The science of climate change

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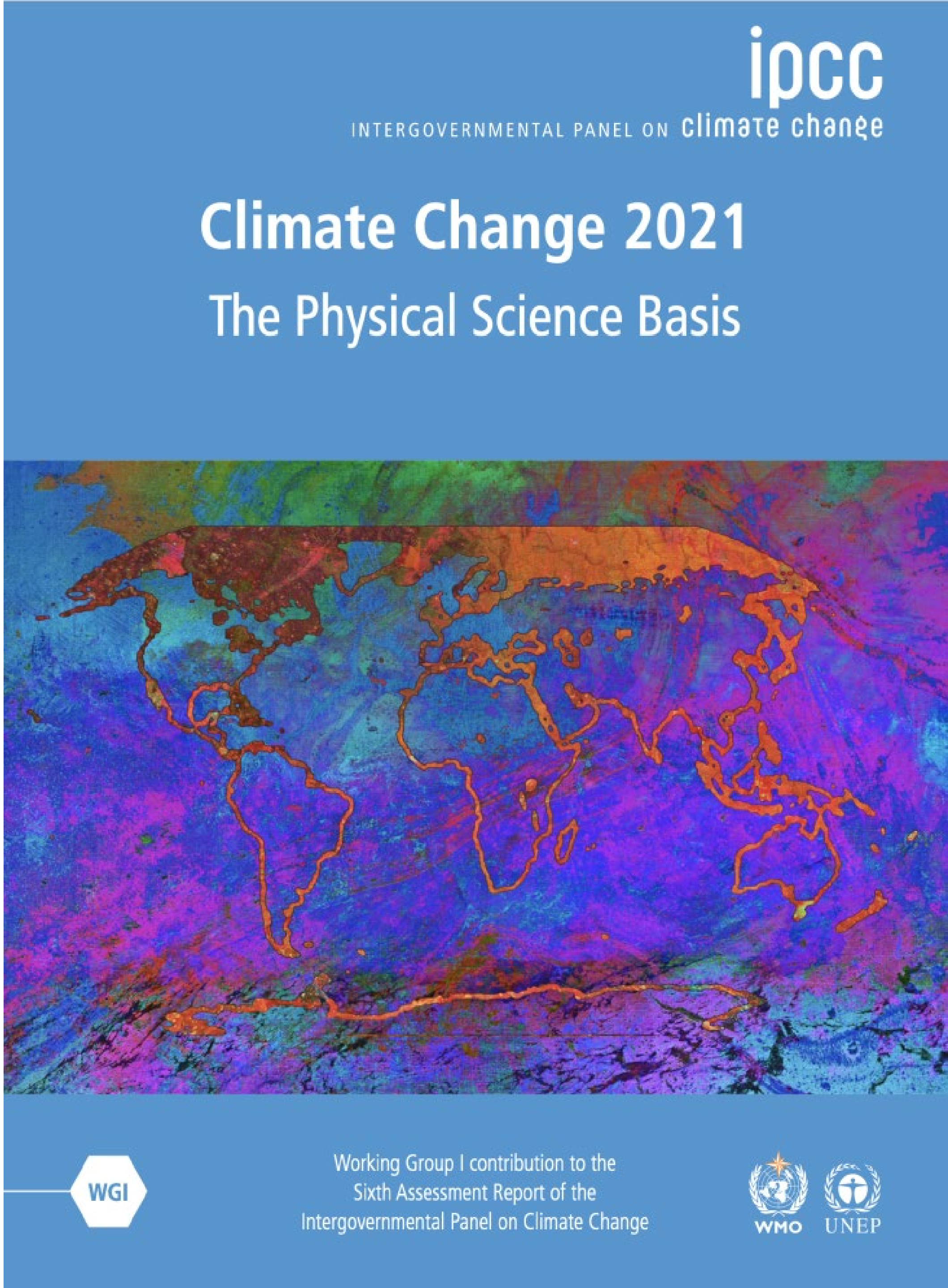
6th IPCC assesment report (AR6)

- Working Group I (physical basis) released in August 2021

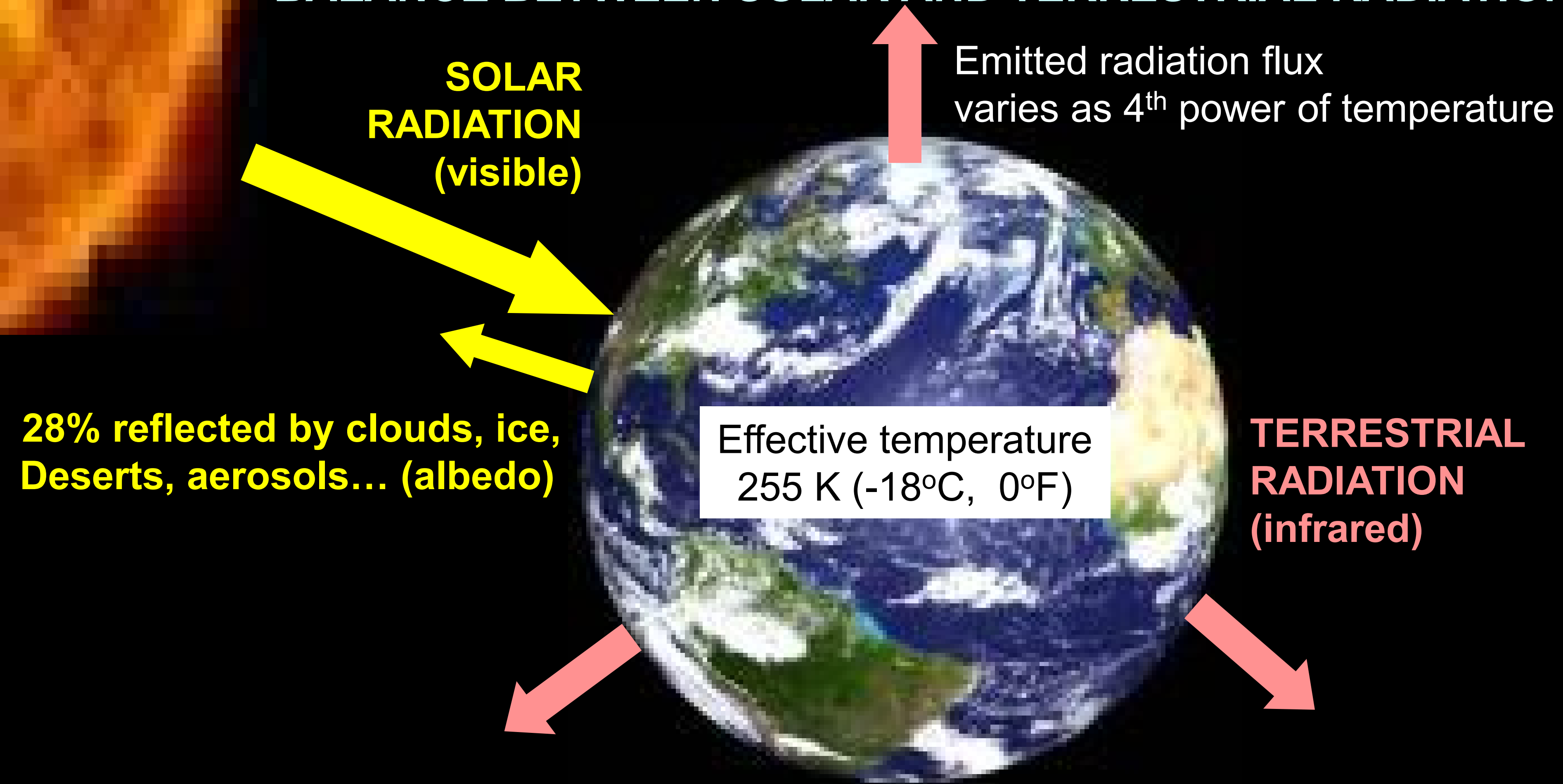
Summary for Policy Makers is good read

- Working Group II (impacts) released in February 2022

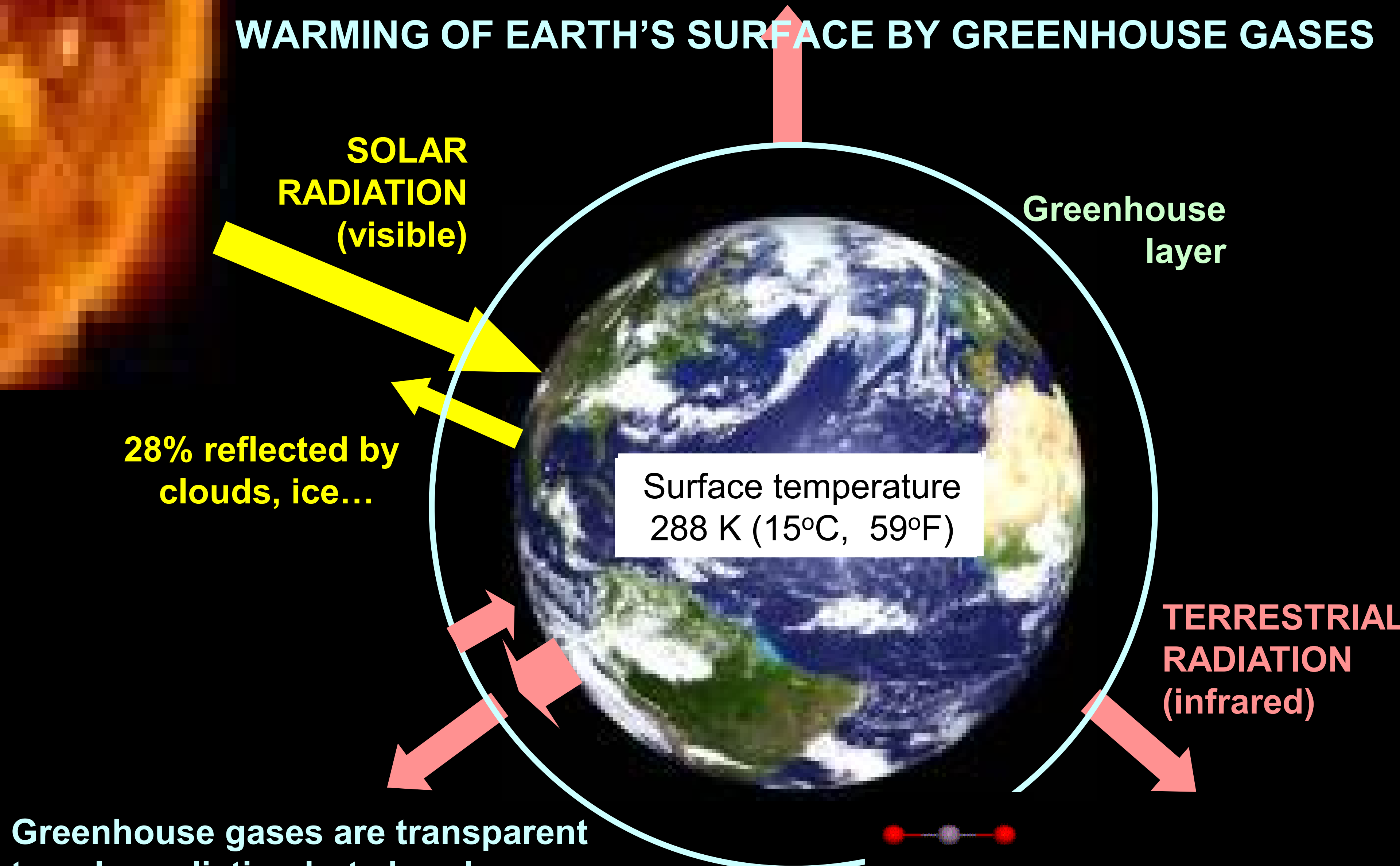
- Working Group III (mitigation) to be released in April 2022



EQUILIBRIUM CLIMATE OF THE EARTH: BALANCE BETWEEN SOLAR AND TERRESTRIAL RADIATION



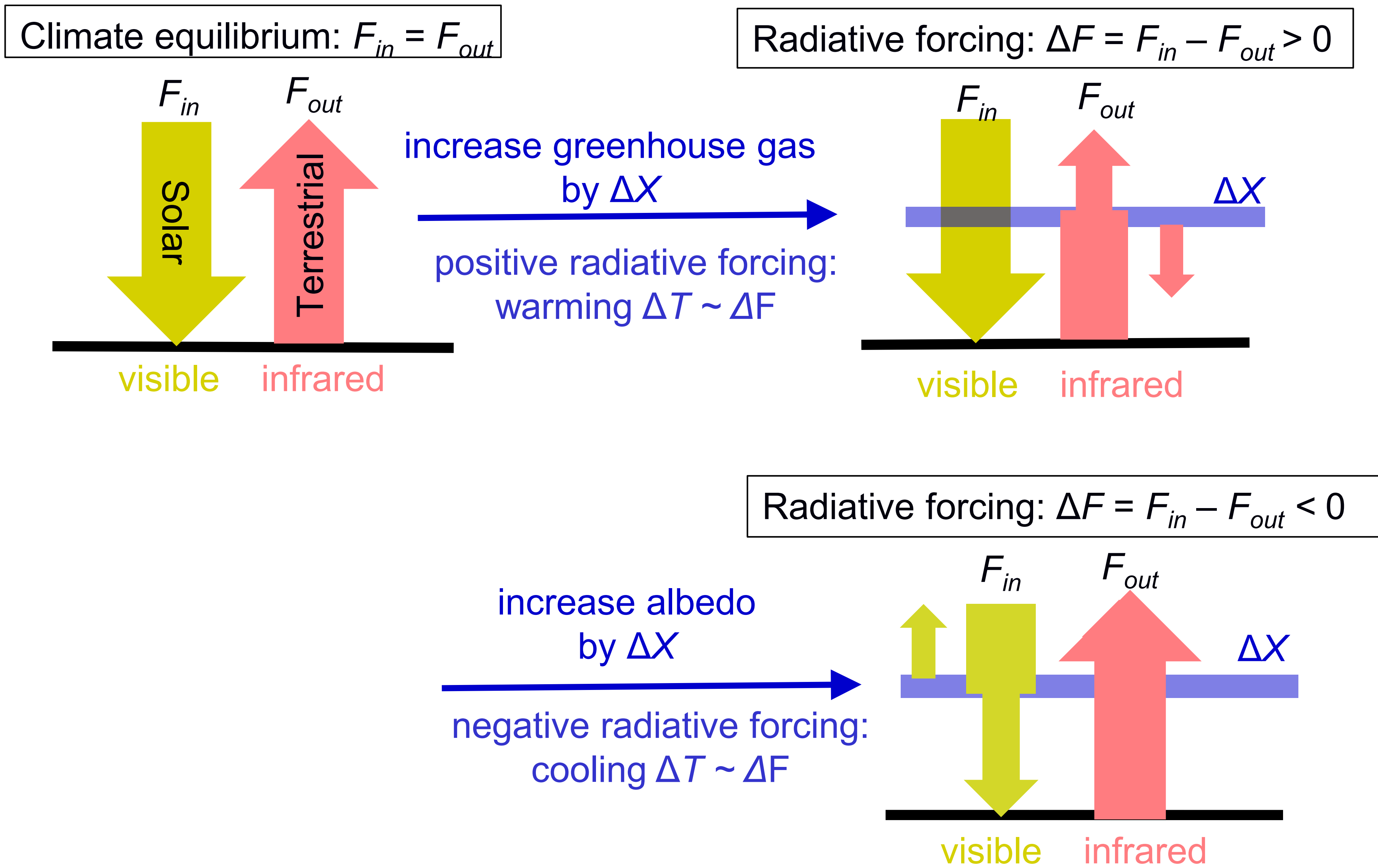
WARMING OF EARTH'S SURFACE BY GREENHOUSE GASES



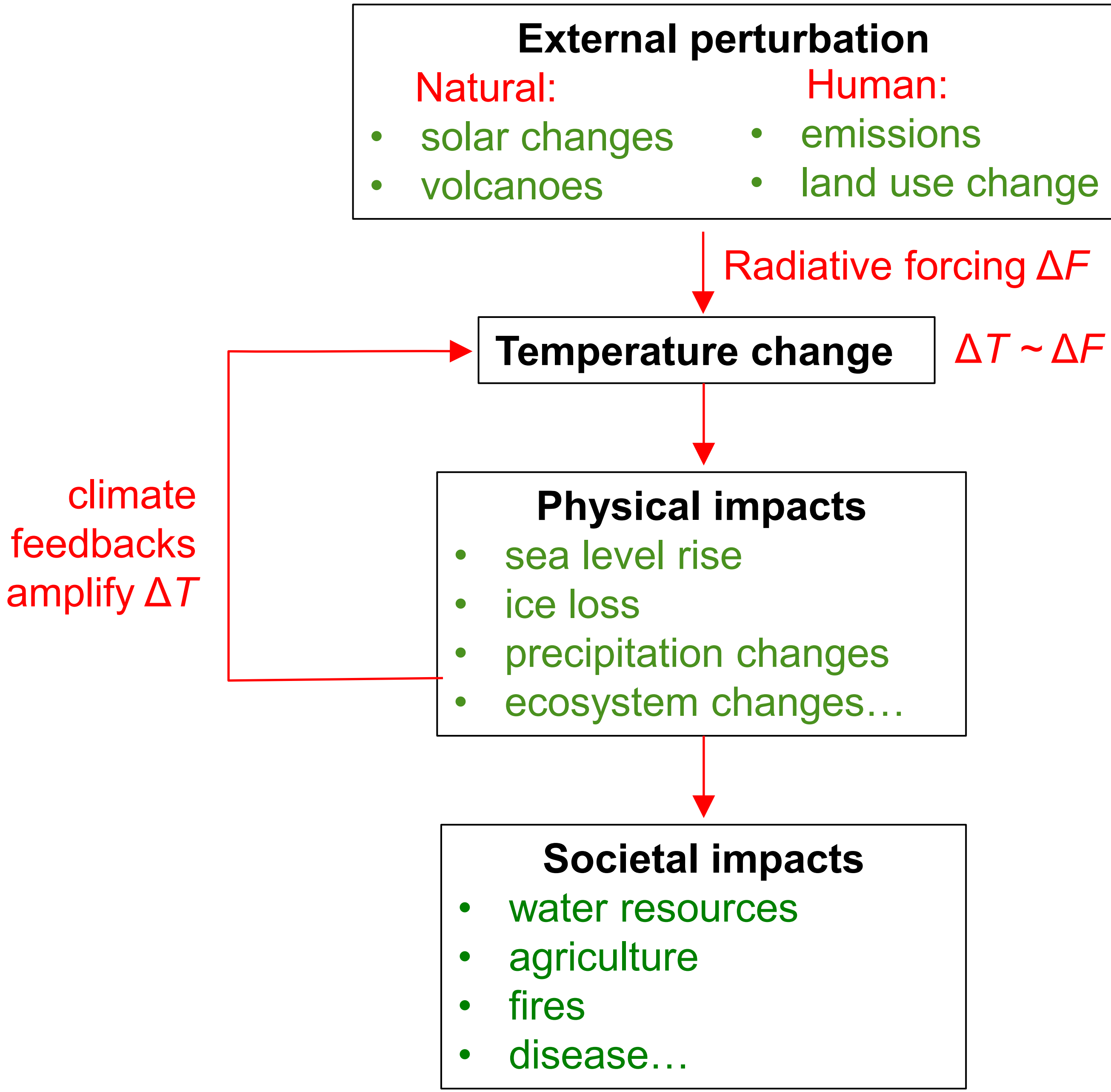
Greenhouse gases are transparent to solar radiation but absorb terrestrial infrared radiation and re-emit it both upward and downward

Water, CO_2, methane are the most important greenhouse gases

Climate change arises from disruption of radiative equilibrium

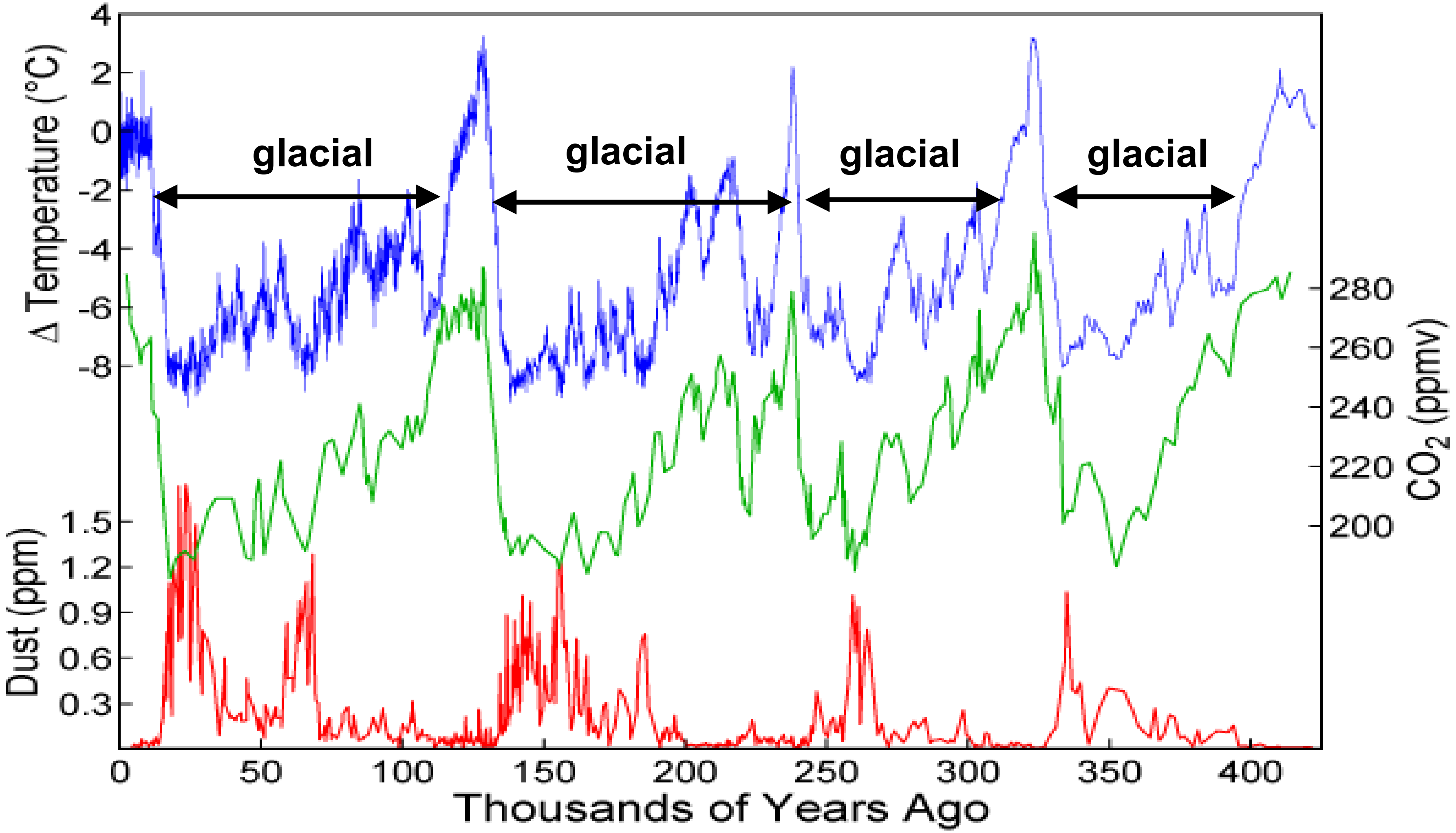


Radiative forcing of climate change drives cascade of impacts and feedbacks



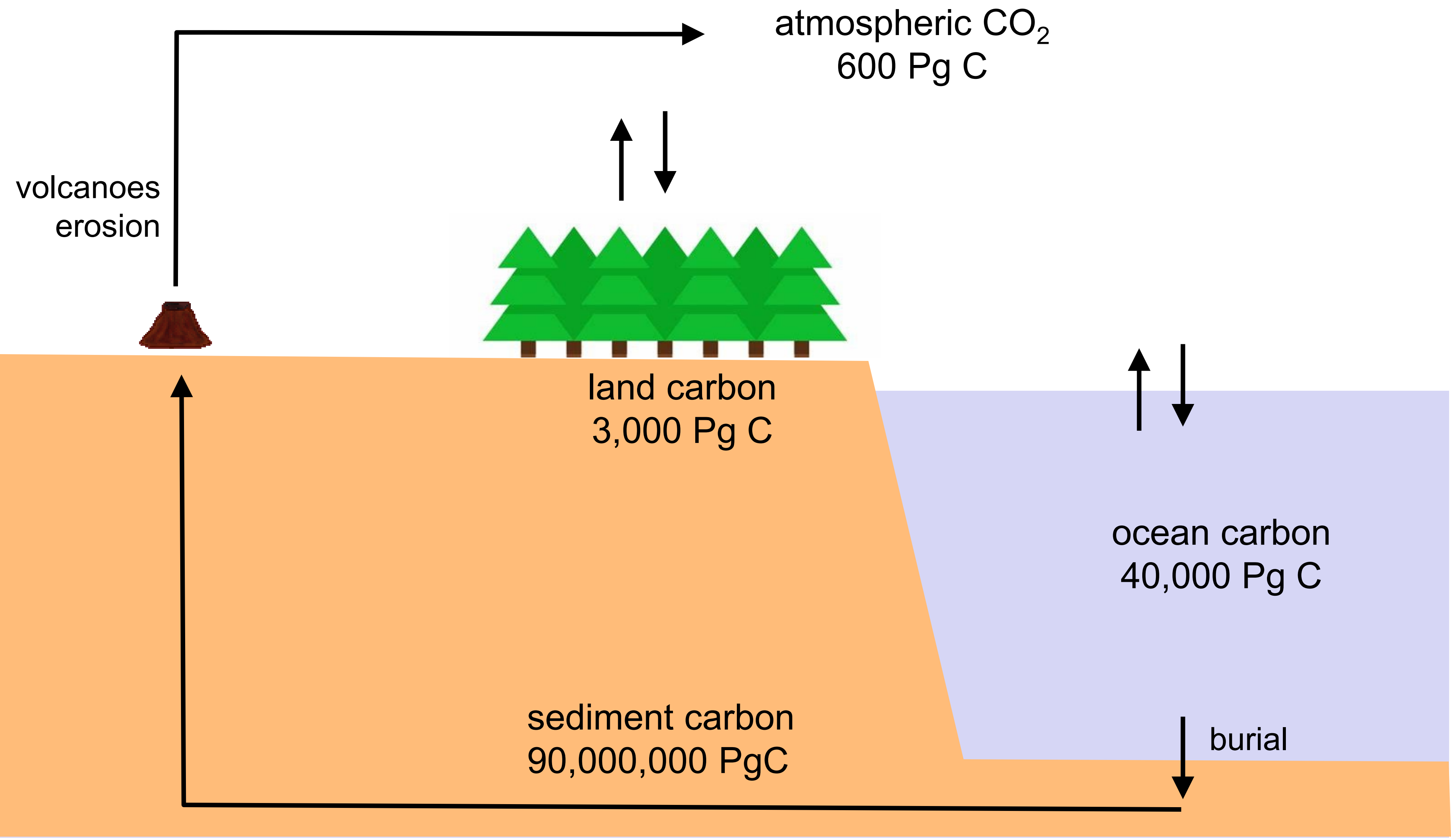
Recent example: glacial-interglacial climate transitions

Fast climate transition driven by water, ice, CO_2 feedbacks on an initial solar forcing

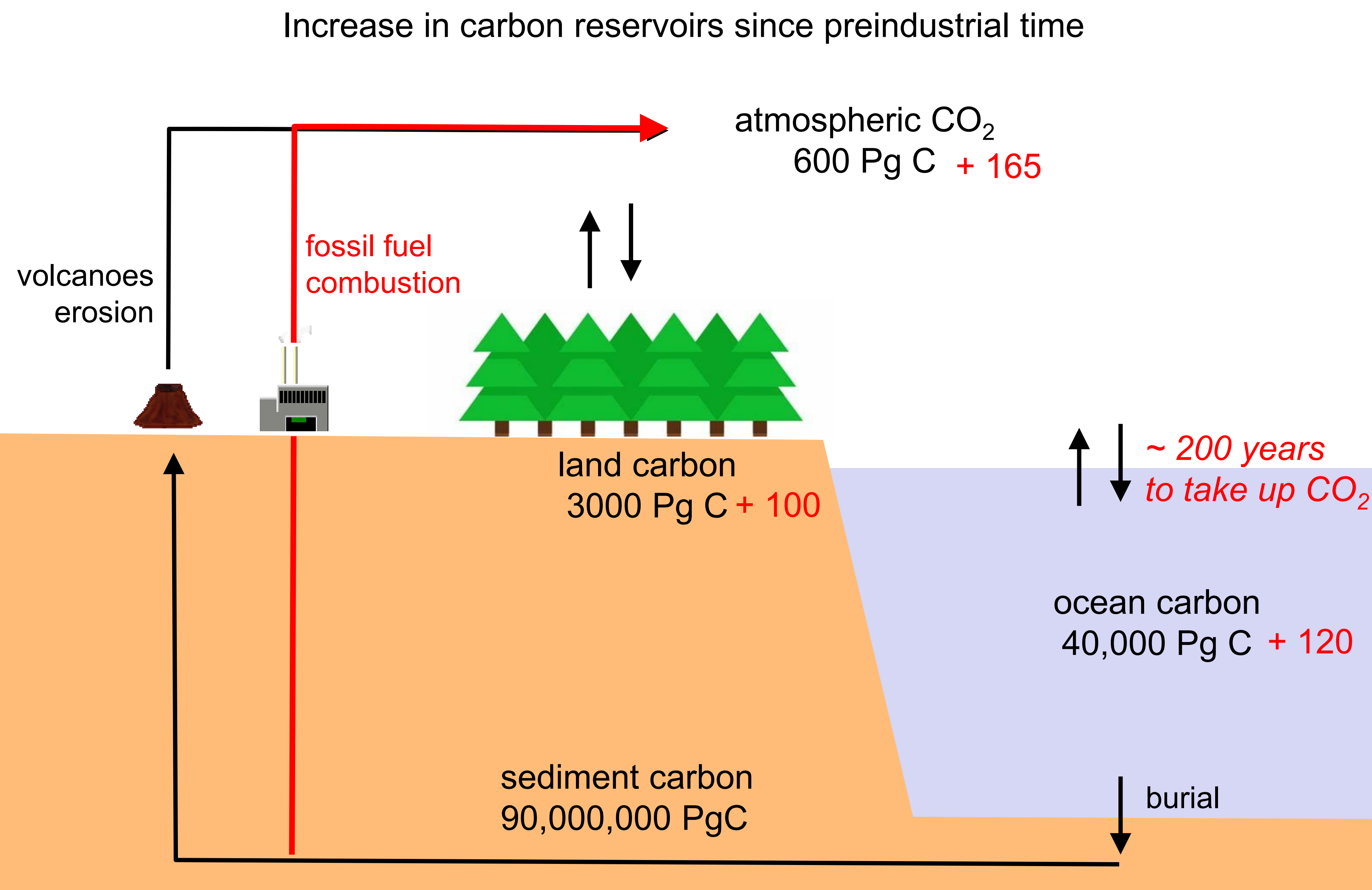


Vostok ice core (East Antarctica)

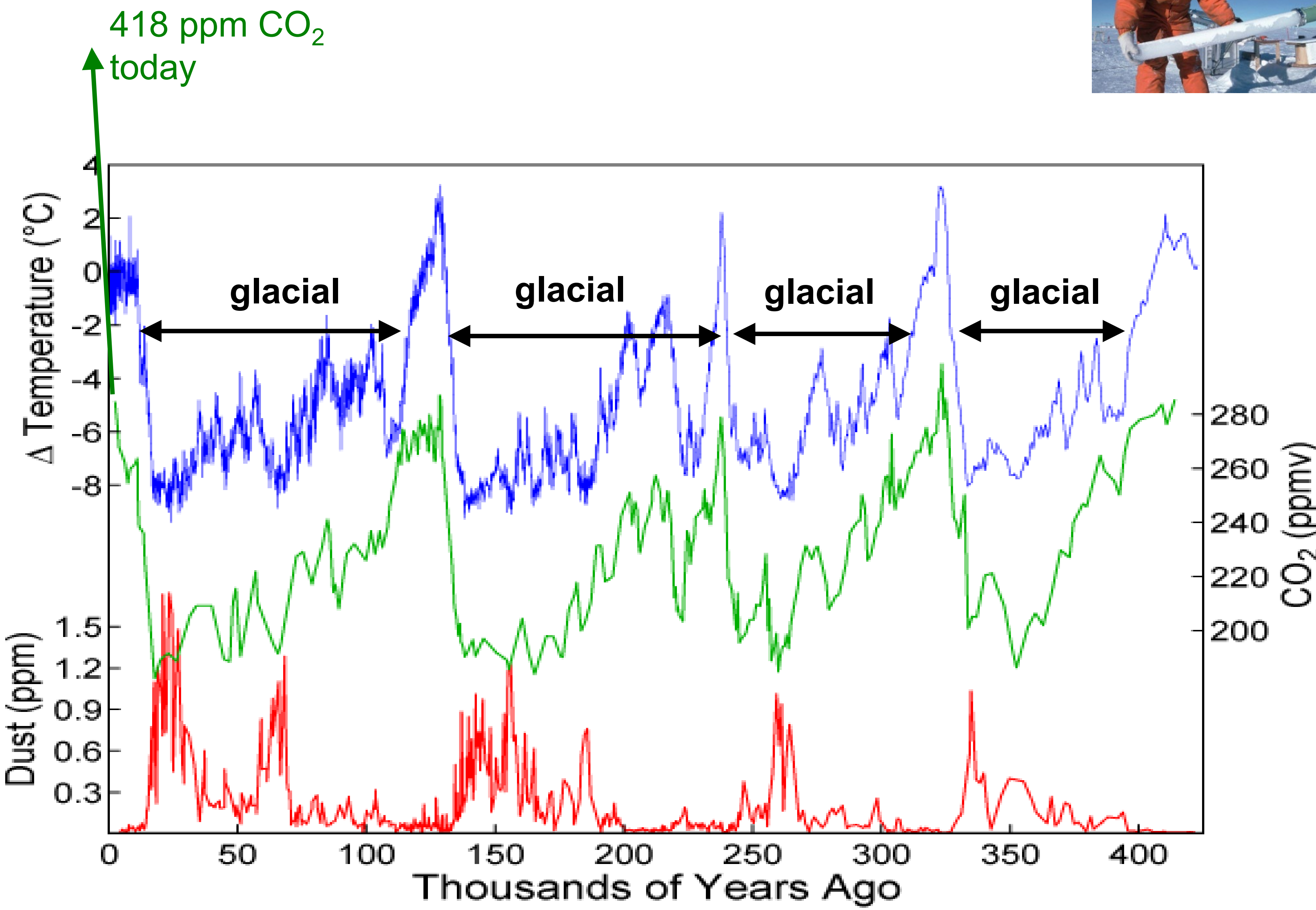
The natural carbon cycle



Perturbation of carbon cycle by fossil fuel combustion



CO_2 levels today are higher than in past 800,000 years

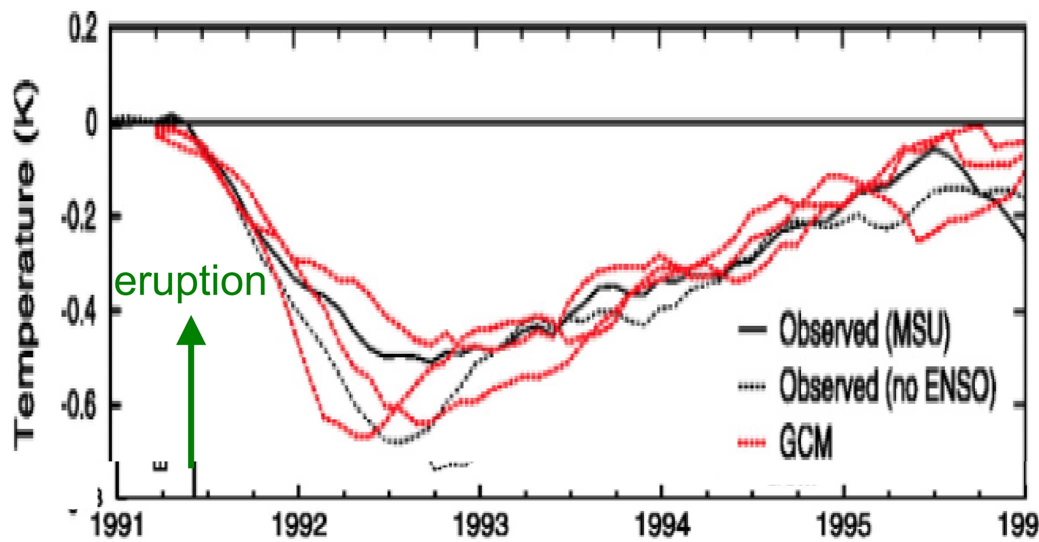


Vostok ice core (East Antarctica)

Cooling from large volcanic eruptions

Volcanic aerosol particles
reflect solar radiation,
increase albedo

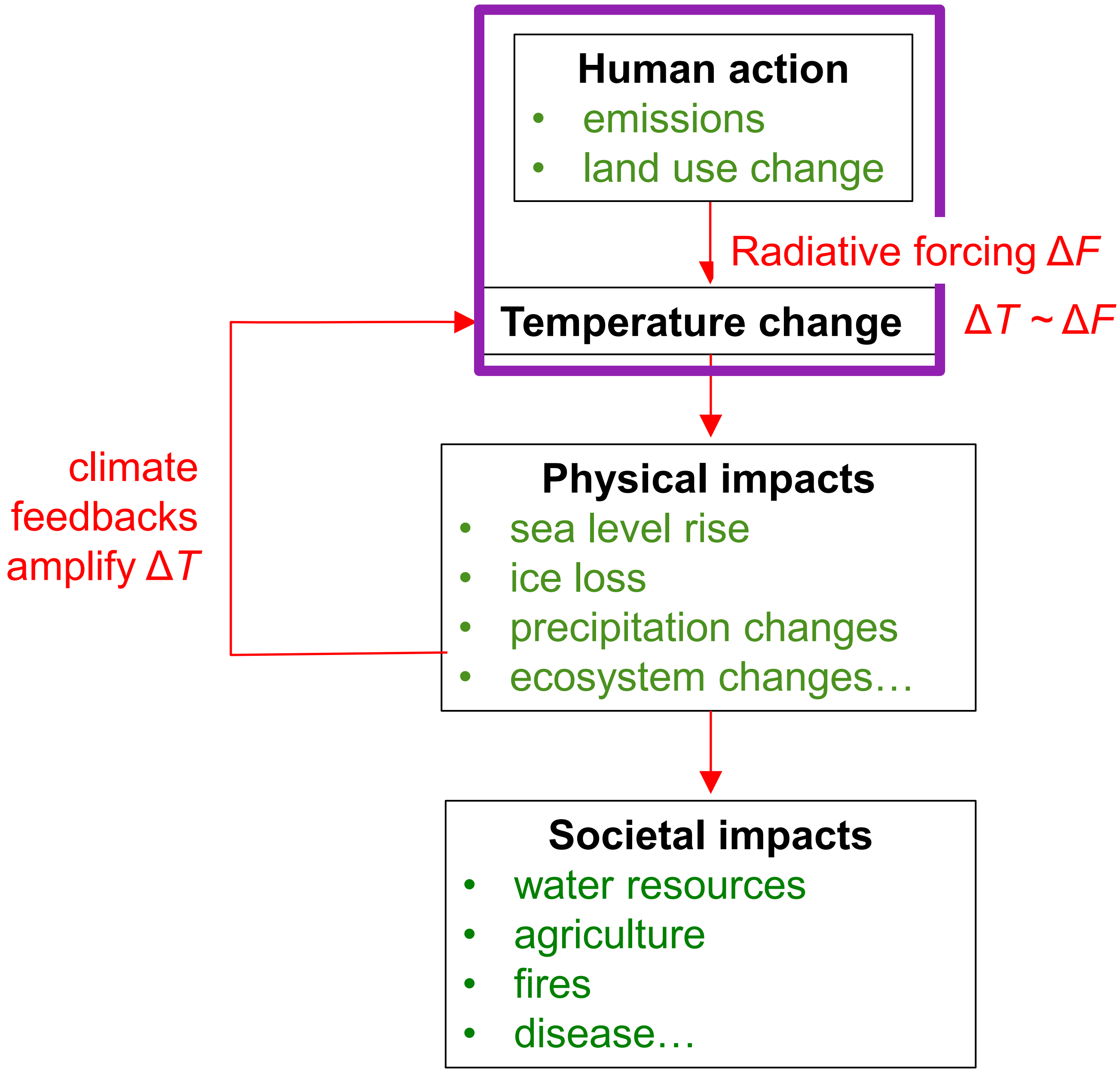
Pinatubo eruption (1991)



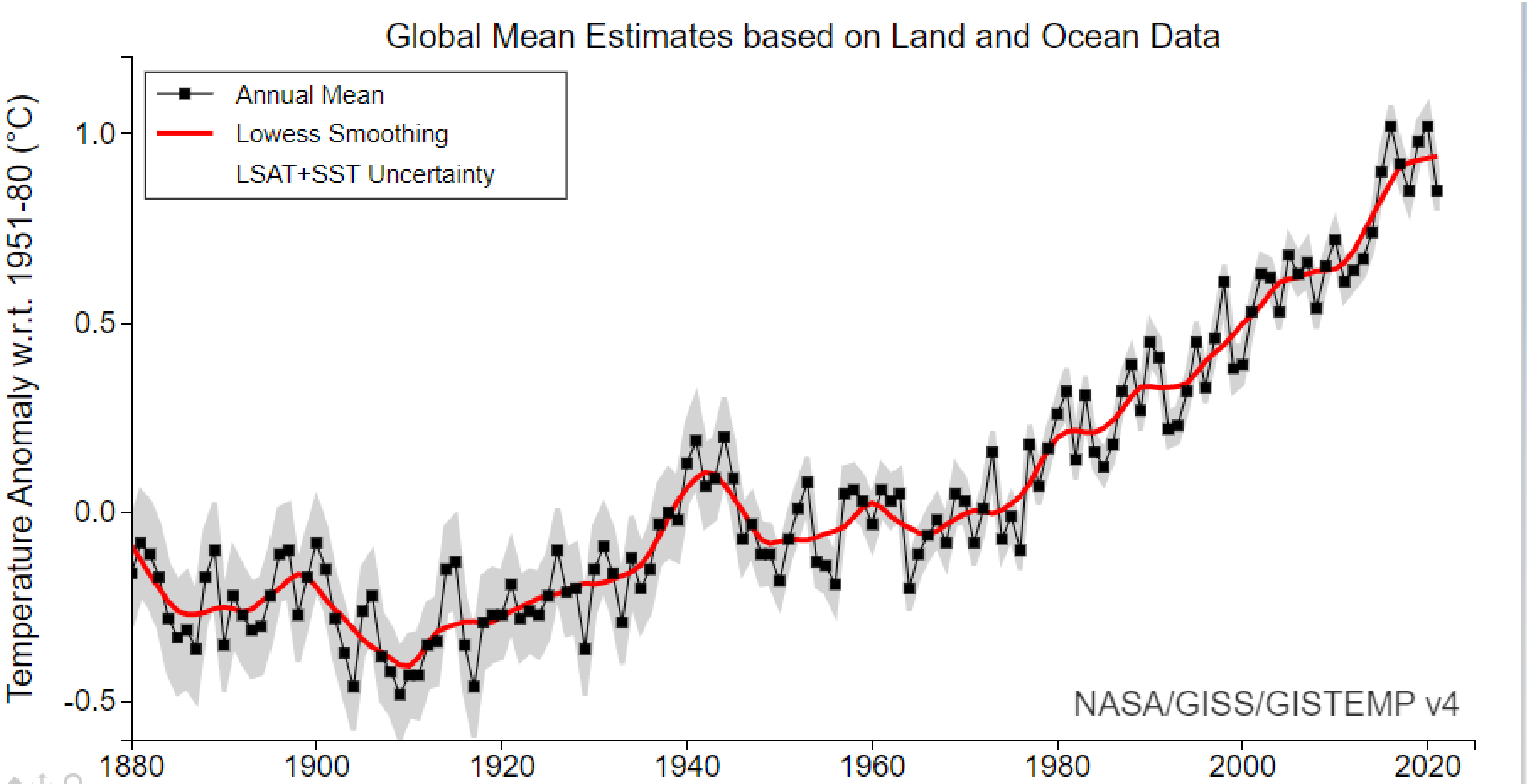
Pinatubo eruption decreased surface temperatures by 0.5^{o}C for 2 years

Soben et al. [2002]

Quantify how human action can disrupt radiative equilibrium

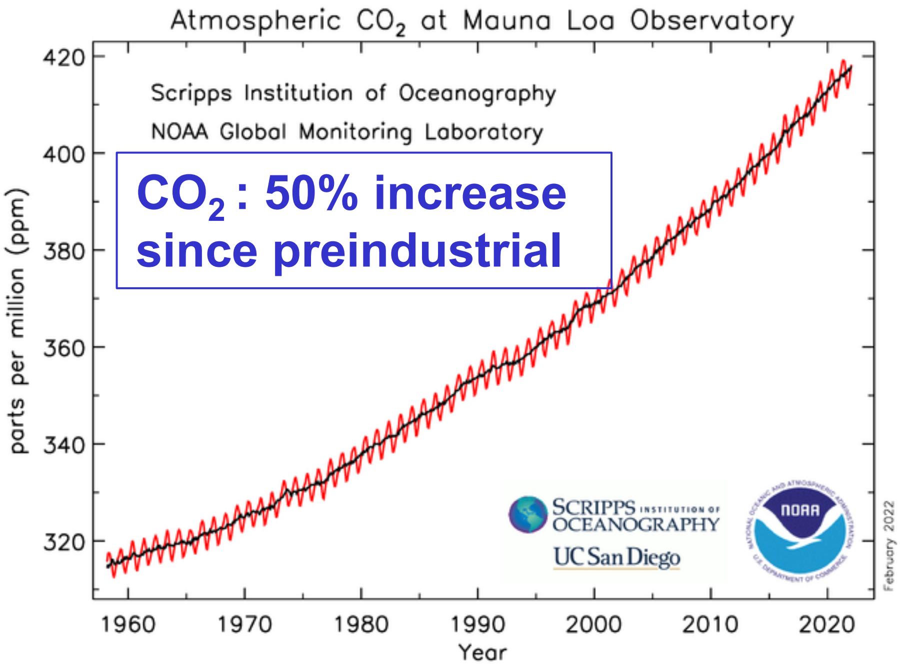


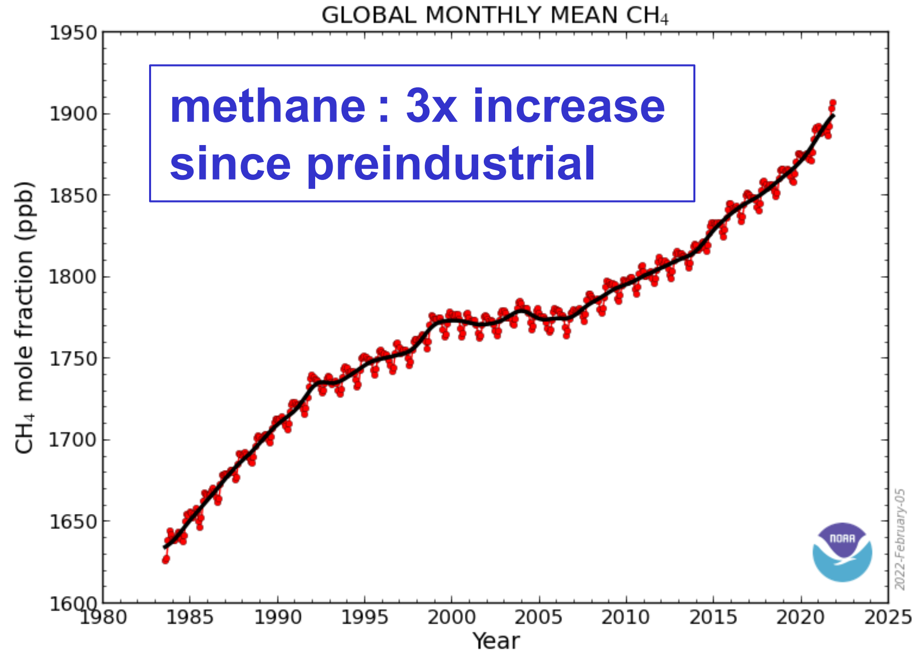
Global surface temperature increase since 1880

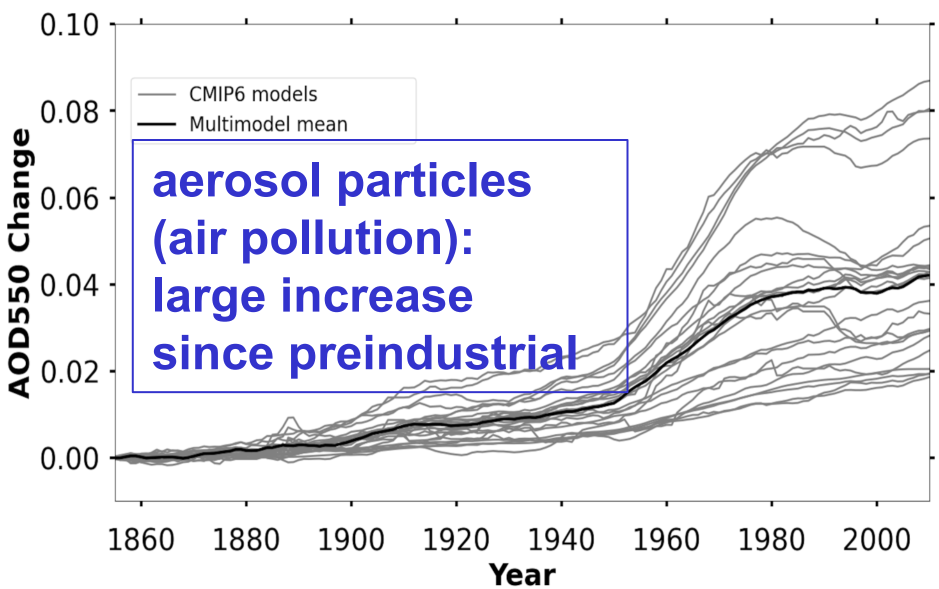


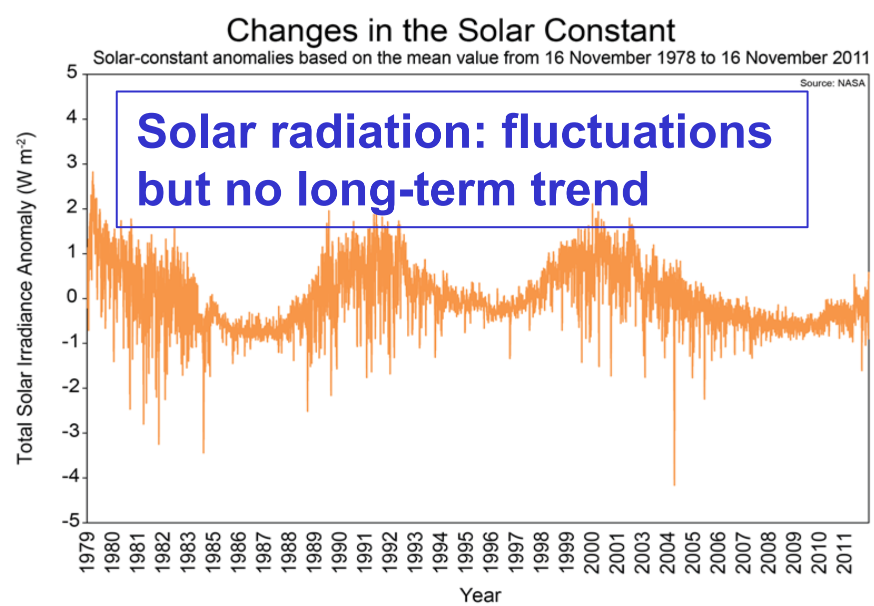
https://data.giss.nasa.gov/gistemp

Can this warming be explained by disruption to climate equilibrium?



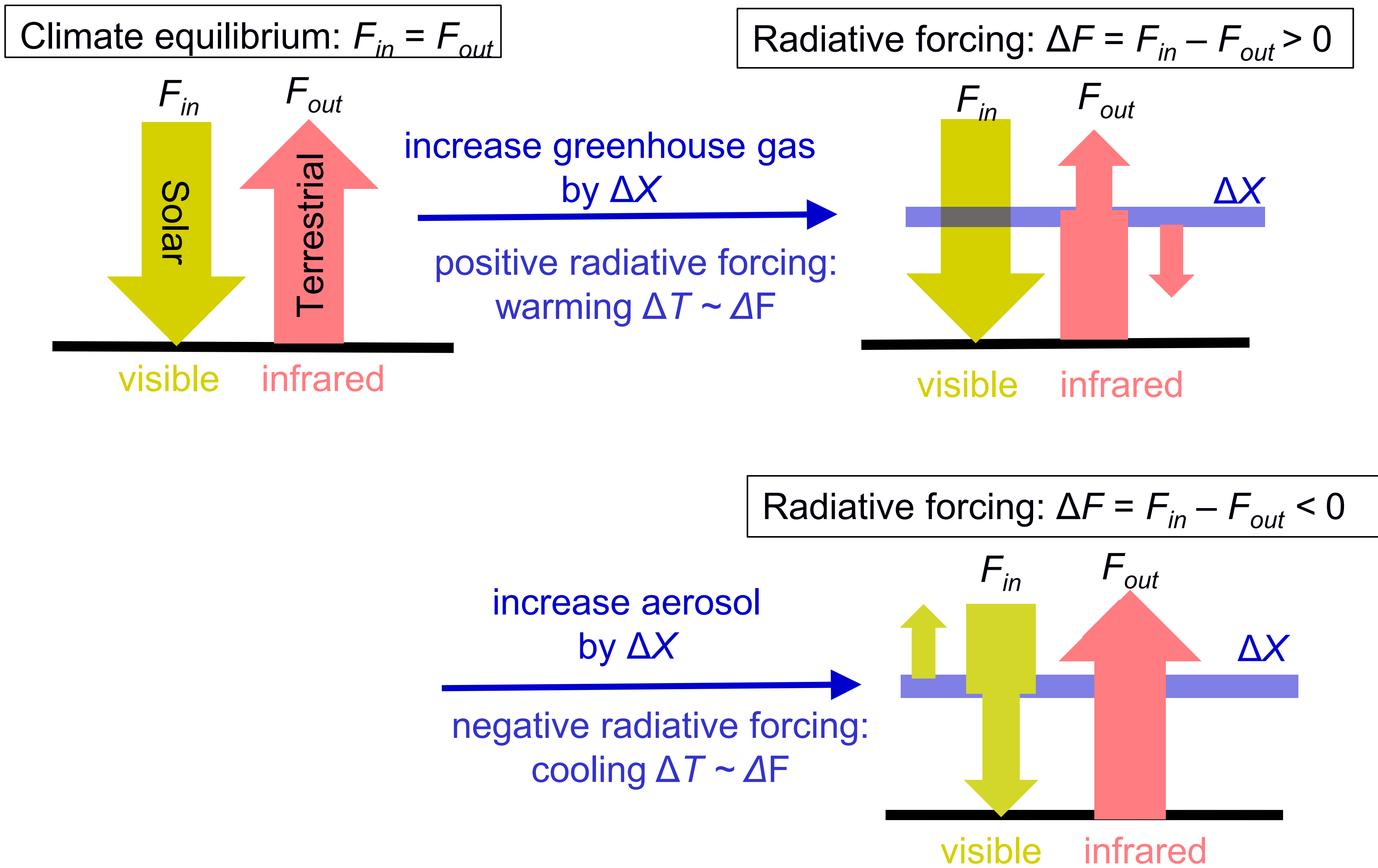




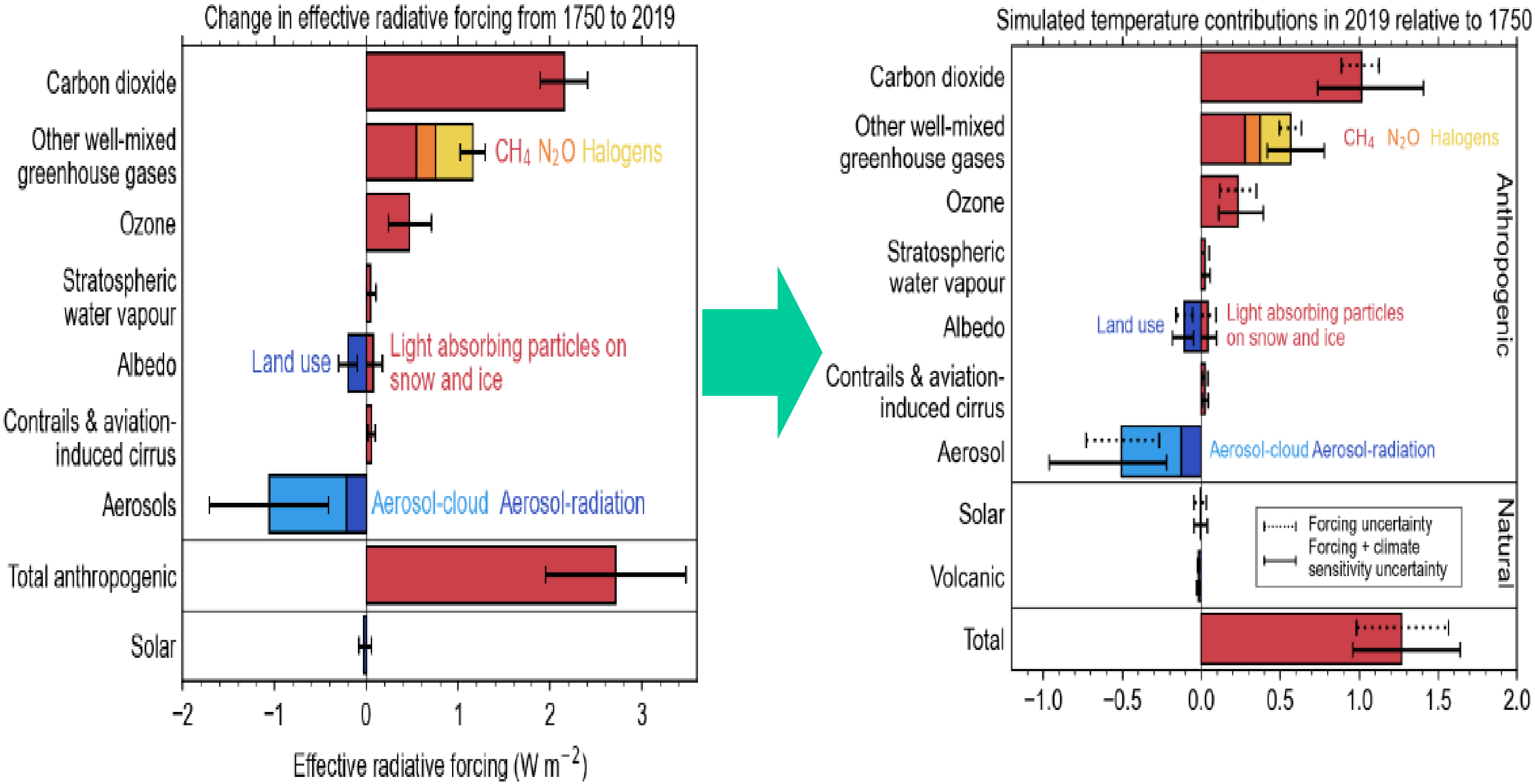


Radiative forcing of climate change: $\Delta F = F_{in} - F_{out}$

Disruption of climate equilibrium between energy in (F_{in}) and energy out (F_{out})



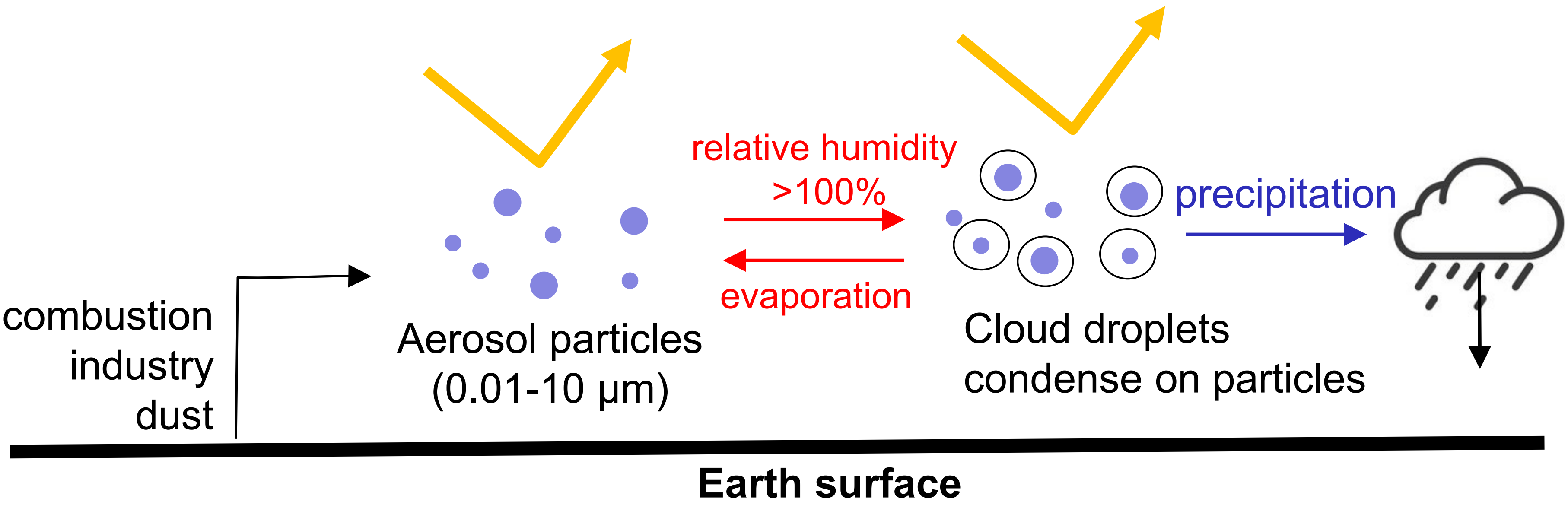
Contributions to radiative forcing since pre-industrial times and temperature response



- Relationship of temperature response to radiative forcing is similar for all agents
- Radiative forcing is relatively easy to compute and is standard metric for climate policy (‘CO_2-equivalents’)
- Aerosols cancel about 30% of warming from greenhouse gases

IPCC [2022]

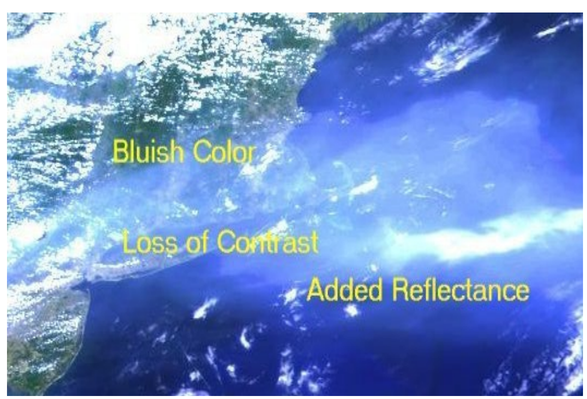
Radiative cooling by aerosols



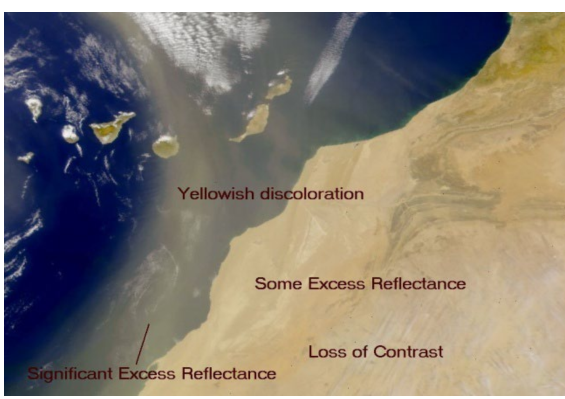
Aerosols scatter solar radiation back to space, increasing albedo;
some aerosols (dust, soot) also absorb solar radiation and have more complicated effects

California fire plumes

Pollution off U.S. east coast

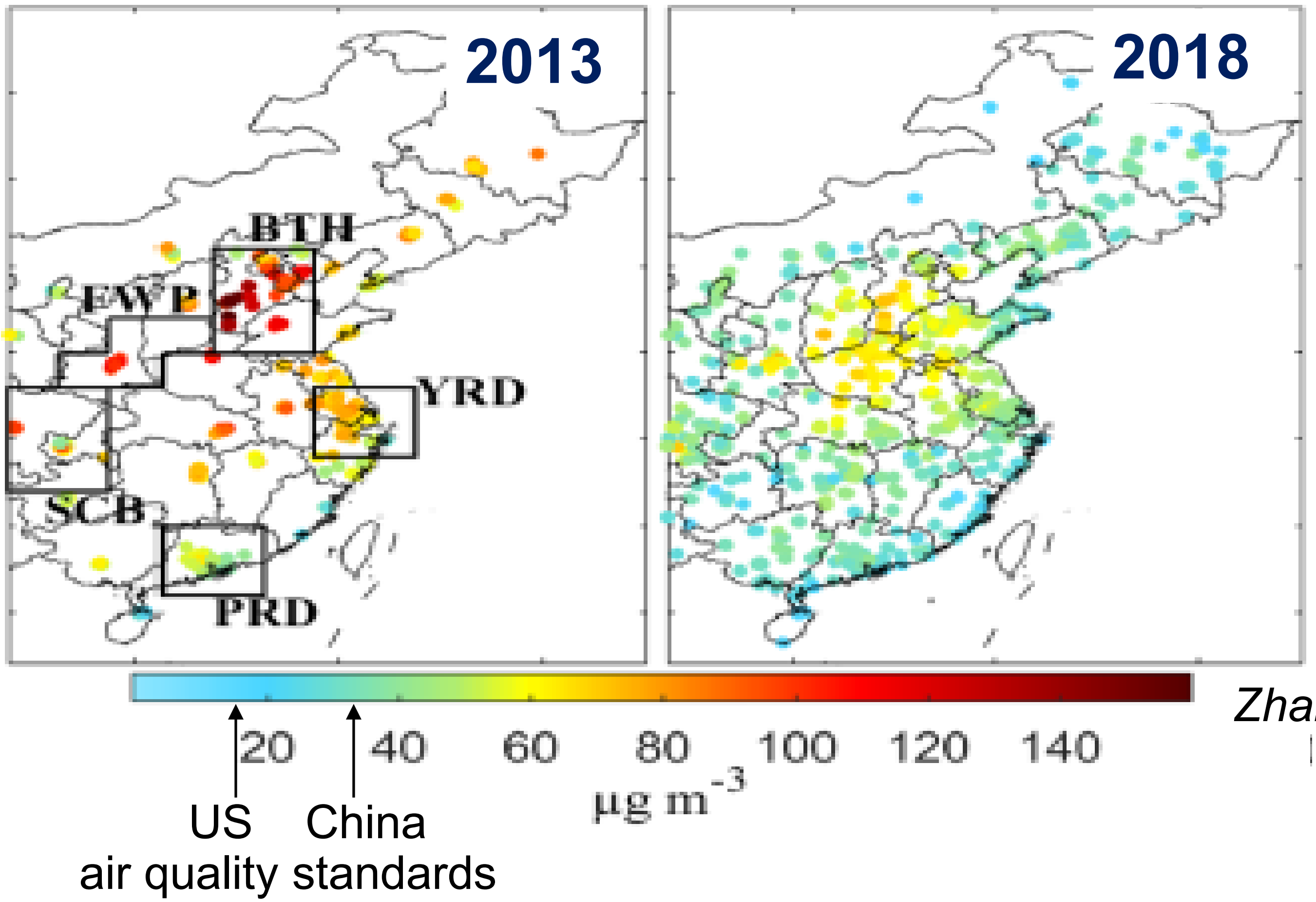


Dust off West Africa



Aerosols (a.k.a. particulate matter) are decreasing worldwide in response to policies to improve air quality

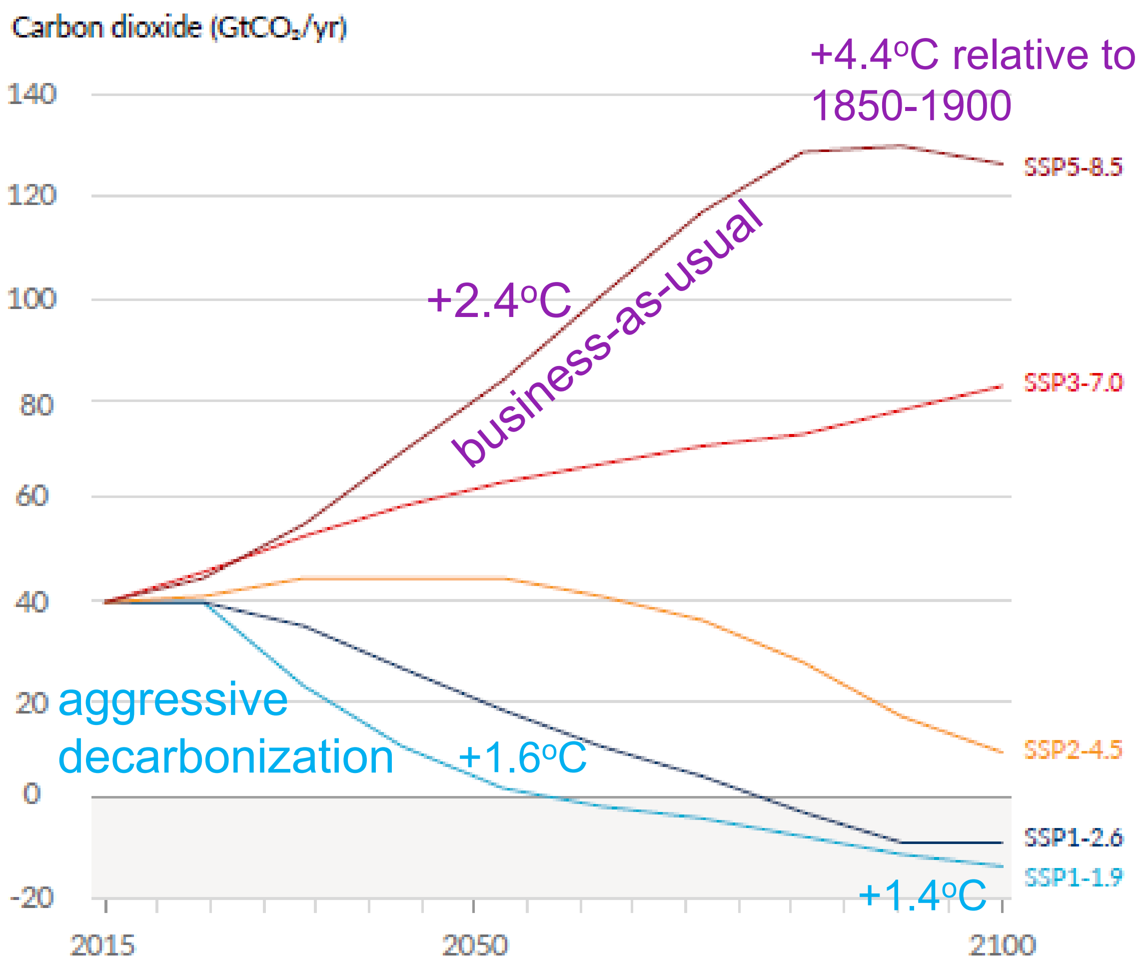
Annual mean fine particulate matter ($PM_{2.5}$) in China

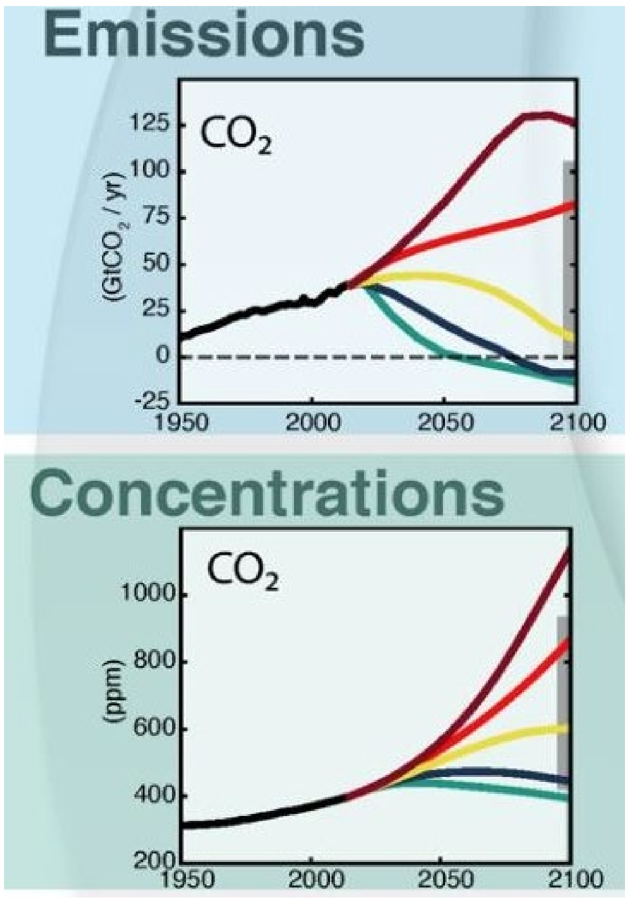


Zhai et al., 2019

Aerosol decrease must be compensated for by more aggressive action on greenhouse gases

Future projections of CO_2 emissions and temperature

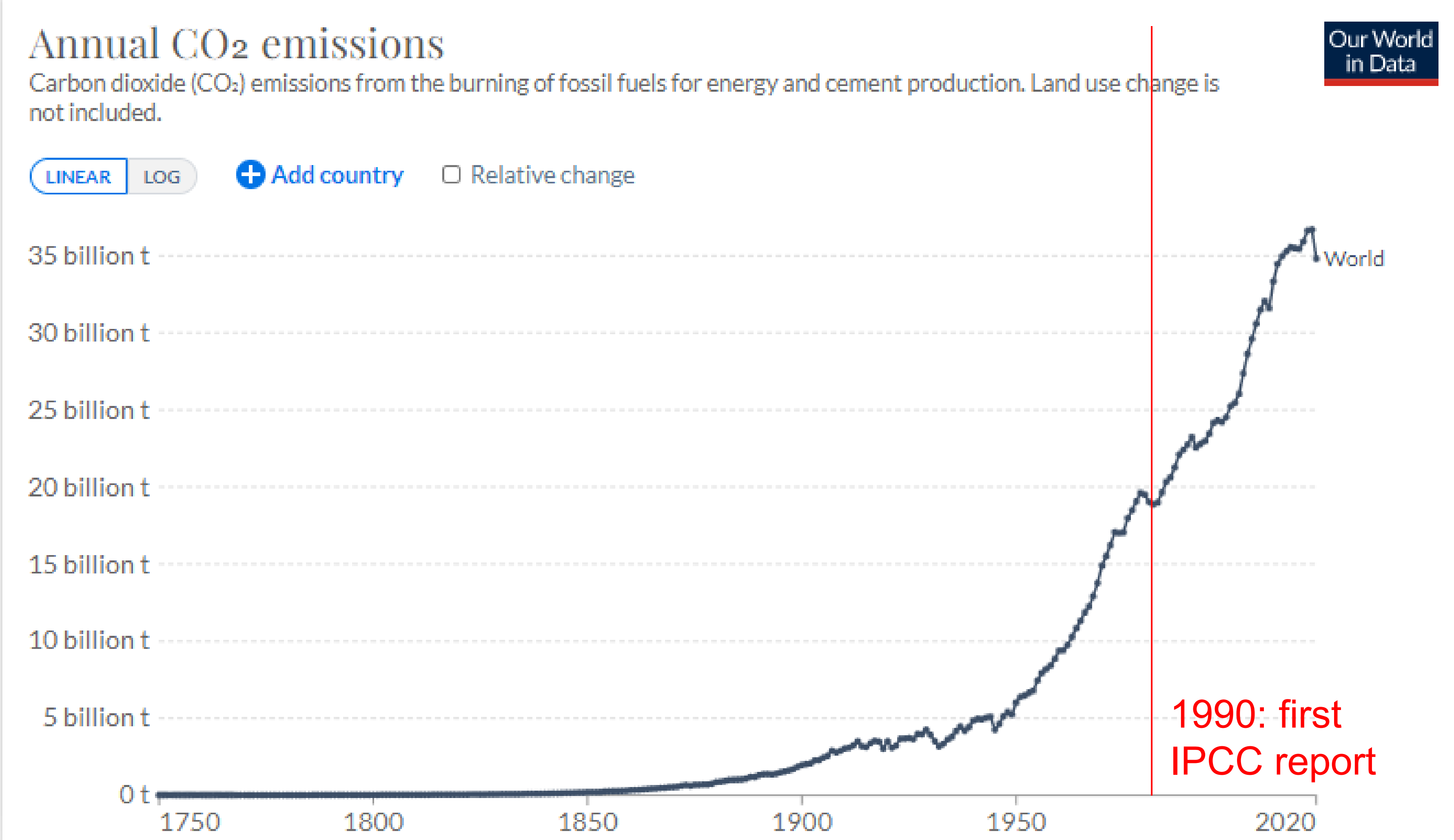




Aggressive action is needed if we are to avoid 2 degrees of danger

IPCC [2022]

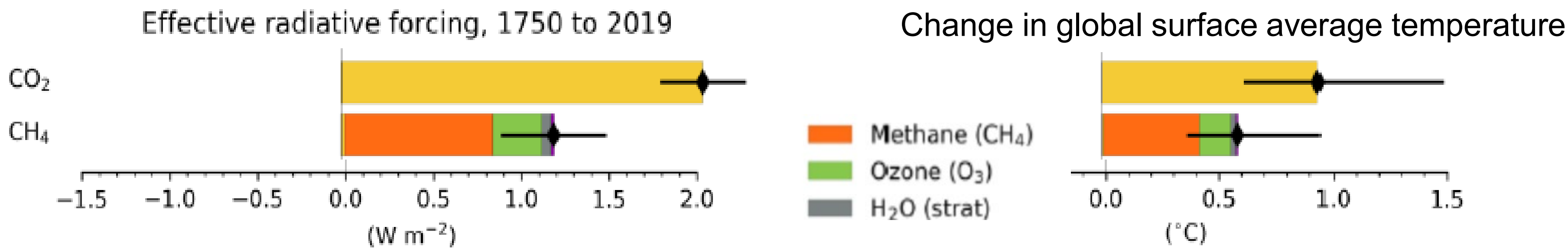
Recent history of CO_2 emission trends is not encouraging



2020 economic slowdown decreased CO_2 emissions but only by a few percent

https://ourworldindata.org/co2-emissions

Methane radiative forcing is amplified by chemistry



- Methane has an atmospheric lifetime of only 9 years (versus ~100 years for CO_2) and produces ozone, water, and CO_2 when oxidized in atmosphere

⇨ Methane emission is 60% as important as CO_2 in explaining 1750-2019 warming

- The short lifetime of methane has consequences for climate policy:
  - ⇨ Reducing methane emissions now would have a fast impact on climate
  - ⇨ It would compensate for the decrease in aerosol pollution
  - ⇨ It could save us from the ‘2 degrees of danger’ (maybe even 1.5)
  - ⇨ But methane is largely irrelevant in the long term (~100 years)
  - ⇨ Methane and CO_2 emissions should not be “equivalent” in climate policy

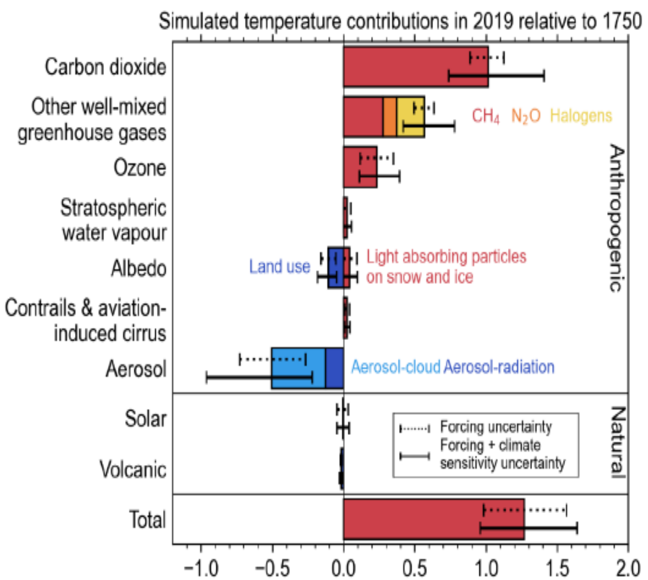
Current policy accounting of methane emissions as ’25 CO_2 equivalents’ is based on radiative forcing of methane only and integrated over 100 years– completely flawed!

IPCC [2022]

Increasing attention to methane in climate policy

Biden at COP26 announcing Global Methane Pledge, now signed by 110 countries

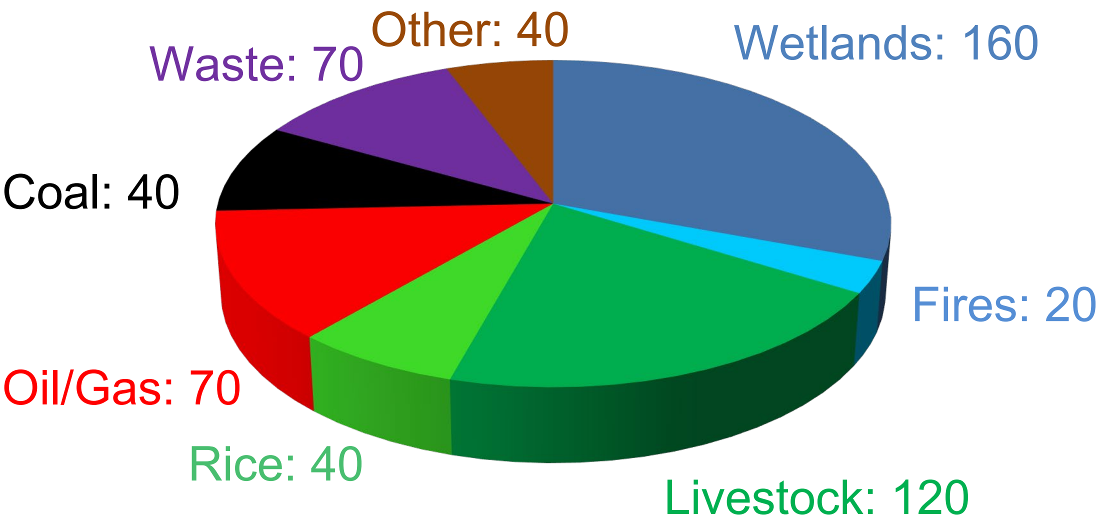
Why did he say that methane causes half the warming? He should have said a third…



Complexity of methane sources

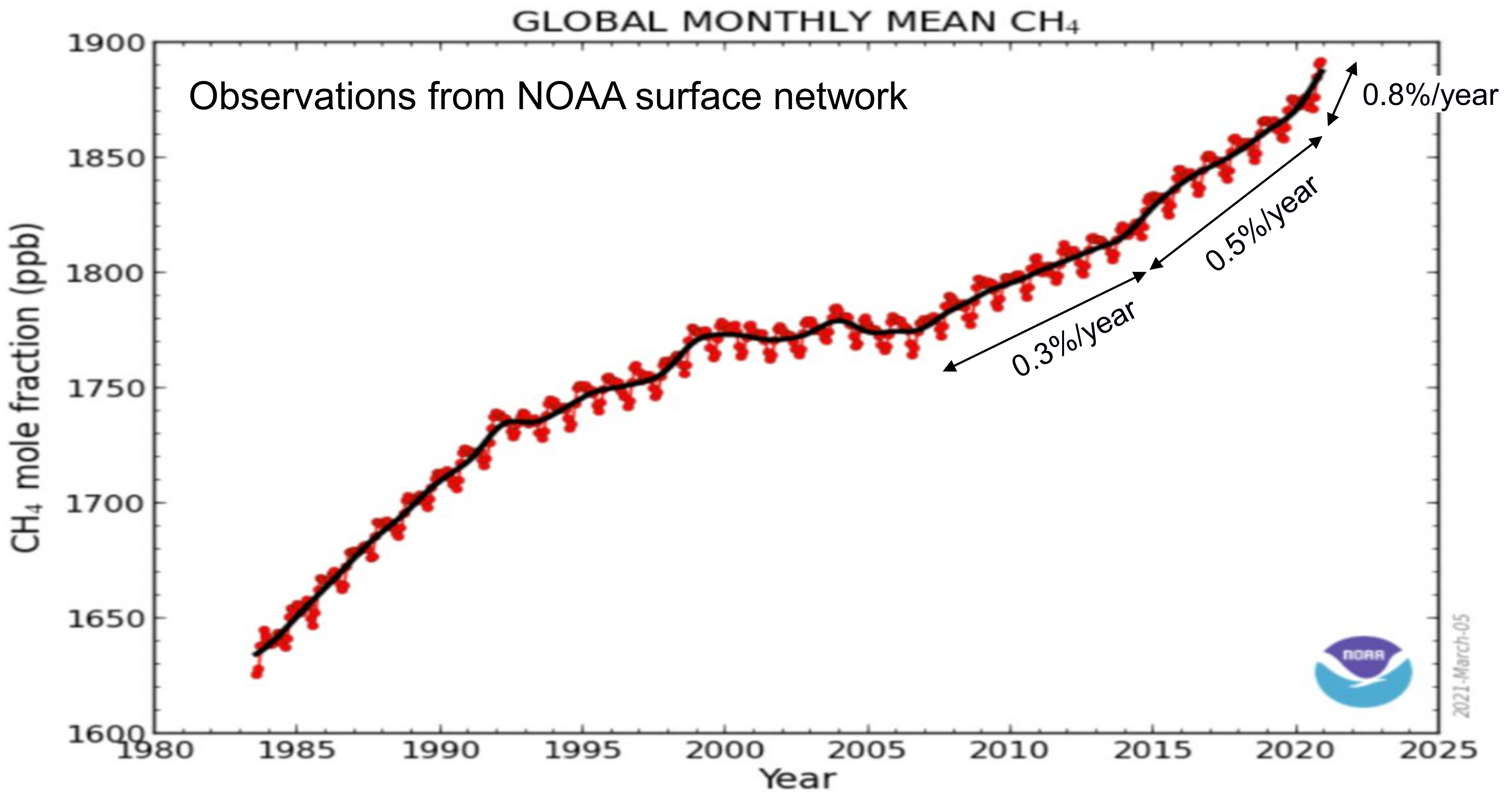
Current emissions in Tg/year (very uncertain!)

Maasakkers et al. [2019]



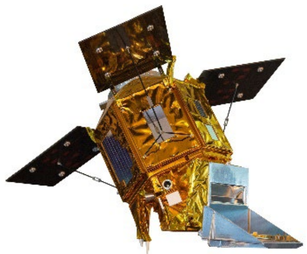
Uncertainty in current methane emissions
makes it challenging to set a 30% reduction target

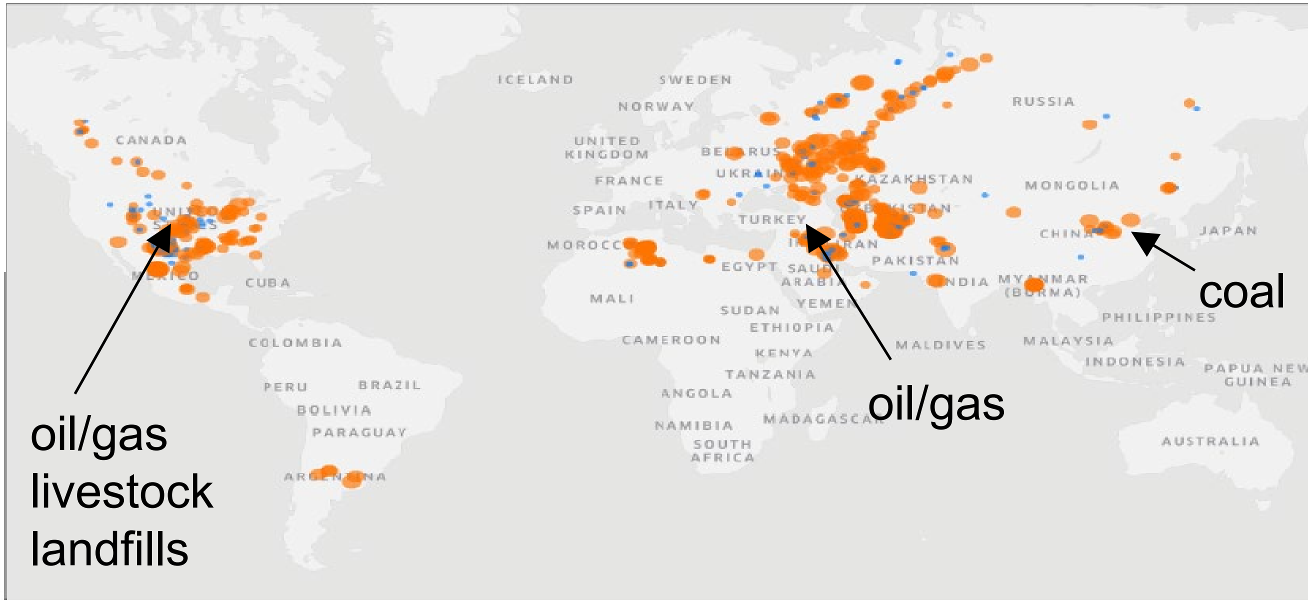
Methane has been rising at accelerated pace since 2007, likely attributable to livestock and fuels – but why?



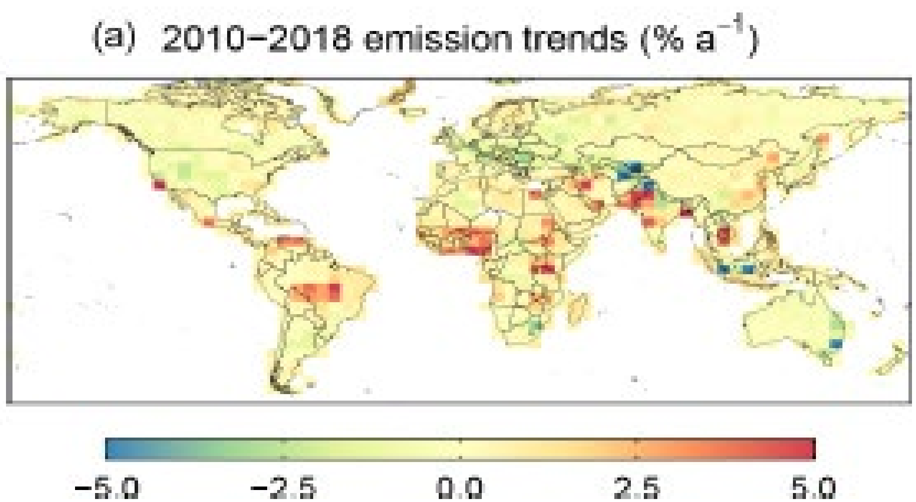
Observing atmospheric methane from satellites

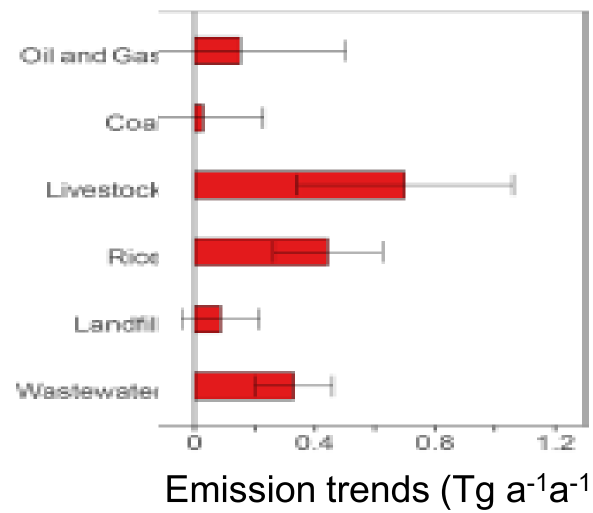
Satellite observations can now monitor methane hotspots…





…and emission trends





Zhang et al., 2021; Lauvaux et al., 2022

Simple measures can go a long way to decrease methane emissions

Fix leaks detected by satellite or aircraft

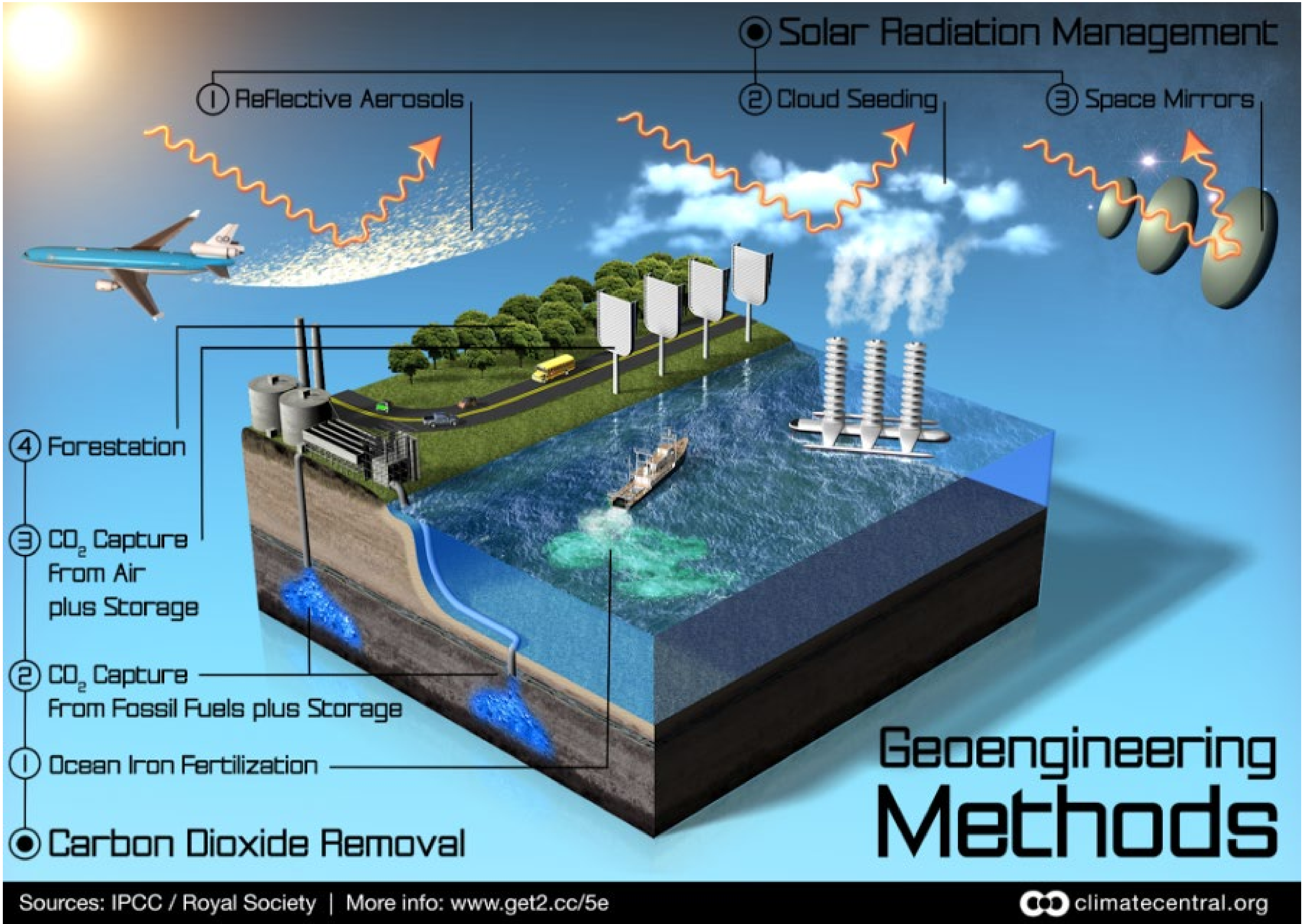
Flare excess gas …or use it

recover gas from landfills

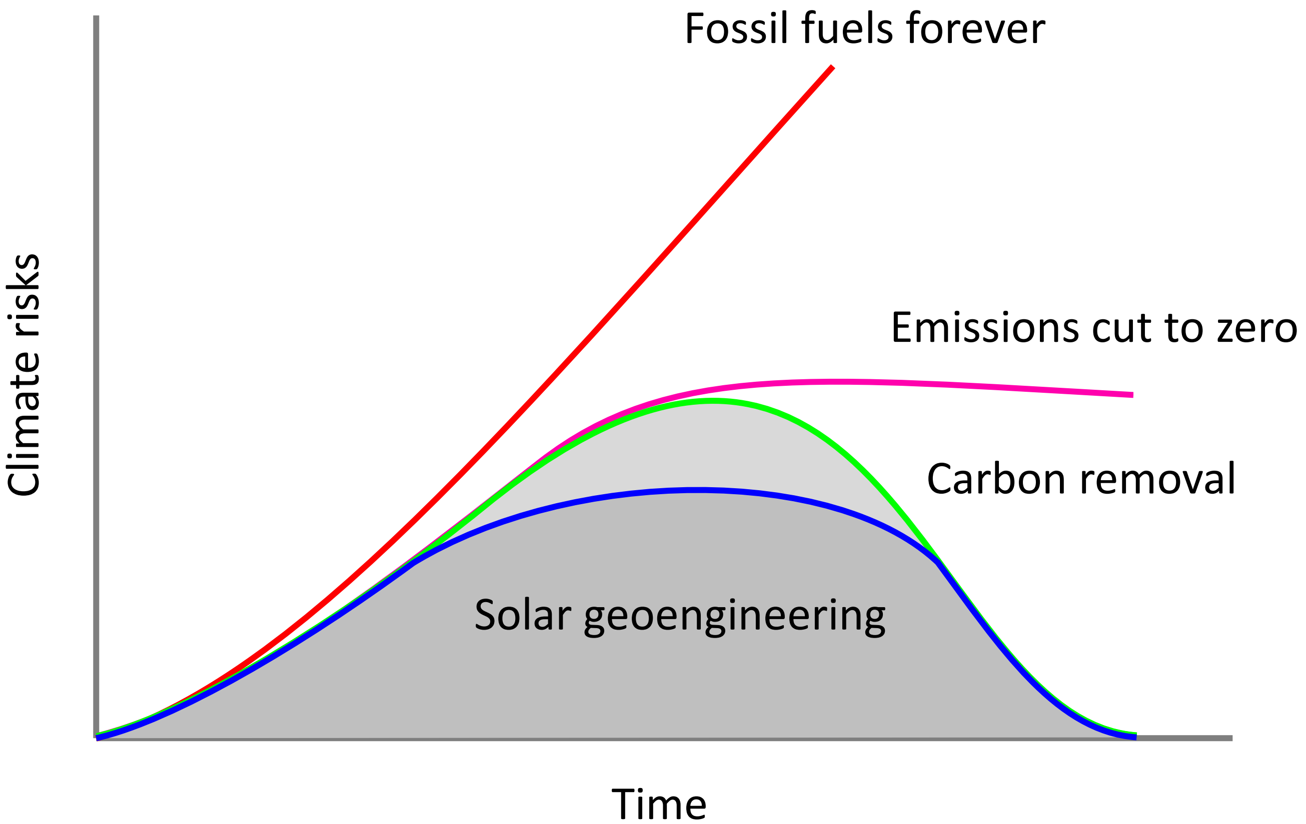
Recover/digest gas from manure ponds, wastewater plants

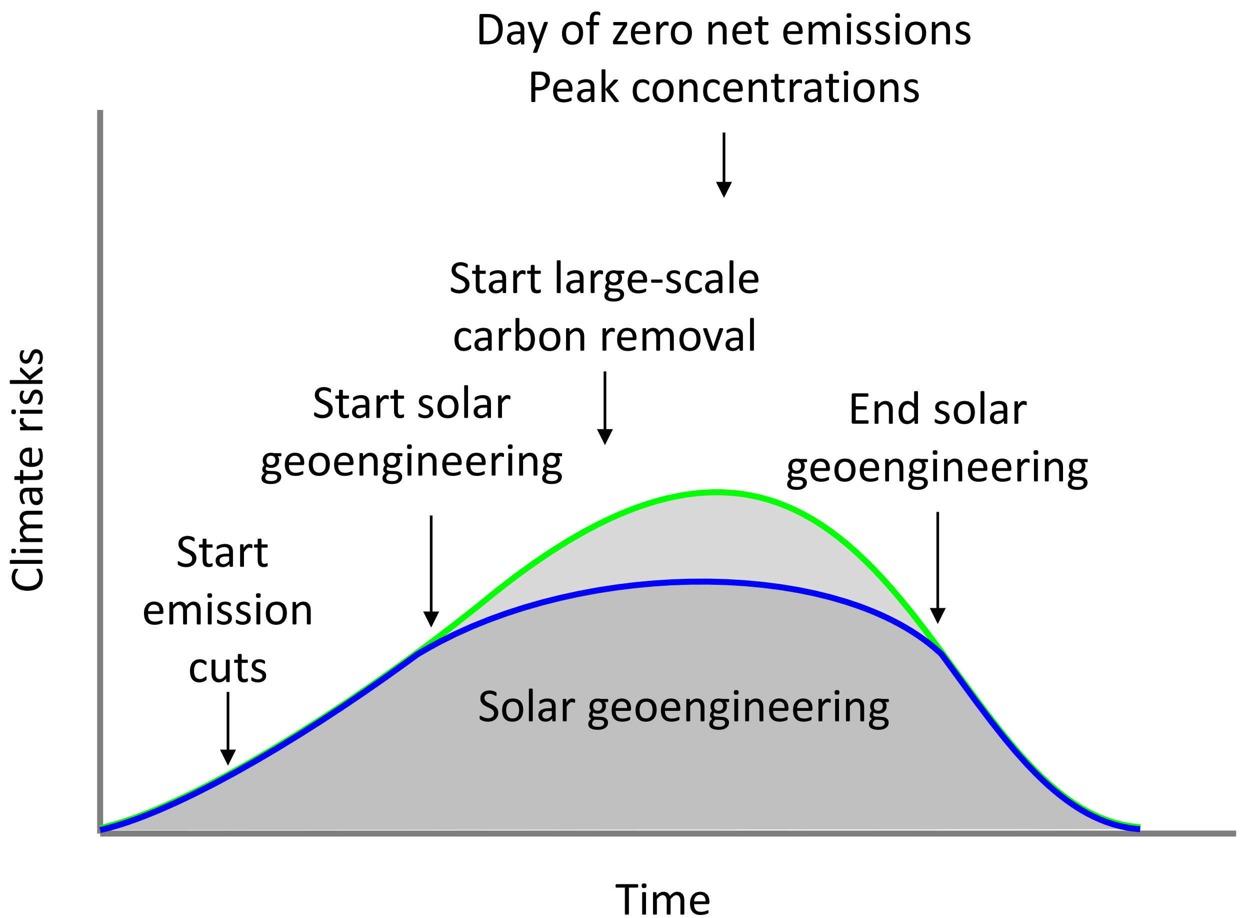
Upland rice agriculture

Geoengineering methods: CO_2 removal, solar radiation management



Geoengineering as a means to reduce climate risk




Day of zero net emissions
Peak concentrations
Start large-scale
carbon removal
Start solar
geoengineering
End solar
geoengineering
Start
emission
cuts
Solar geoengineering
Climate risks
Time

Some key take-aways

- There is no doubt that current climate change is driven by human activity
- Reducing climate risk requires immediate and strong action on reducing emissions of CO_2 and methane
- Reducing aggressively methane emissions *together* with CO_2 emissions can avoid the ‘2 degrees of danger’
- Although methane emission estimates are uncertain, controlling large point sources identified by satellite data is a ripe strategy for climate action
- Avoiding 1.5 or 2 degrees of danger may require geoengineering to remove CO_2 and (temporarily) decrease solar radiation input.