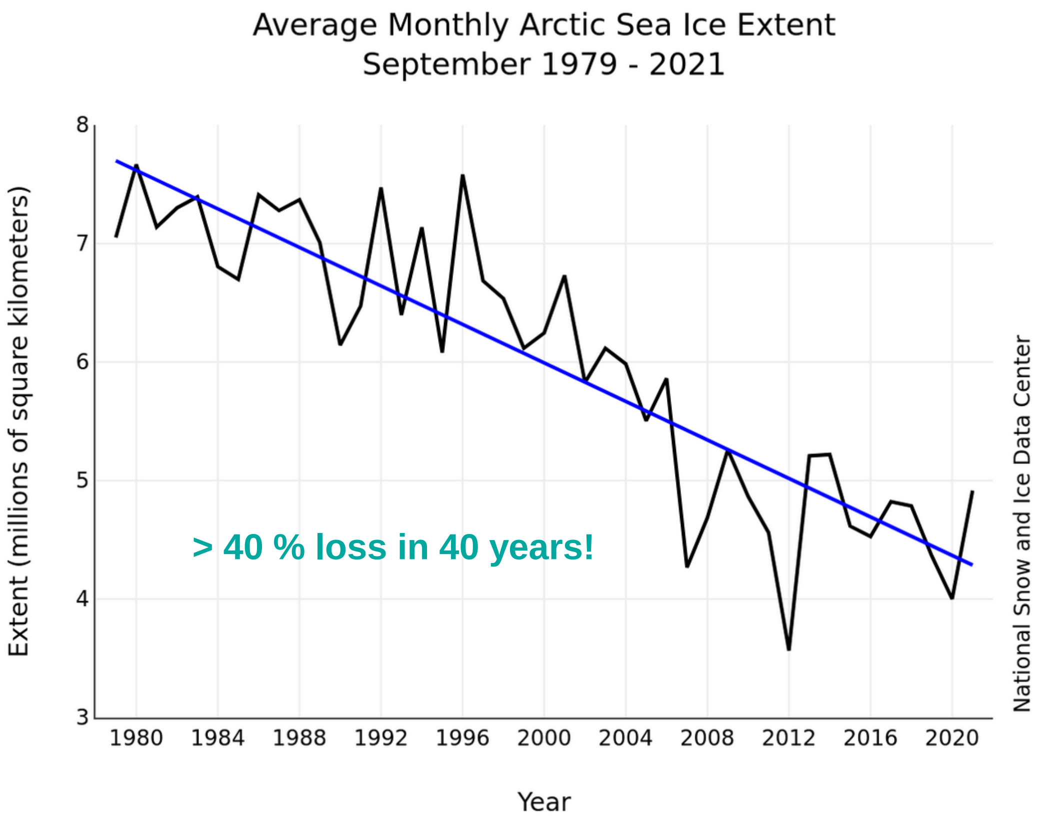


- Need to distinguish winter and summer mechanisms.
- Note the role that CO_2 plays.

- Pithan and Mauritsen, Nat. Geoscience, 2014

1. Albedo effect: Arctic sea ice retreat

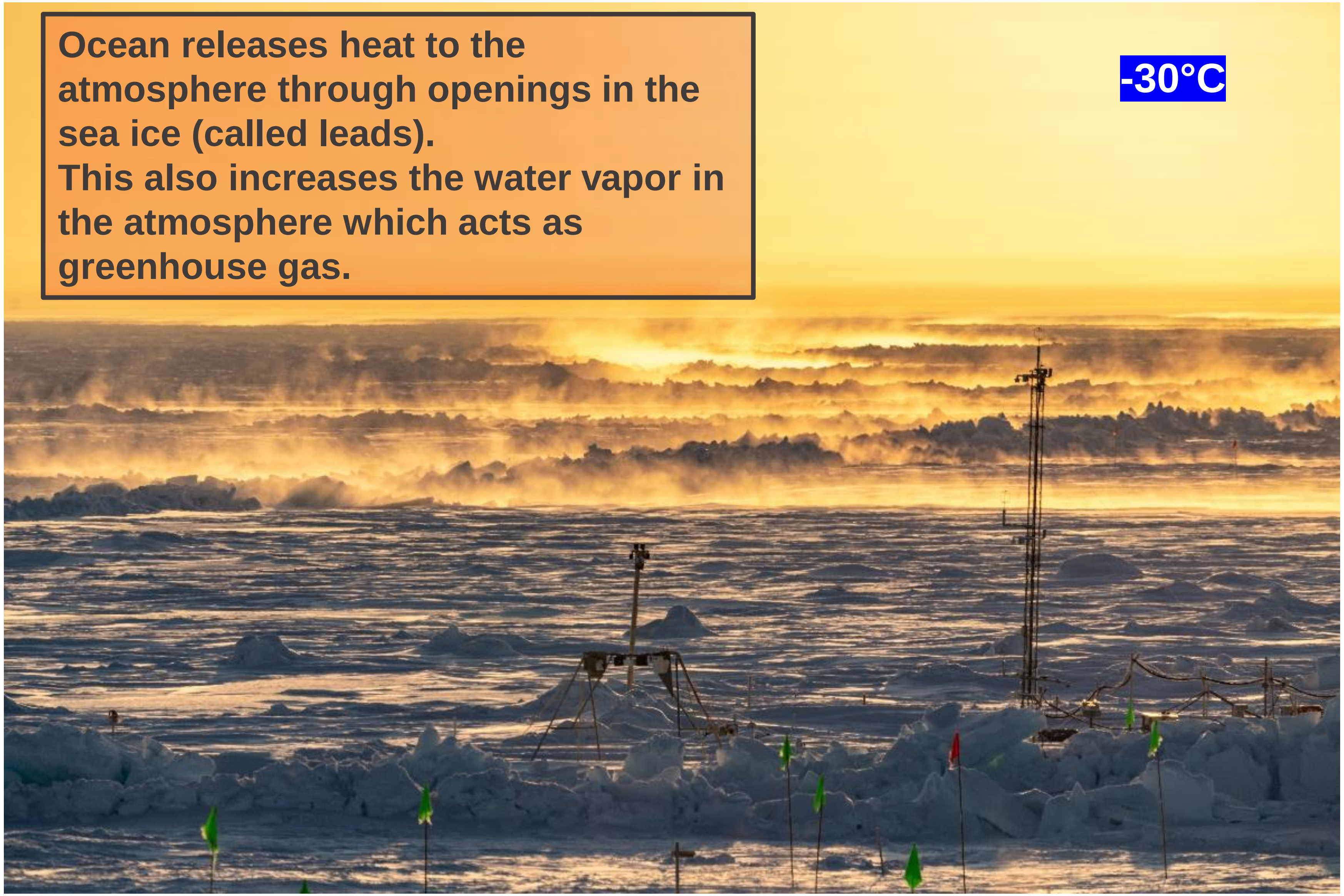




Less sea ice means that less solar radiation is reflected back to space and that the ocean absorbs more heat.

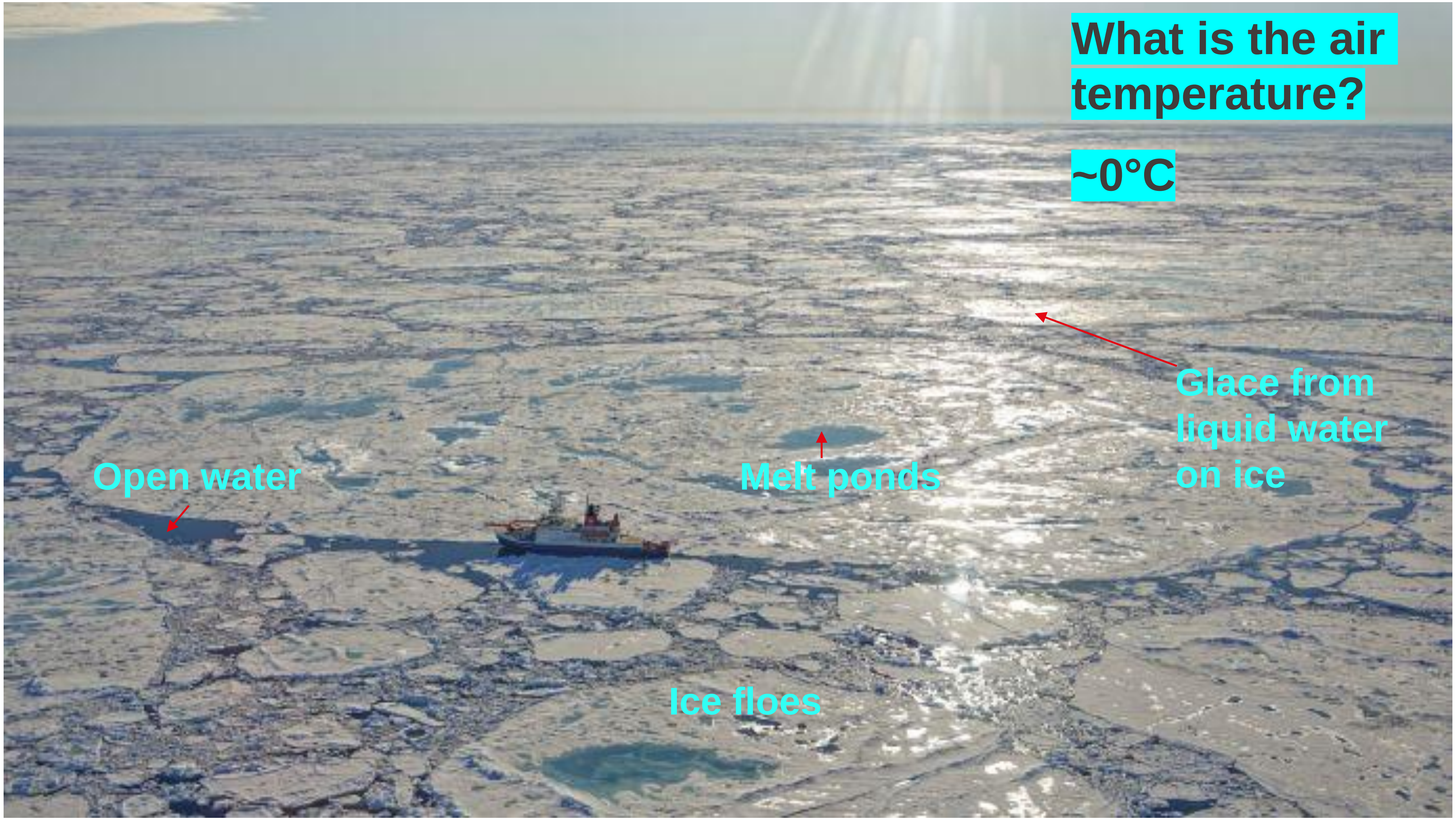
- http://nsidc.org/arcticseaicenews/

2. Ocean effect: winter



Ocean water -1.6°C

2. Ocean effect: summer



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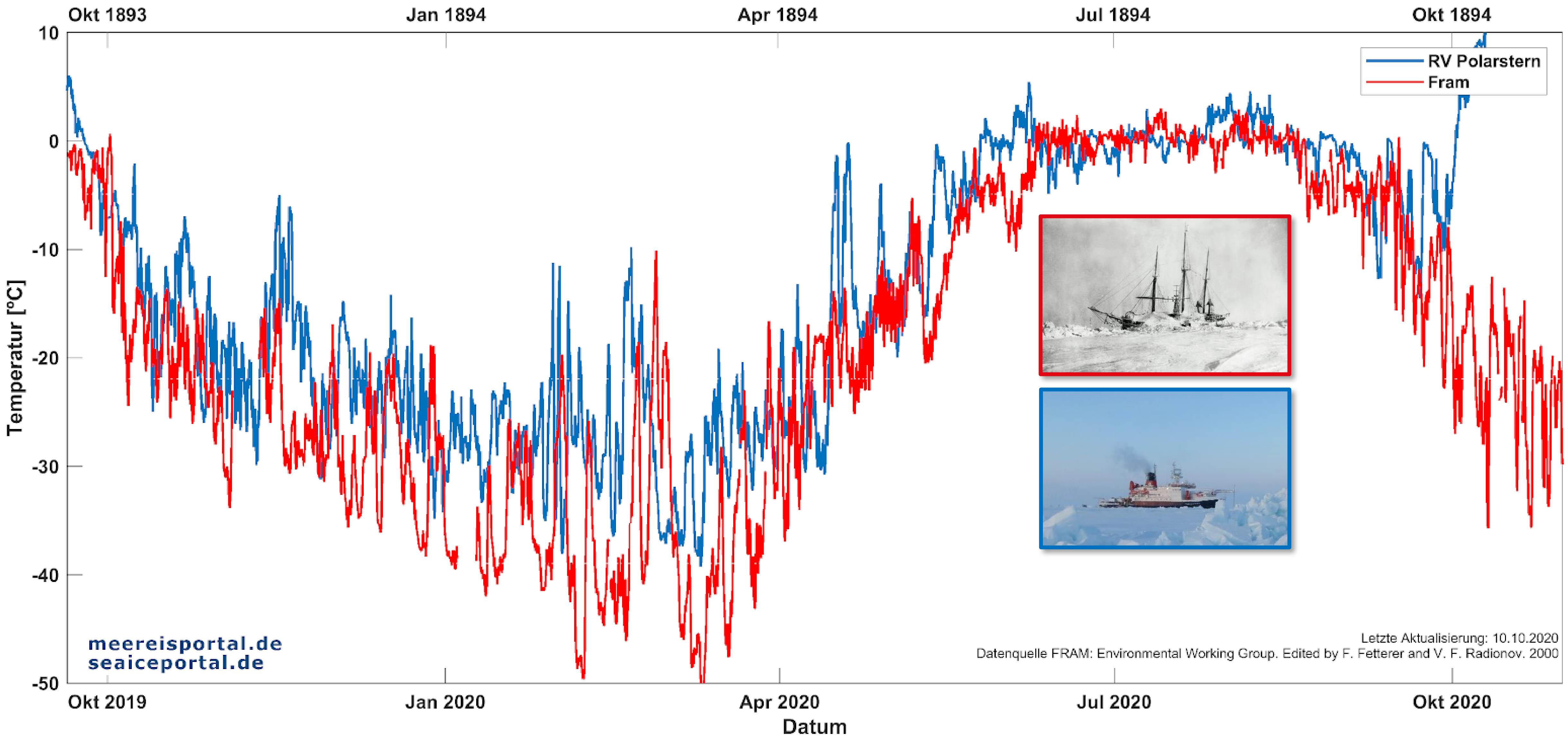
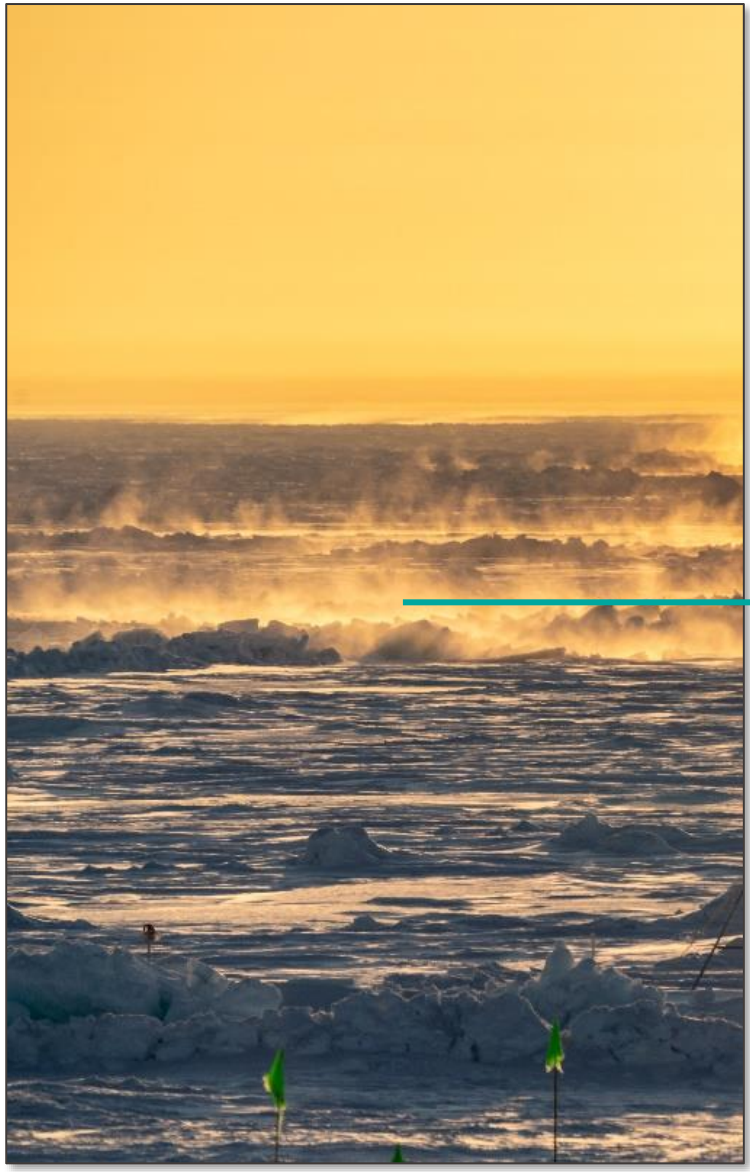
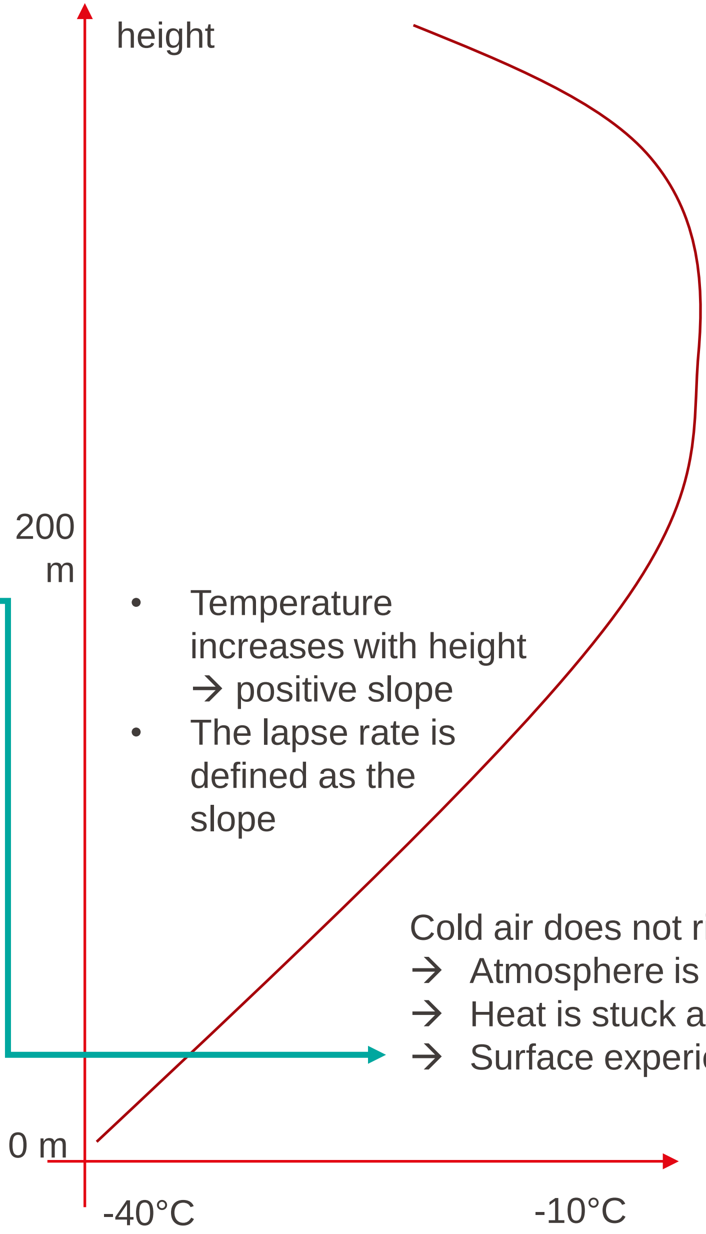
Arctic temperature change: 1893/94 vs 2019/20



3. Lapse rate effect





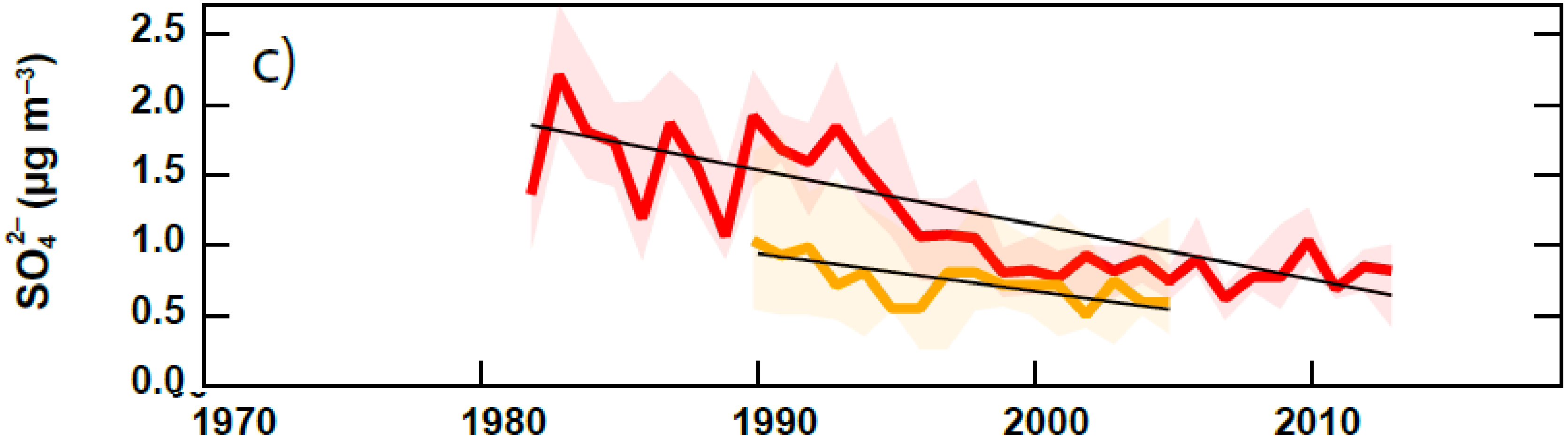
- Temperature increases with height → positive slope
- The lapse rate is defined as the slope

Cold air does not rise
→ Atmosphere is highly stratified
→ Heat is stuck at the surface
→ Surface experiences amplified warming

The lower Arctic atmosphere is unable to transport heat upwards because of positive lapse rates (also called temperature inversions).

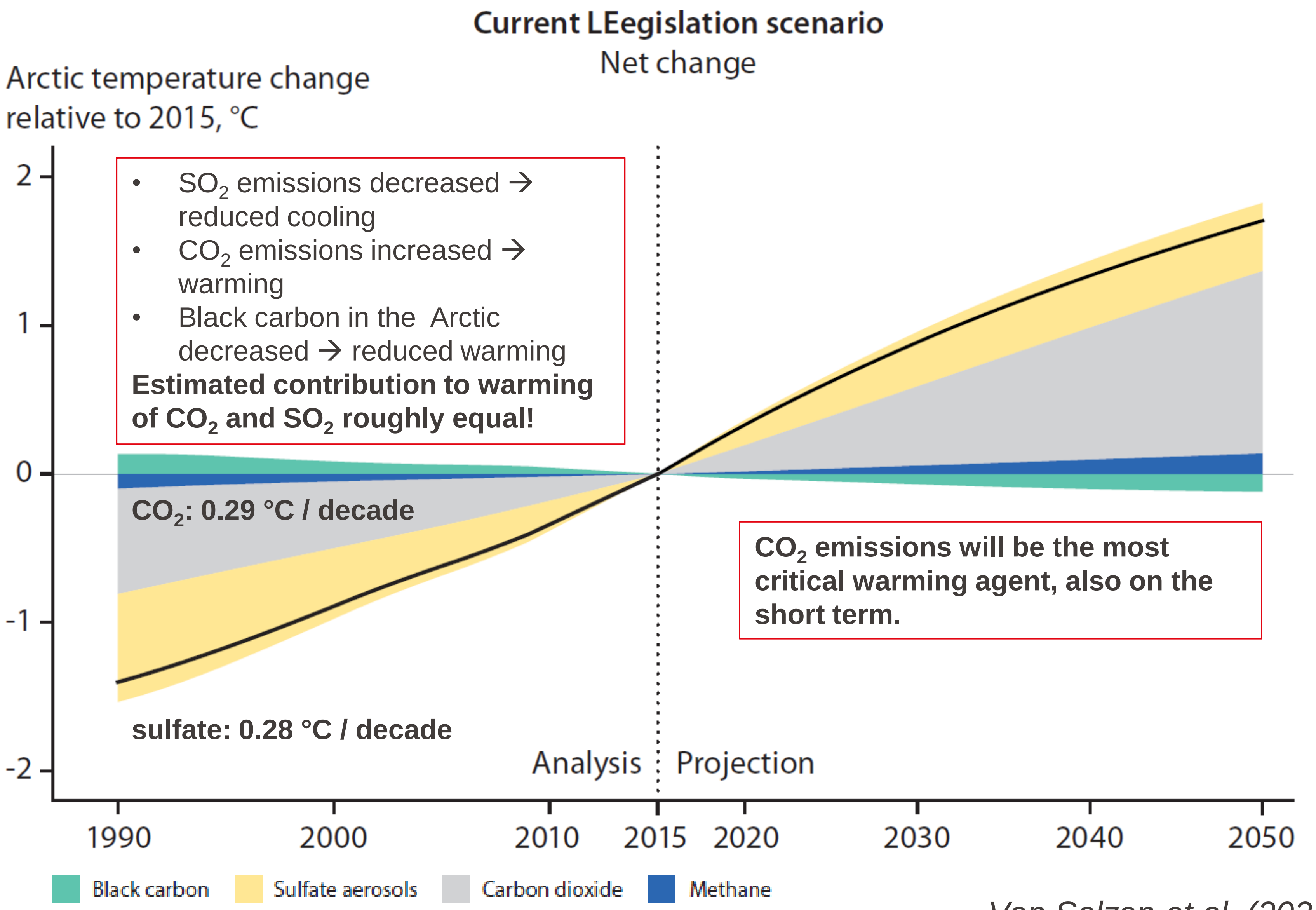
4. Aerosol effect

- Anthropogenic emissions have decreased in the past decades because of cleaner air policies.
- There are less aerosols in the Arctic.



Schmale et al. (2022)

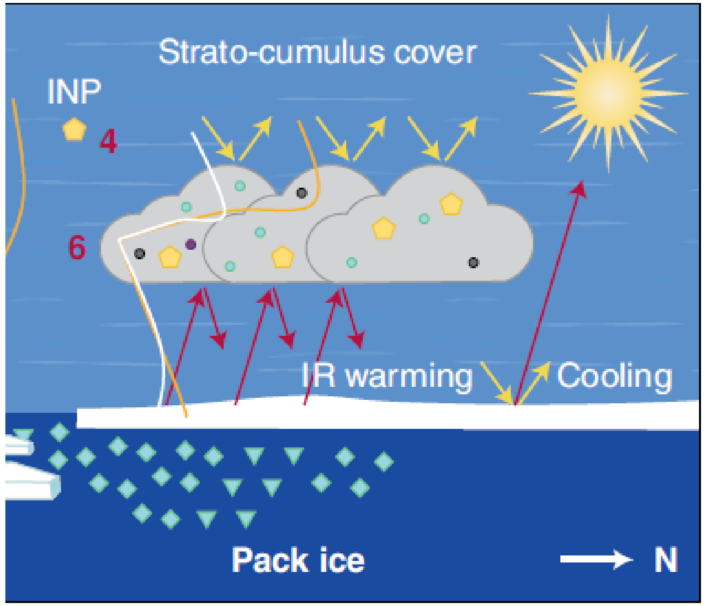
4. Aerosol effect

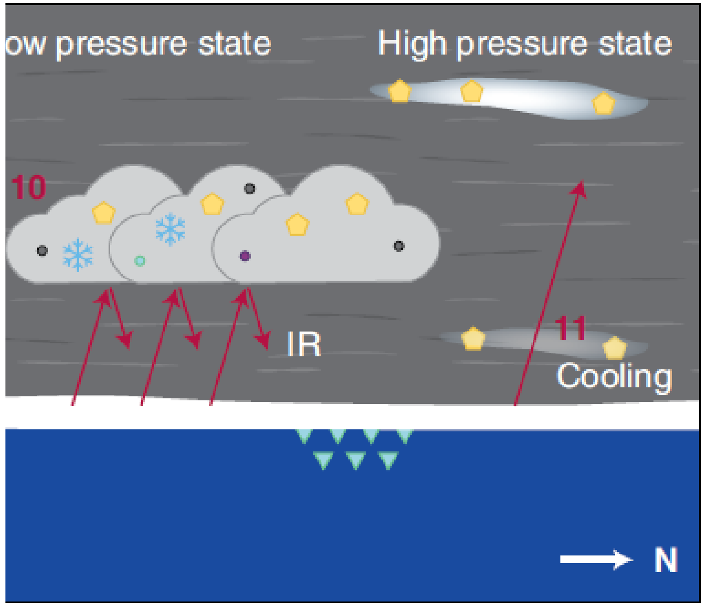


Von Salzen et al. (2022)

4. Cloud effect

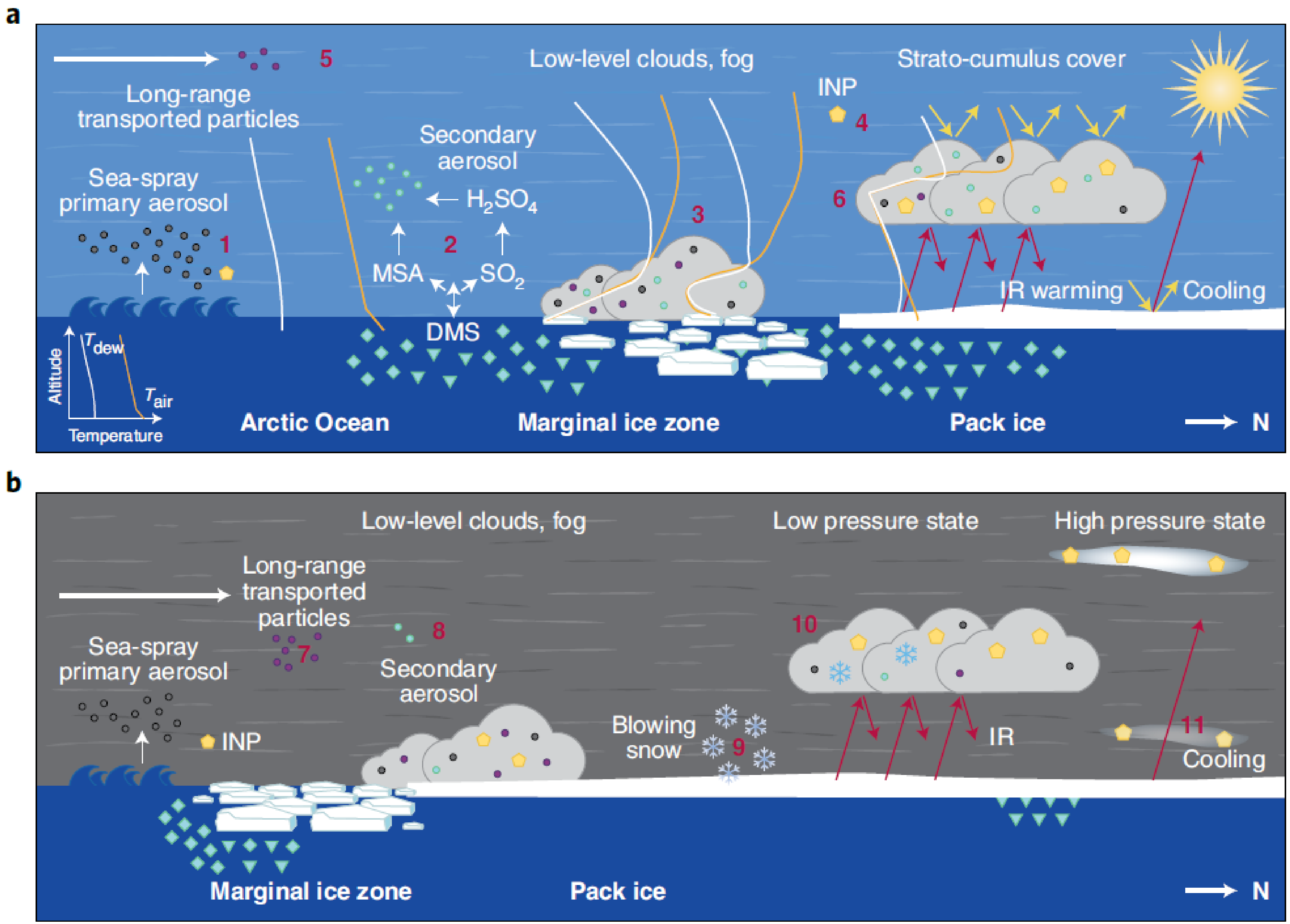
- The typical low level clouds in the Arctic act as a blanket. They absorb longwave radiation and re-emit it to the surface.
- The surface warms.
- This effect is opposite to the global cooling effect of low clouds.
- The reason is that the shortwave radiation does not play much of a role. The sea ice under the cloud reflects the solar radiation as much as the cloud, so there is no surface warming and it does not matter whether there is a cloud or not from the shortwave perspective.





4. More aerosol and cloud effects

This is what my group typically works on.



Schmale et al. (2021)

Studying reasons for Arctic Amplification

Credit: Oden Crew

Impacts of Arctic warming

- Sea level rise because of the melting Greenland ice sheet (up to 6 m if all melts)
- Changing weather patterns in the nothern hemisphere.
- Potentially large amounts of greenhouse gases will be emitted because of thawing permafrost, leads to more warming globally.
- Vegetation changes, e.g., more boreal forest (larger cabon sink).
- Fish populations in the Arctic Ocean will change.
- And many more…

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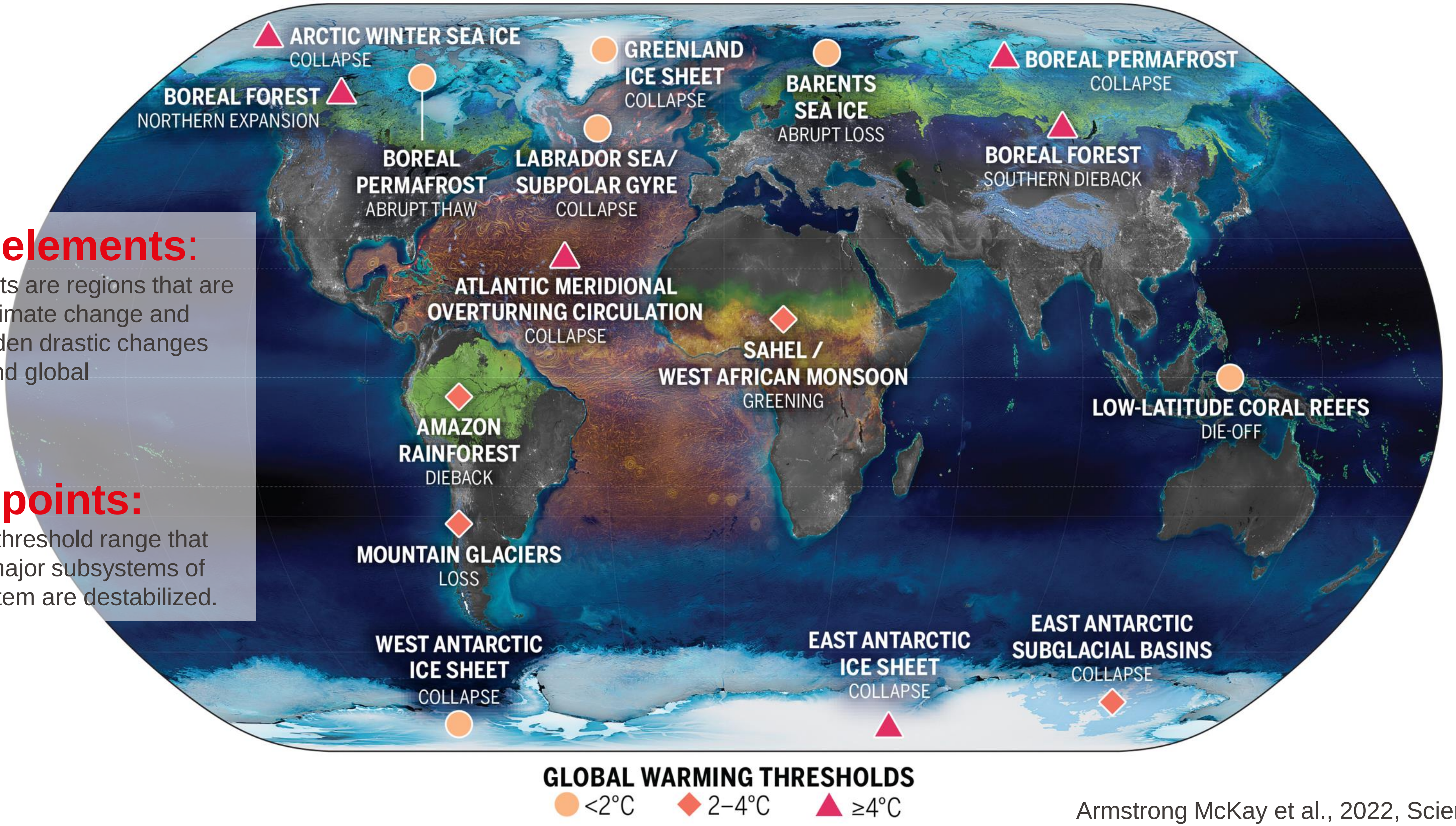
What is at stake?



Tipping elements:

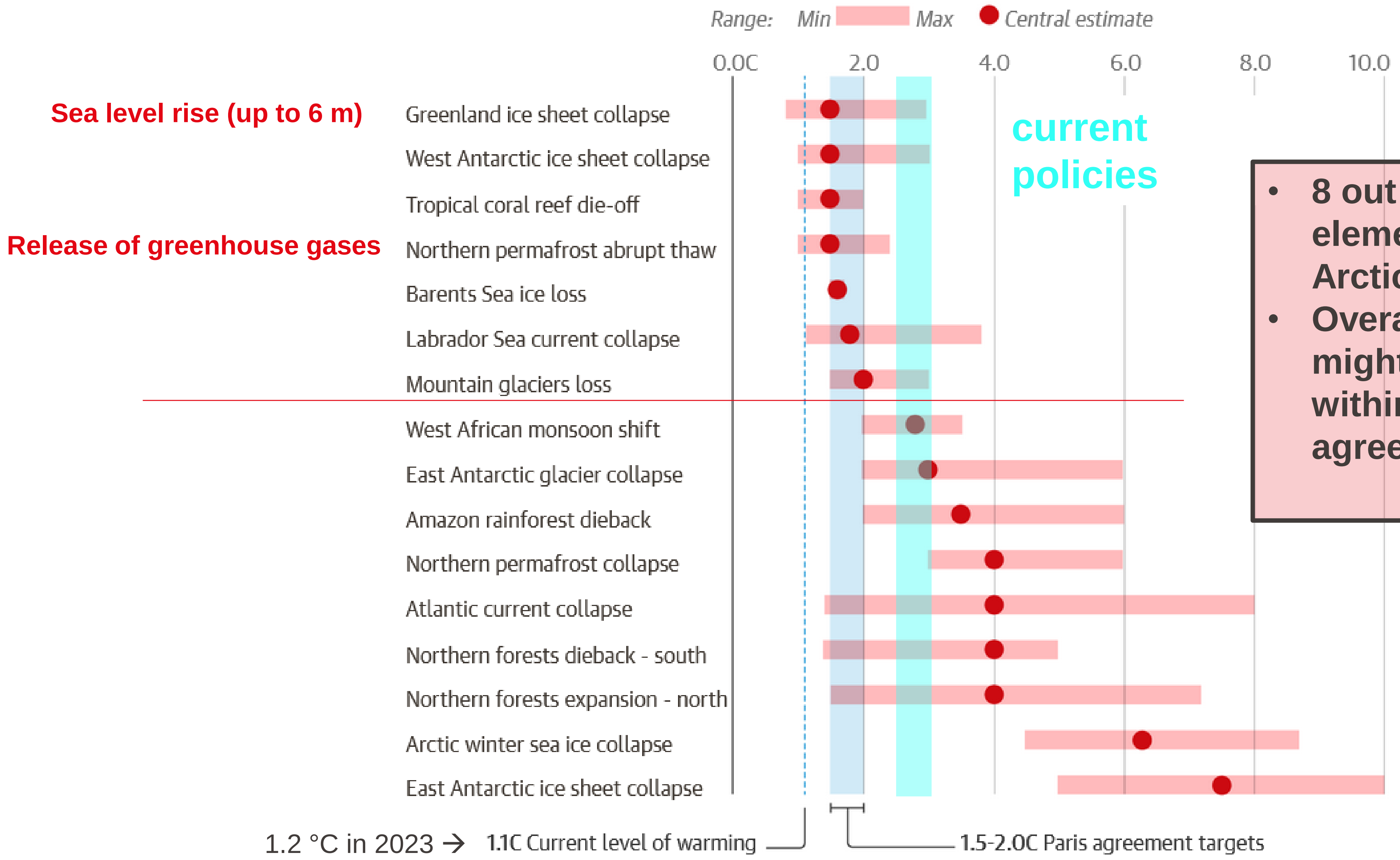
Tipping elements are regions that are vulnerable to climate change and capable of sudden drastic changes with regional and global consequences.

Tipping points:

A temperature threshold range that when passed major subsystems of the climate system are destabilized.

Armstrong McKay et al., 2022, Science

What can the Paris Agreement prevent?



- 8 out of 16 tipping elements are in the Arctic.
- Overall, 7 tipping points might be surpassed within the Paris agreement range.

Guardian graphic. Source: Armstrong McKay et al, Science, 2022. Note: Current global heating temperature rise 1.1C Paris agreement targets 1.5-2.0C

Climate Emergency in a nutshell

1. We are extremely close to our global temperature target of 1.5/2.0°C for 2100.
   1. Changing conditions (sea level rise, what grows where, biodiversity)
   2. Impact of extreme events
   3. Surpassing tipping points → irreversible effects

2. Drastic emission reductions are needed now and net-zero needs to be achieved by 2050.
   - The current decade (2020-2030) is called the decisive decade. If we wait longer, we have lost the opportunity to keep global warming in a reasonable range.

3. Humanity is faced with a technological, political, regulatory and behavioral challenge never encountered before.
   - Large-scale transformation is needed. This is a process that takes time.

We cannot wait for solutions, we must drive solutions.

Food for thought throughout your studies

- What do you want to learn so
  you can contribute to driving solutions?

- What will you do to **have positive impact**?
  Positive impact: the world is better off with your presence and action than without

Thank you for your attention!