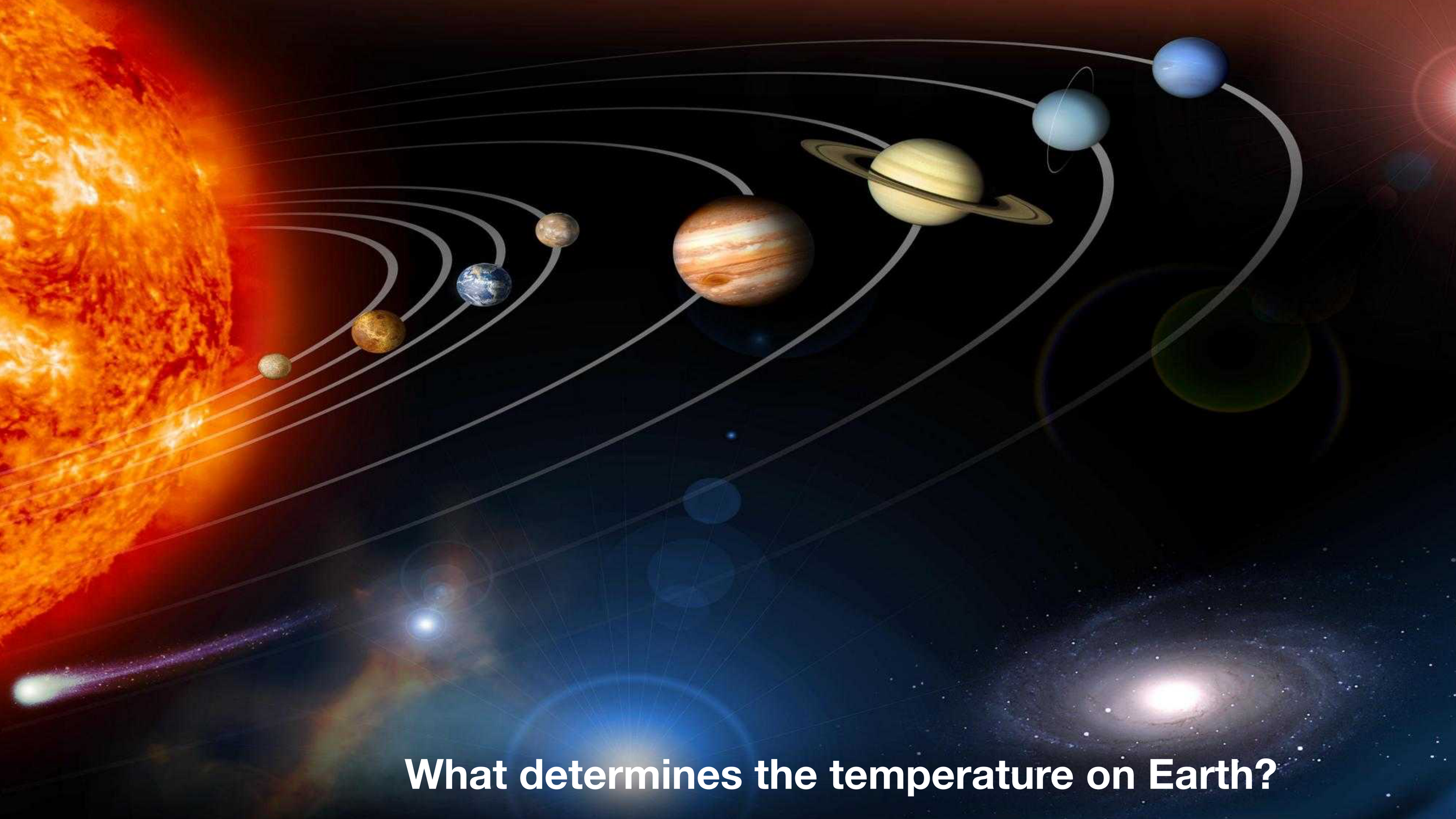
Processes of local climate change

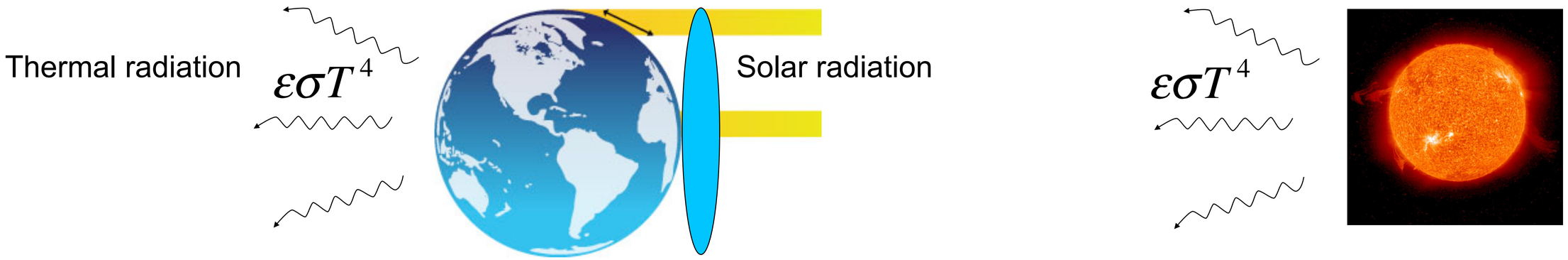
Application of laws of nature

Frank Selten, climate scientist, KNMI


What determines the temperature on Earth?

Application of the conservation law of energy: simplest climate model

netto received solar radiation = outgoing thermal radiation



$$\pi R^2 S_0 (1-\alpha) = 4\pi R^2 \varepsilon\sigma T^4 \longrightarrow T = -18 \text{ degree Celsius}$$

R : radius of earth (6378 km)

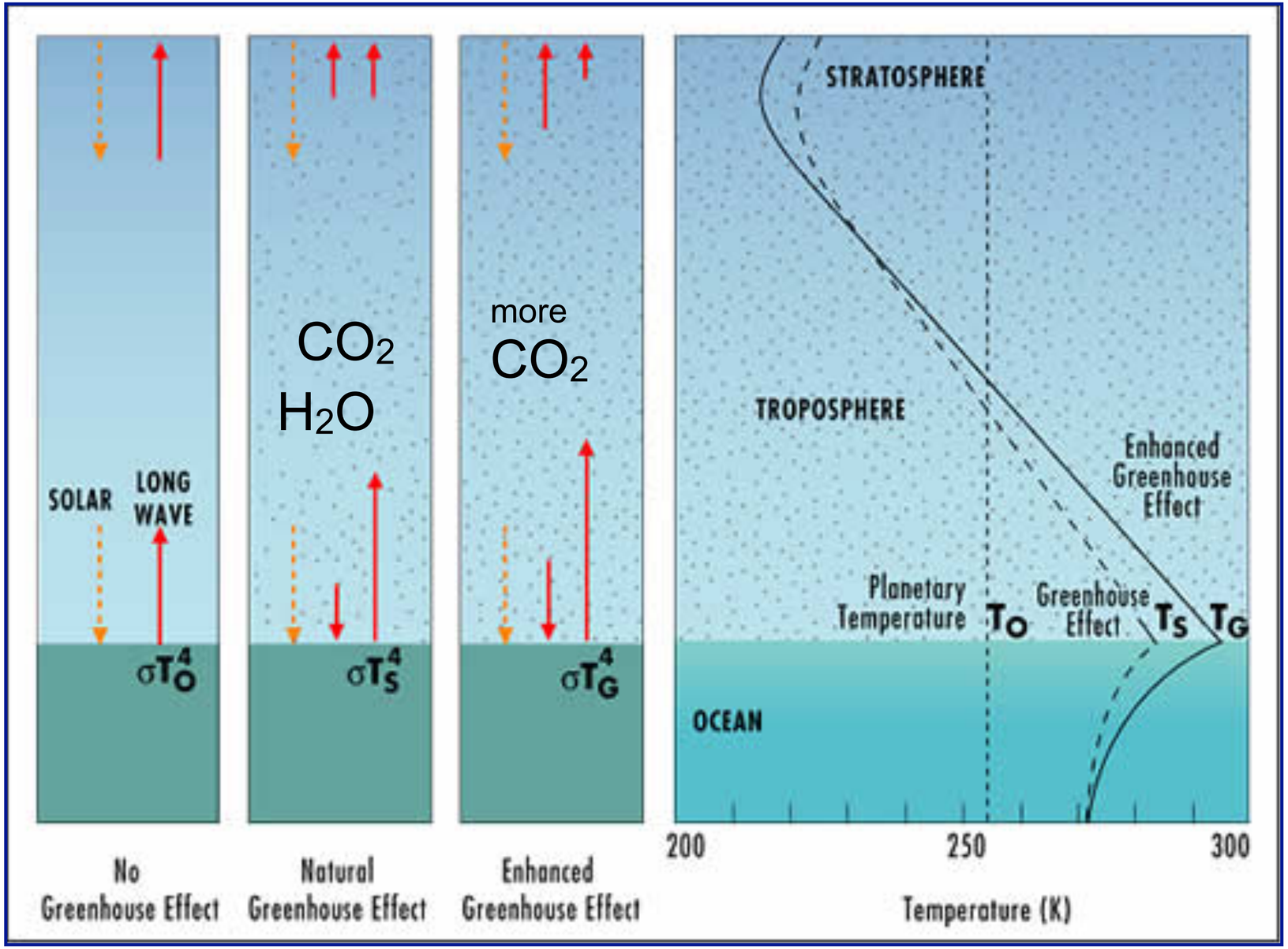
S_0 : solar constant (1370 W / m^2)

α : mean reflection (0.3)

ε : emissivity (≈ 1)

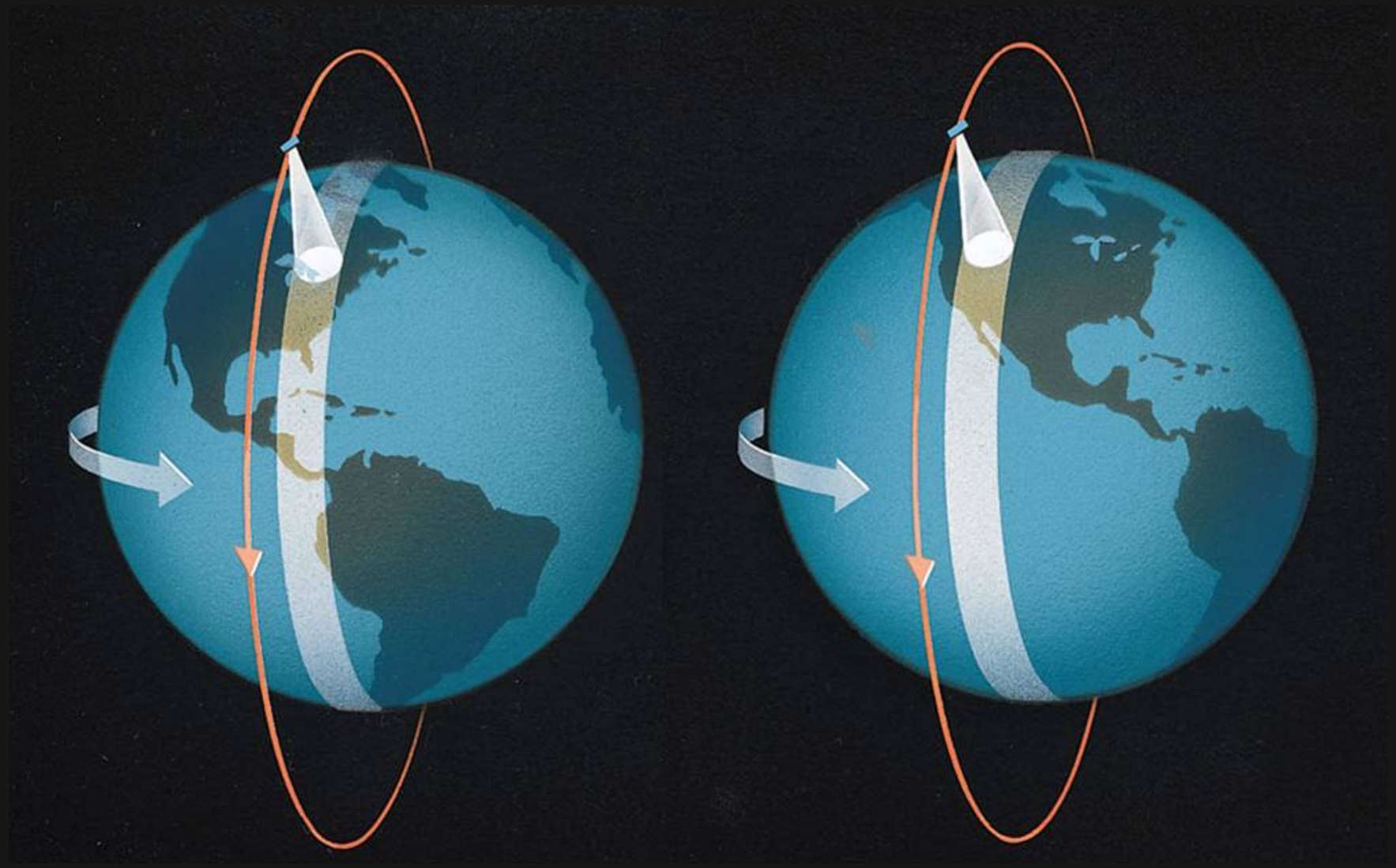
σ : Stefan-Boltzmann constant ($5.67 \cdot 10^{-8} W / m^2 / K^4$)

The greenhouse effect: thermal radiation is absorbed by CO_2 and H_2O (CH_4, N_2O,..)



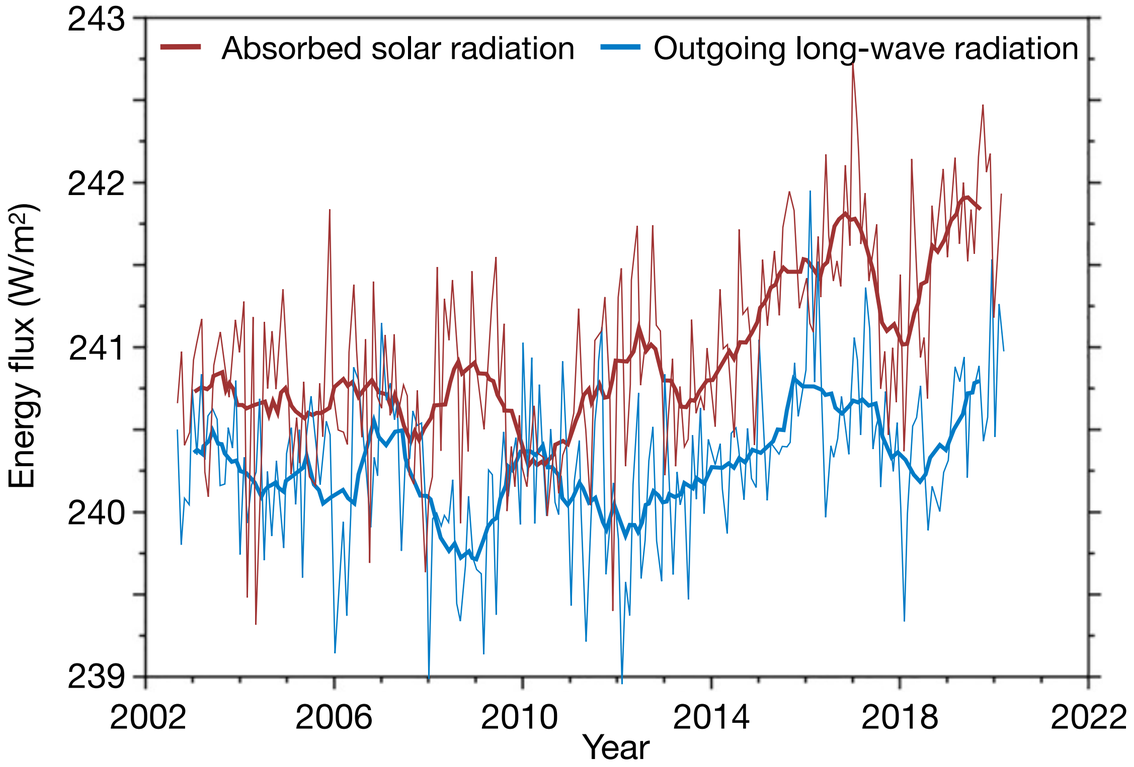
Without and with greenhouse effect: -18 / 15 degree Celsius

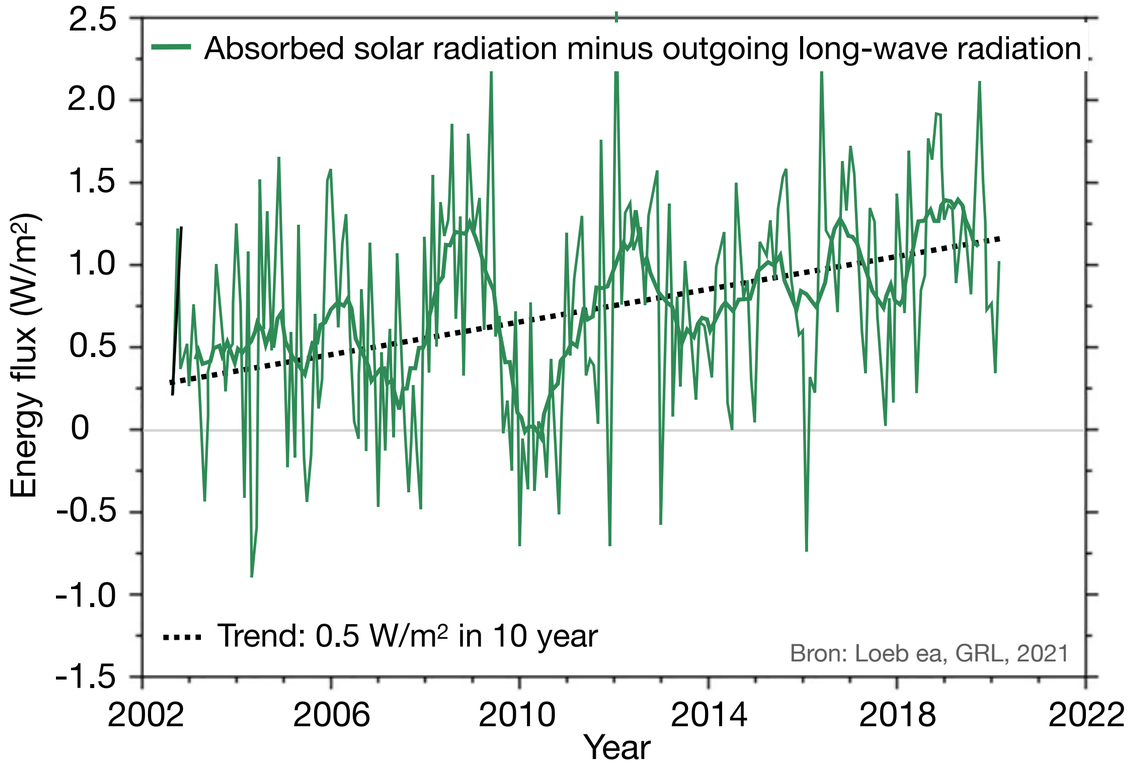
Polar orbiting satellites measure reflected solar and outgoing thermal radiation



Rate of extra energy input into the climate system has more than doubled in the past 20 years

Measurements of CERES satellite instrument of absorbed solar radiation and outgoing long-wave radiation

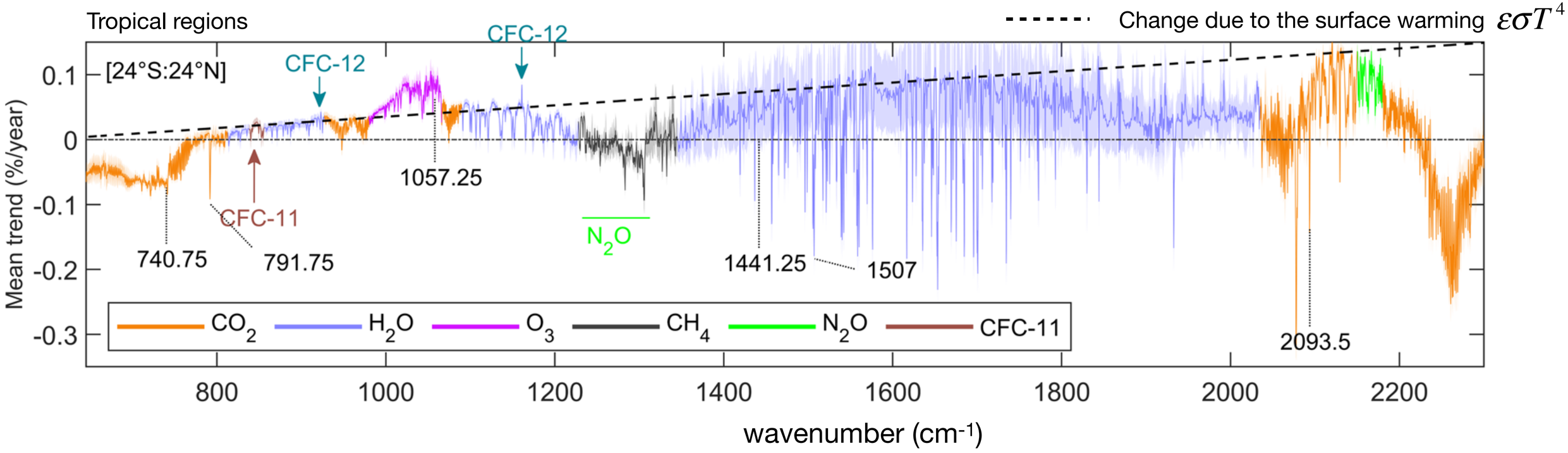




Climate change is accelerating ….

Measured trend in the spectrally resolved outgoing thermal radiation 2008-2017

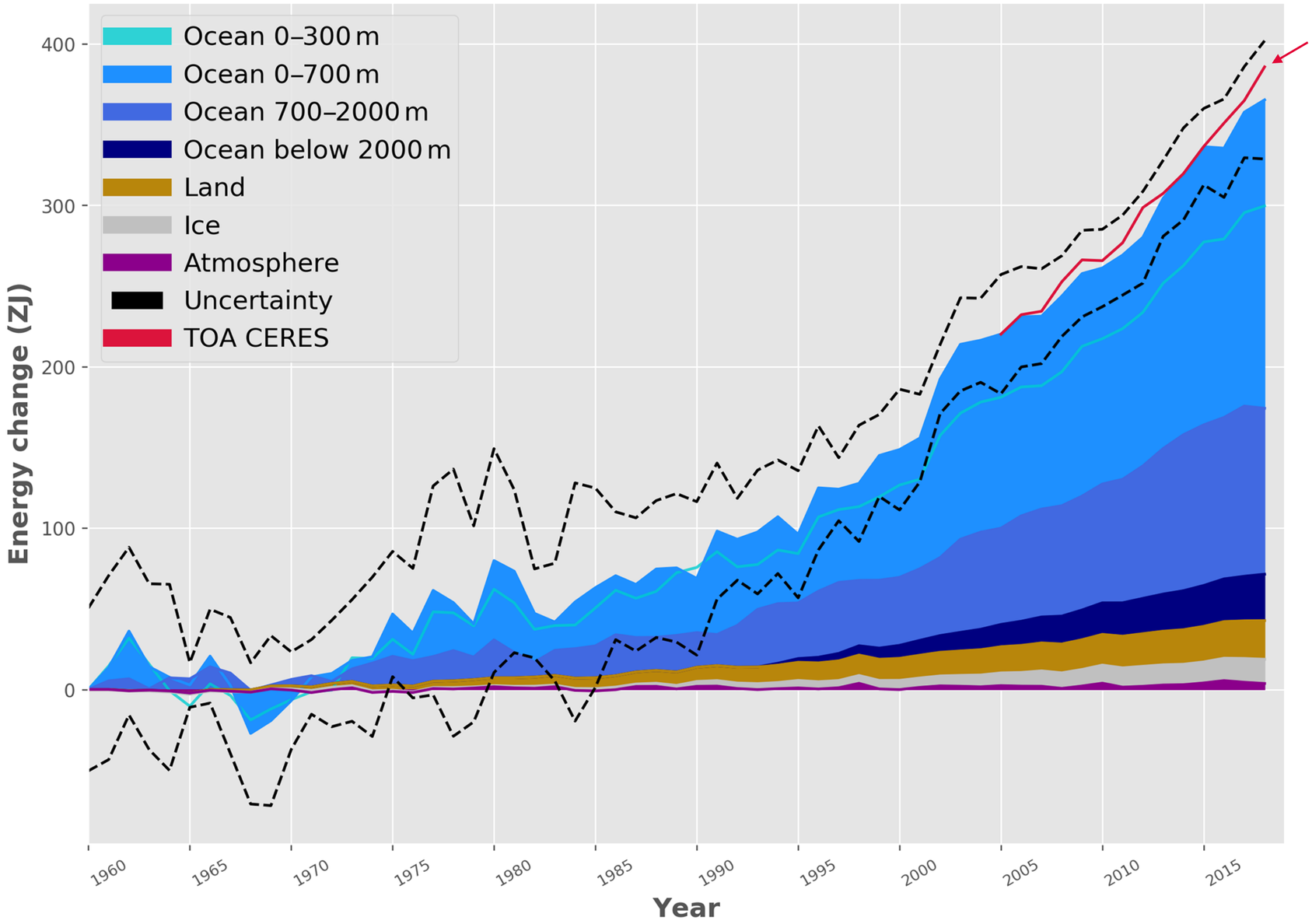
Infrared atmospheric sounding interferometer (IASI) aboard Metop satellites



In the CO_2, CH_4, N_2O and H_2O bands we see reduced outgoing radiation: enhanced greenhouse effect

Increase in concentration greenhouse gasses reduces the outgoing thermal radiation

Where does the extra energy go to?



Measured energy input by satellites matches the measured increase in energy storage in the climate system

81 % upper 2000 meter of the ocean

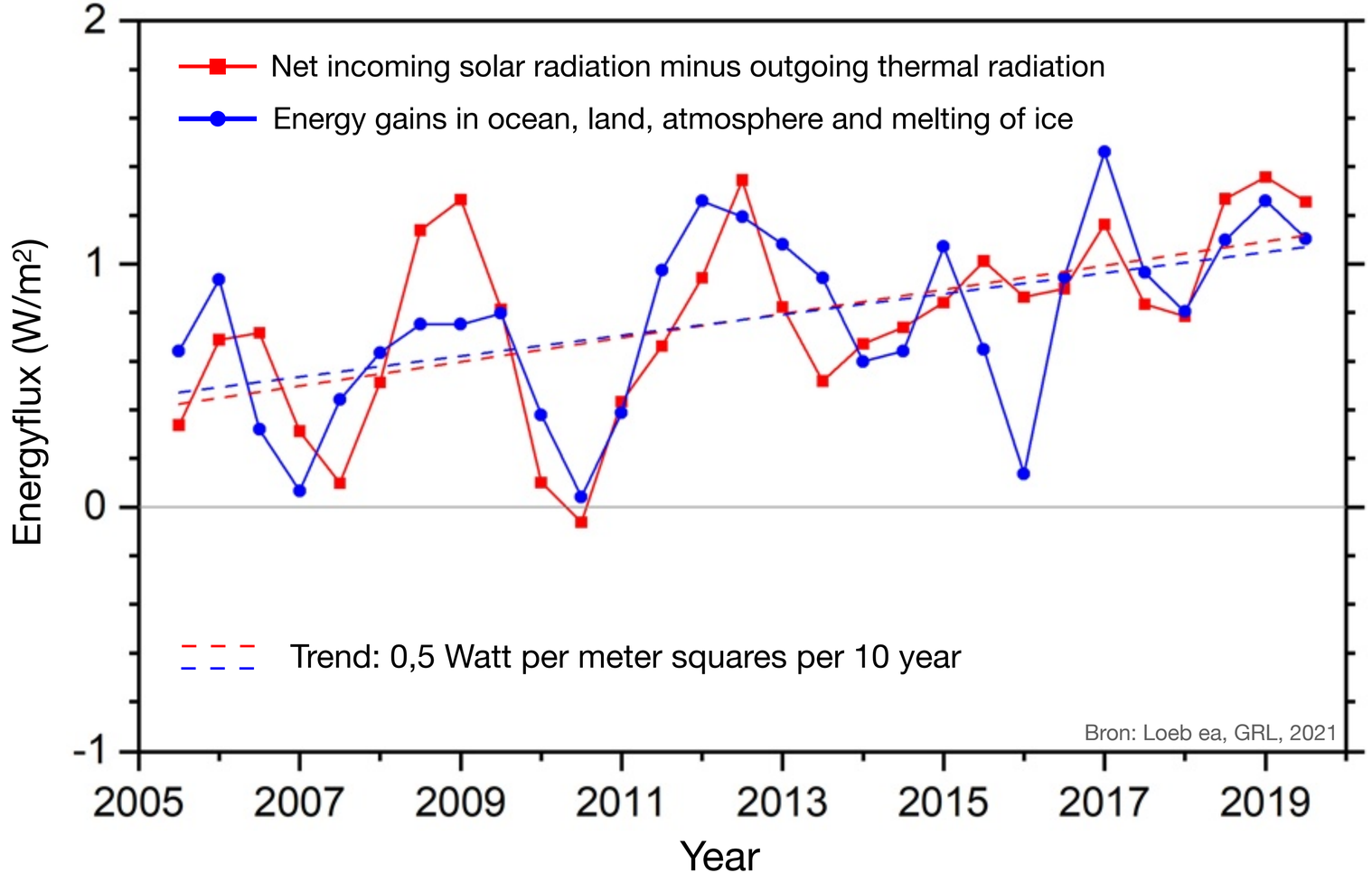
8 % upper deep ocean

5 % land warming

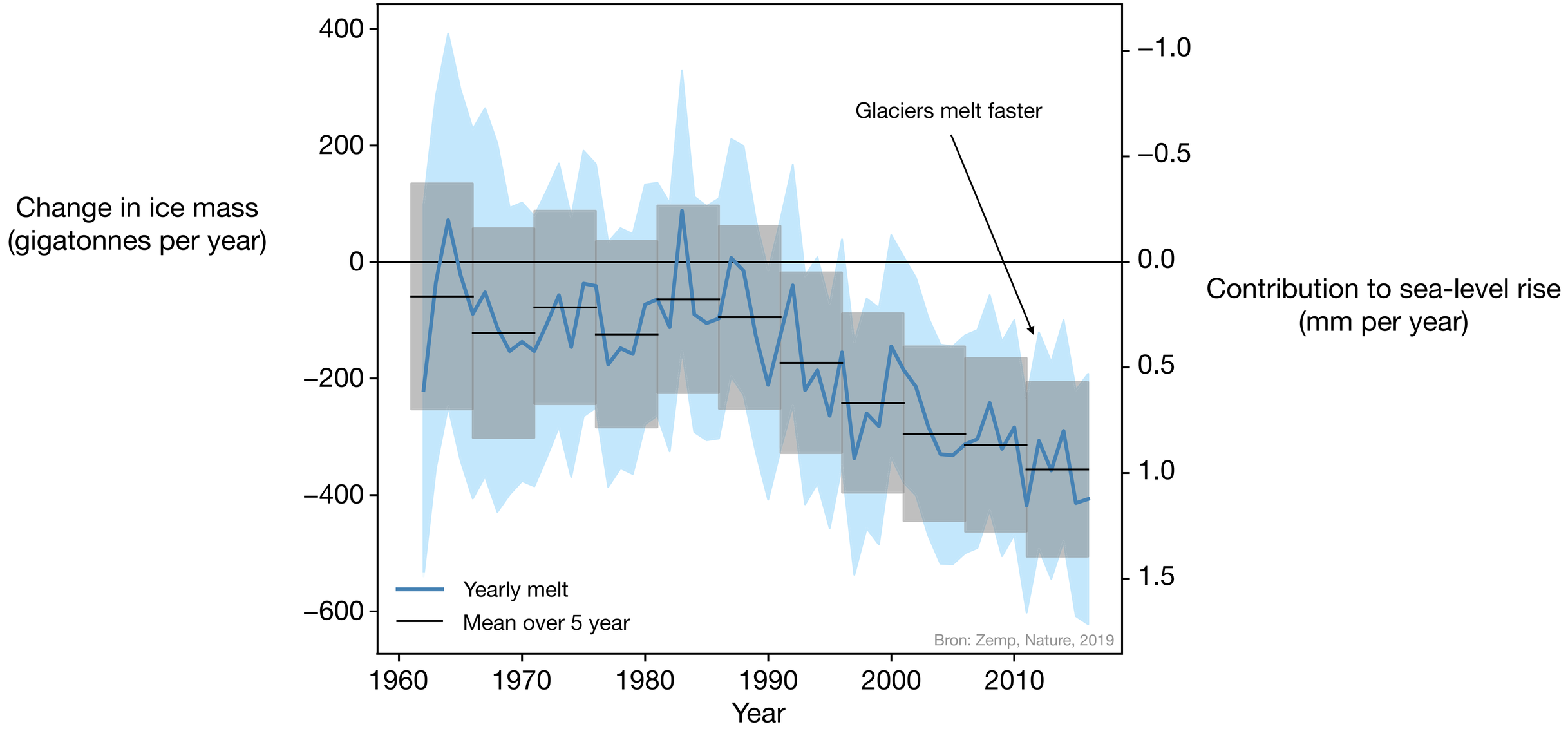
4 % ice melting

2 % atmosphere moistening and heating

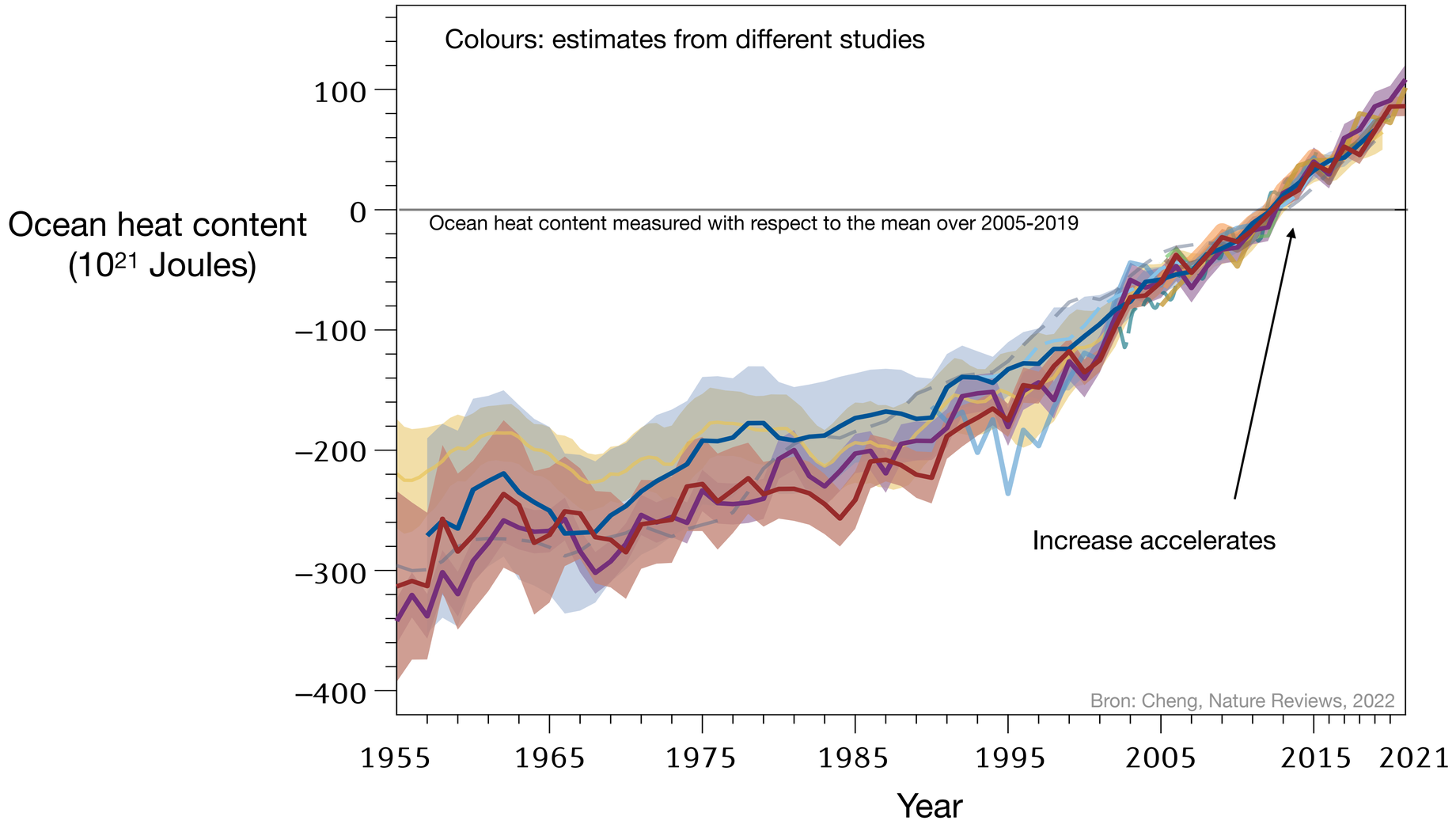
Extra energy input measured by satellites matches the energy increase in the climate system



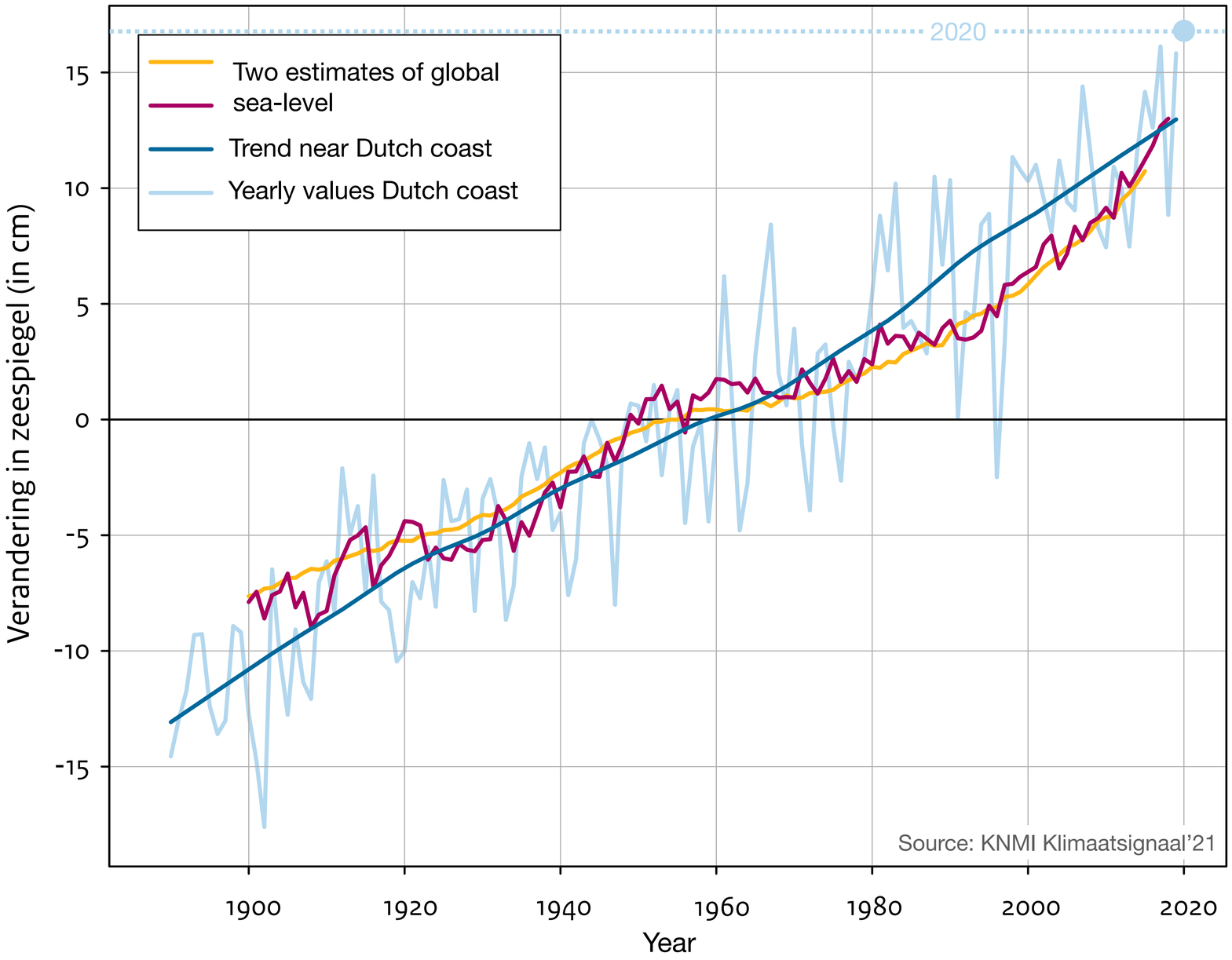
Global melt of glacier ice accelerates



Ocean heat content (upper 2000 m) increase accelerates

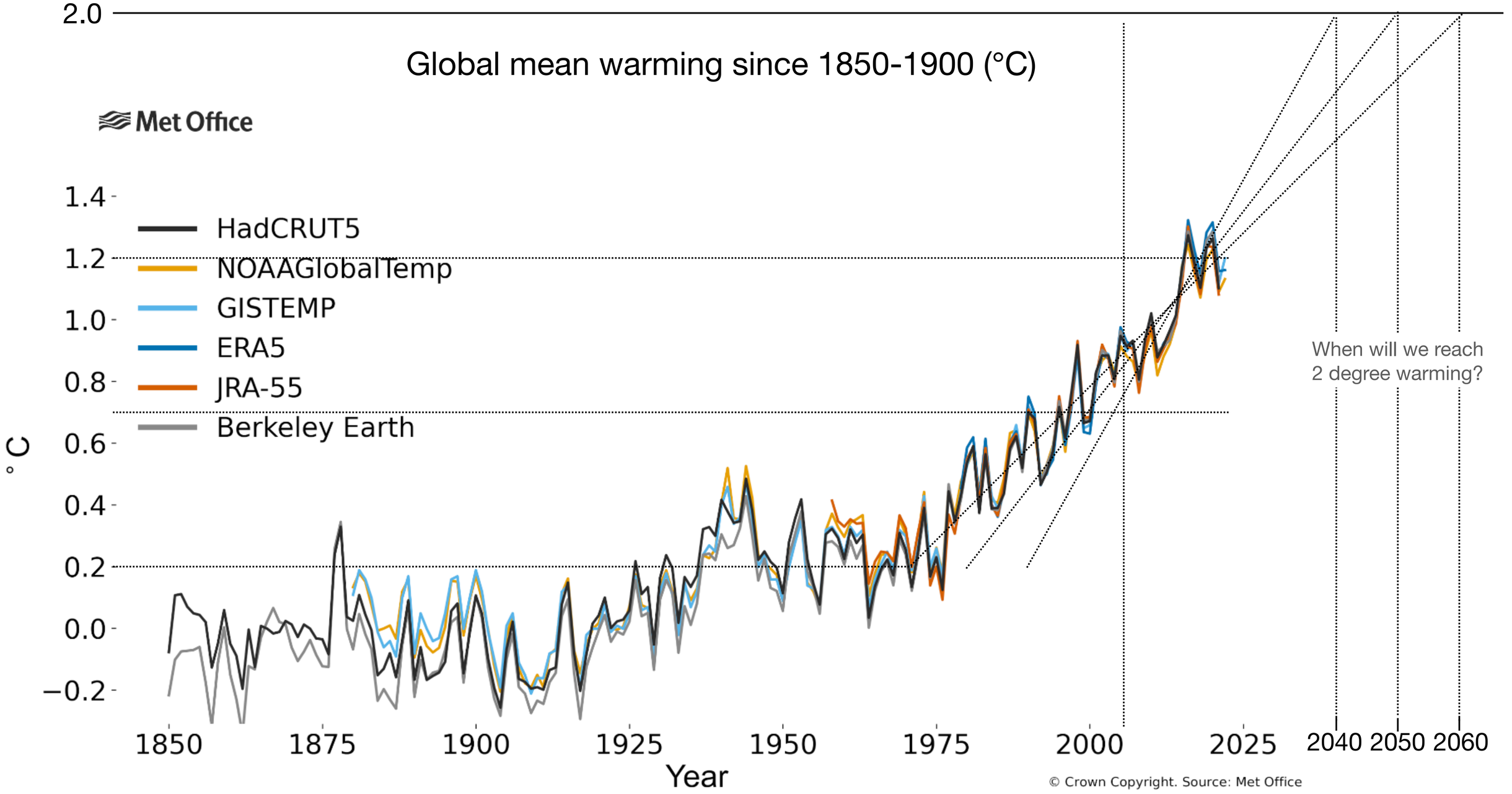


Sea-level rise globally and near Dutch coast accelerates



Acceleration near the Dutch coast is masked by natural variations in the wind

Surface air temperature is rising: accelerated warming expected in next 10 years



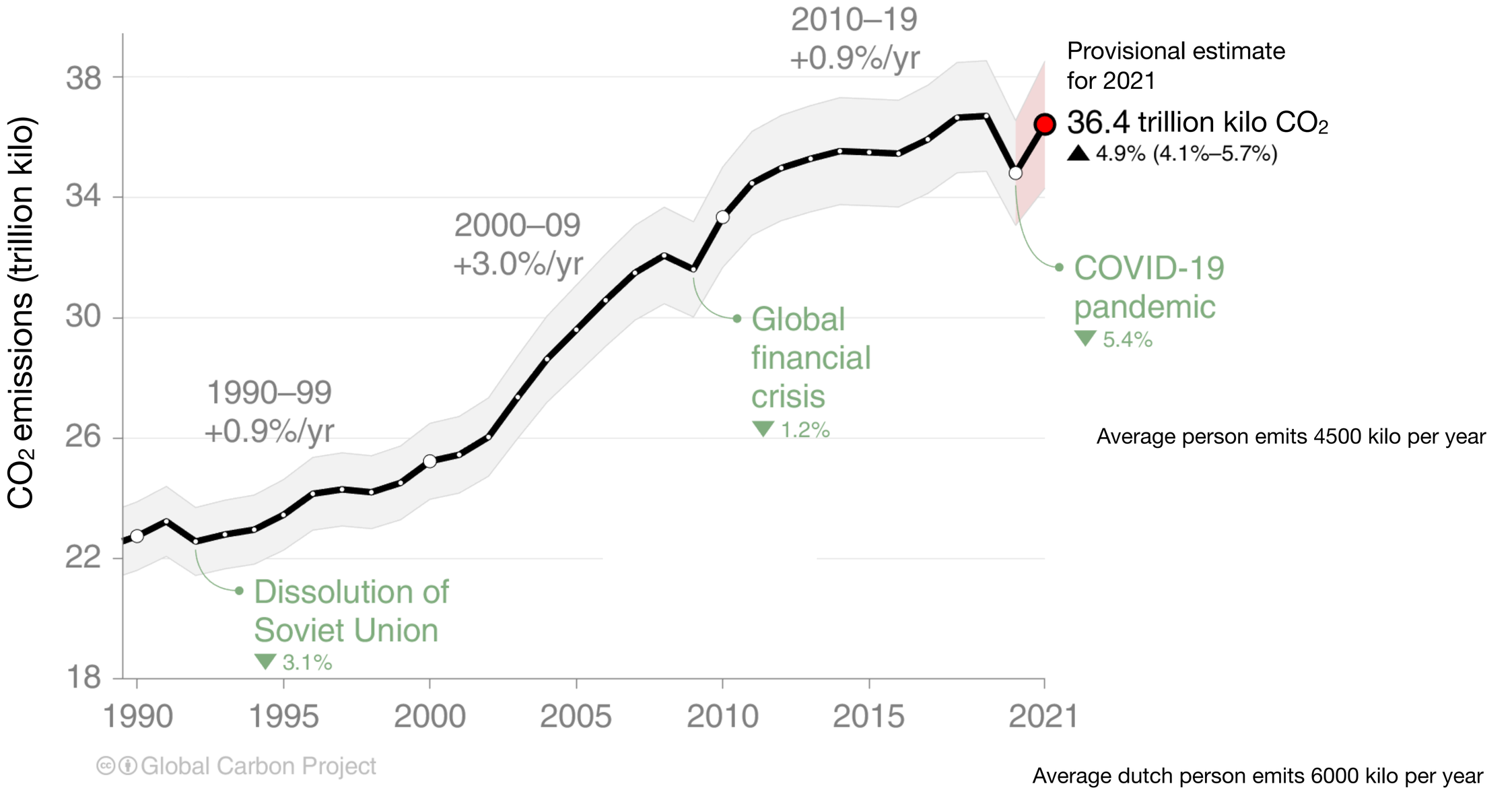
The rise CO2 concentration in the atmosphere is accelerating

Carbon dioxide concentration at Mauna Loa Observatory

Charles Keeling

observations

Worldwide emissions of CO_2 due to burning of oil, gas and coal and the production of cement are still rising !!!!

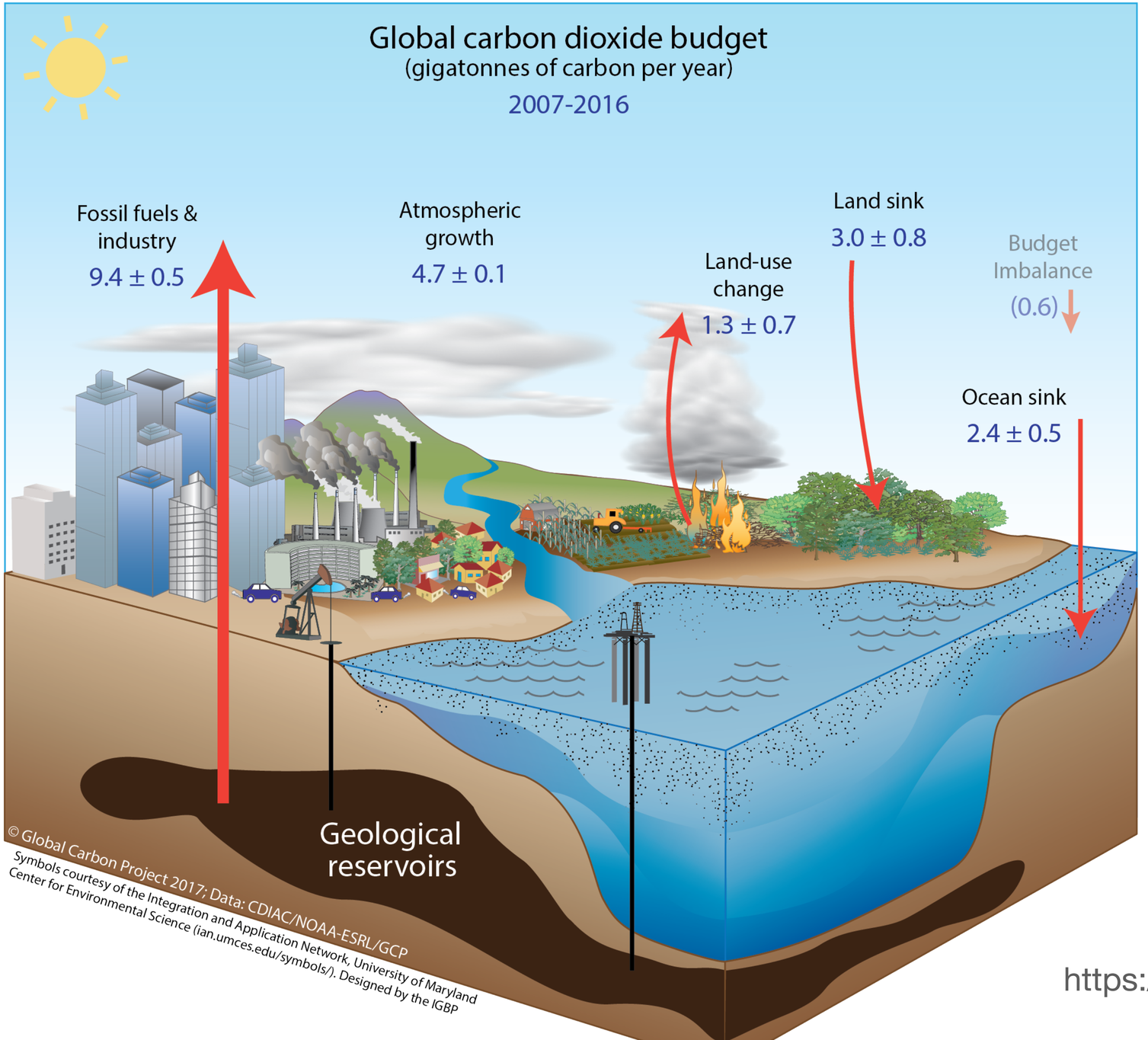


Average person emits 4500 kilo per year

Average dutch person emits 6000 kilo per year

Conservation law of mass (carbon atoms)

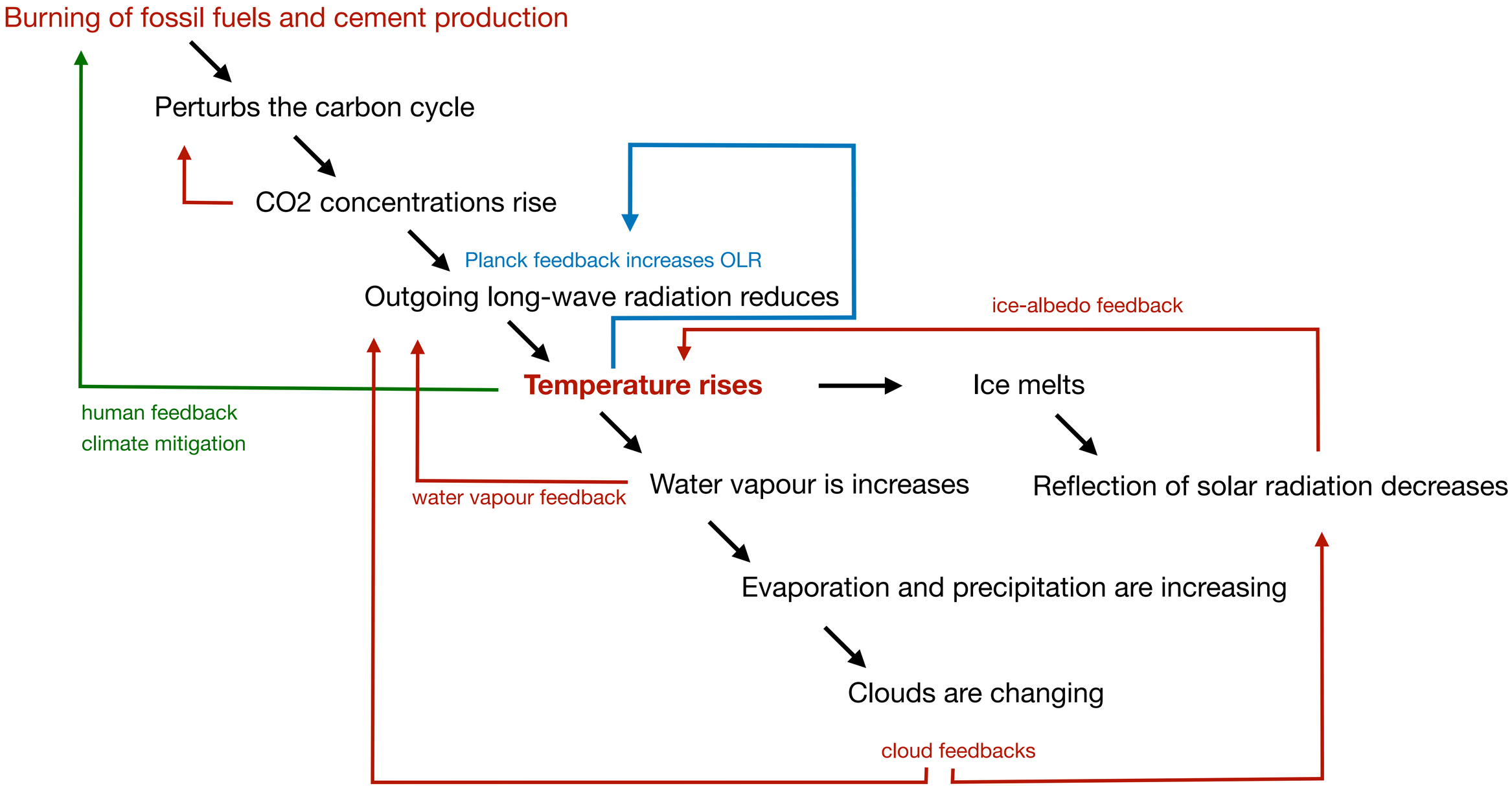
Emissions by humans disturb the natural balance



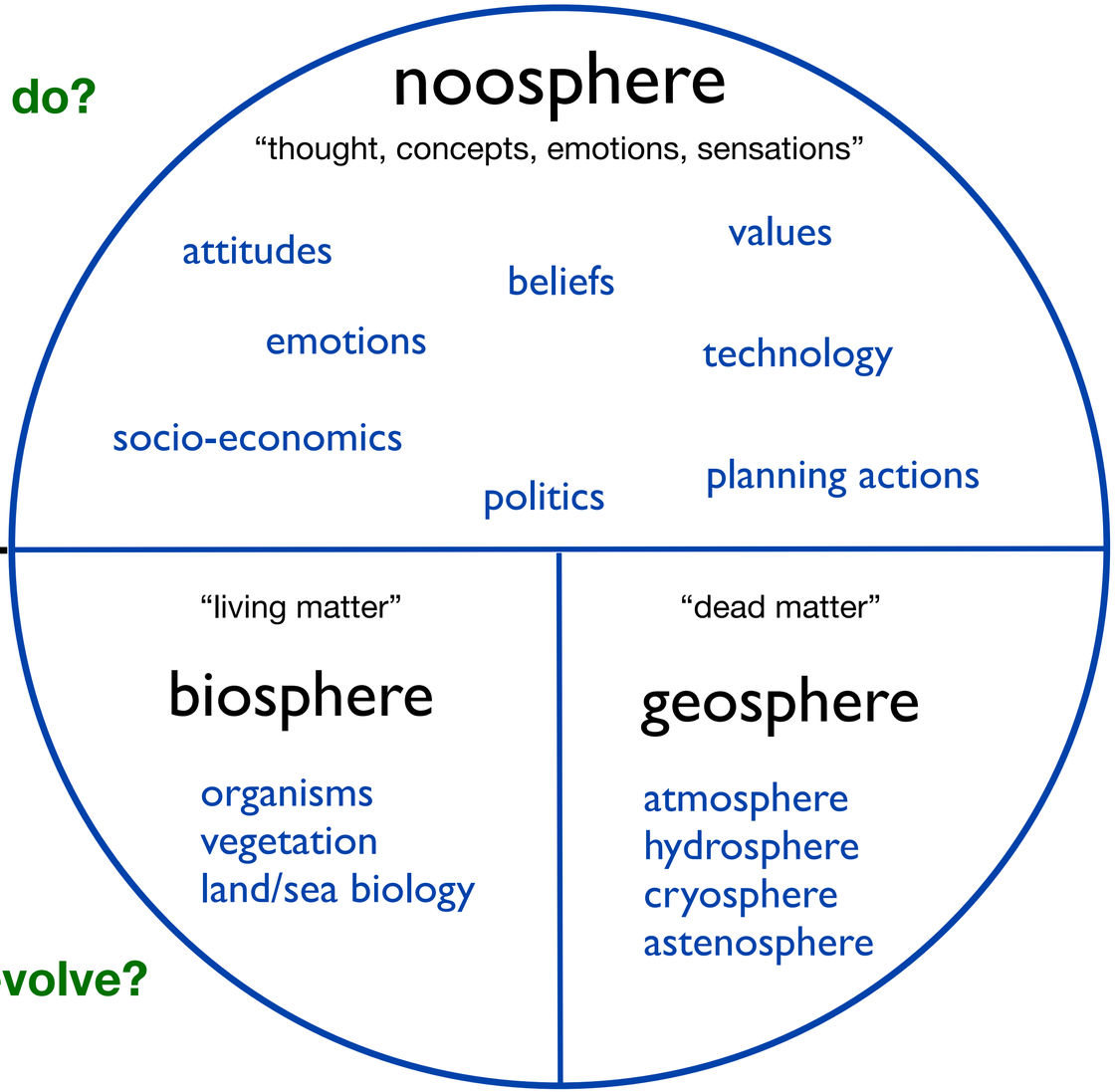
Half of the anthropogenic emissions accumulate in the atmosphere

https://www.globalcarbonproject.org

Human activities kick off a complex chain of events ….



Future ?



1. What will humans do?

scenario based

lack of laws

2. how will climate evolve?

model based

apply laws of nature

impacts of climate change felt by humans

- land slides
- floods
- wild-fires
- sea level rise
- water availability
- land degradation
- loss of species

sustainability

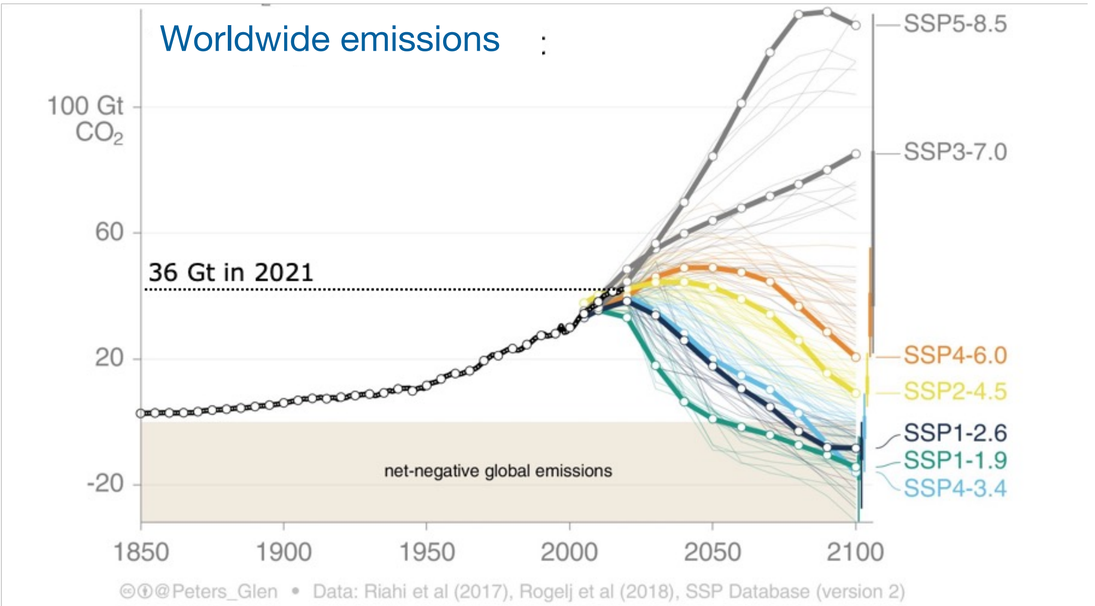
- emissions
- mining
- fishing/hunting
- waste
- land-use
- live-stock
- water use

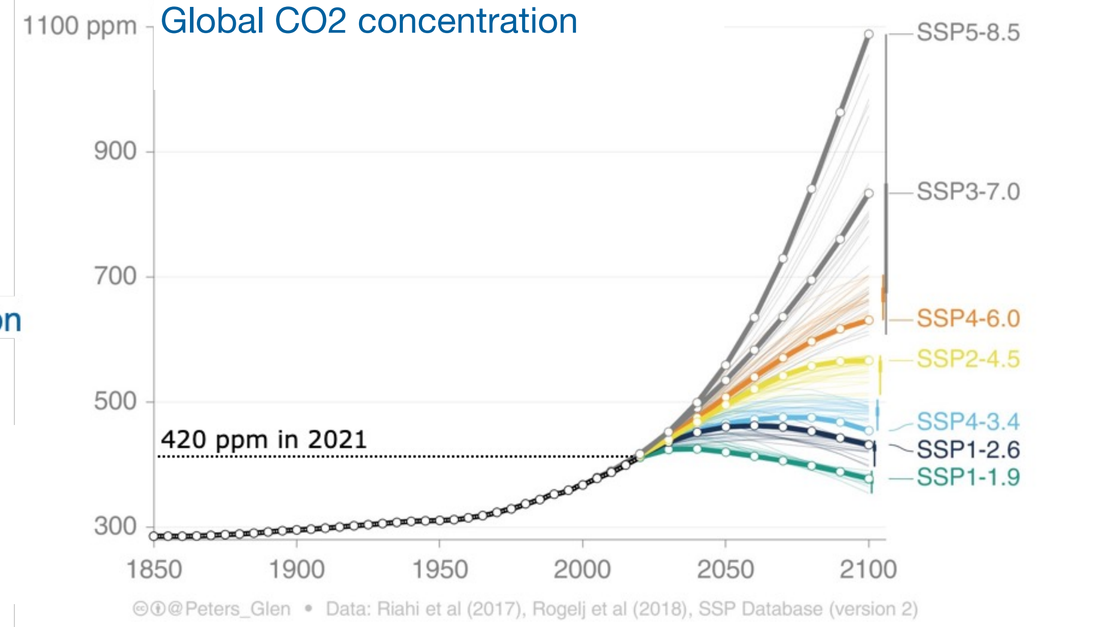
impacts of human change felt by climate

1. What will humans do?

Shared Socioeconomic Pathways (SSPs): storylines for consistent socio-economic developments until 2100

- **SSP1:** Sustainable future (the green road)
- **SSP2:** Middle of the road
- **SSP3:** Regional constrasts (bumby road)
- **SSP4:** Inequality (divided road)
- **SSP5:** Fossile-intensive (the highway)





SSP storylines → Population, cities, Brute National Income

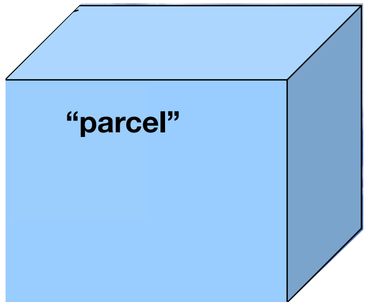
'Integrated assessment models' → Emissions GHG and Aerosols

'Atmospheric chemistry and carbon cycle models' → Concentrations GHG and Aerosols

2. how will climate evolve?

- Calculate the change using climate models for various pathways of future emissions

Apply laws of nature to parcels of air



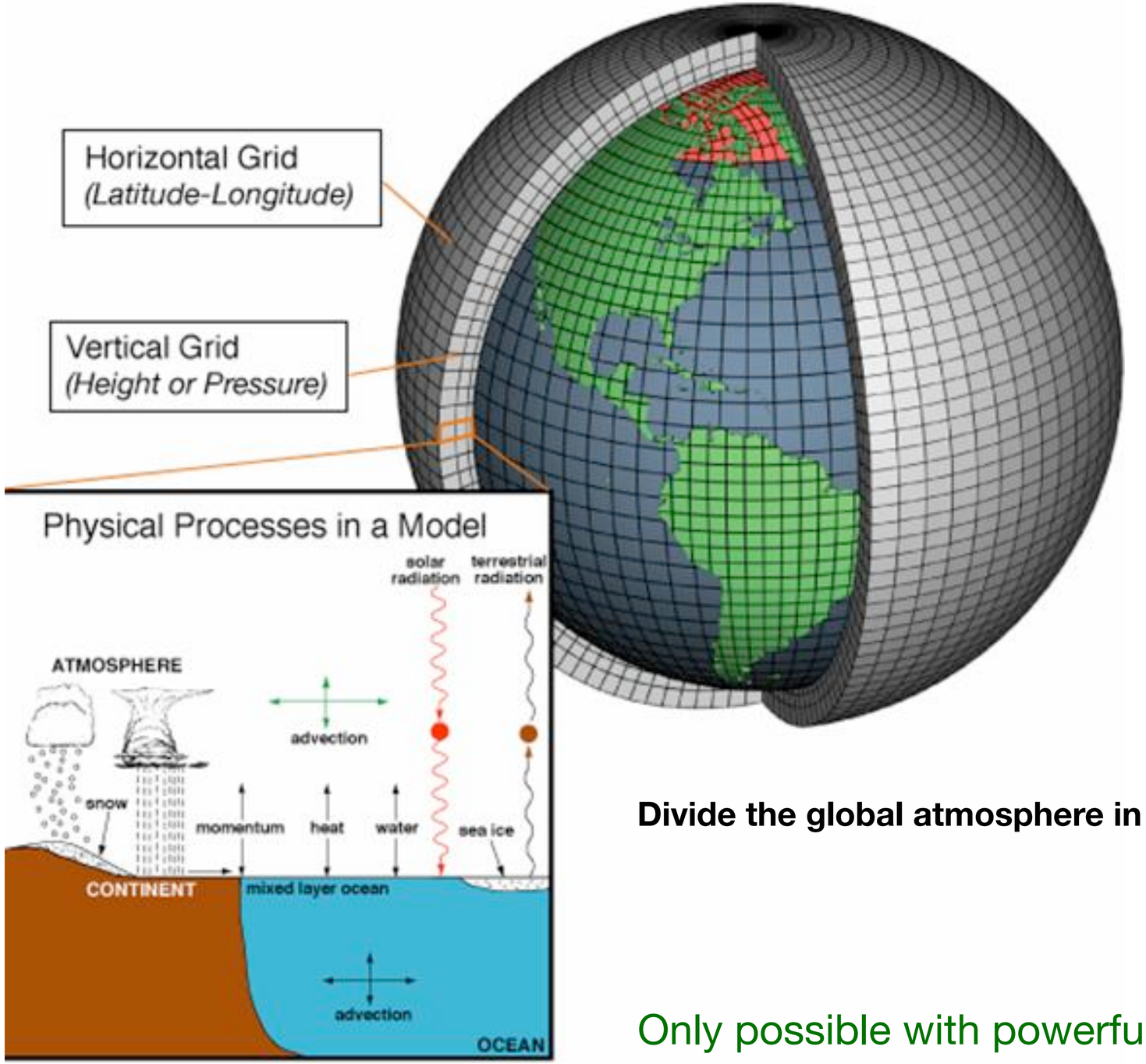
1. **Conservation of momentum** $$F = m \cdot a = m \cdot \frac{dU}{dt} \rightarrow \quad \frac{d\overline{U}}{dt} = -\frac{1}{\rho}\overline{\nabla} p + \overline{g} + \frac{1}{m} F_w - 2\overline{\Omega} \times \overline{U}$$

2. **Conservation of mass** $$\frac{\partial \rho}{\partial t} + \overline{\nabla} \cdot (\rho \overline{U}) = 0$$

3. **Conservation of energy** $$\frac{\partial T}{\partial t} = -\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) - w\frac{\partial T}{\partial z} + \frac{1}{\rho c_p}\frac{dp}{dt} + \frac{1}{c_p}\frac{dQ}{dt}$$

4. **Ideal gas law** $$\rho = \frac{p}{RT}$$

Solve these equations with computers on a 3 dimensional computation grid that spans the whole atmosphere

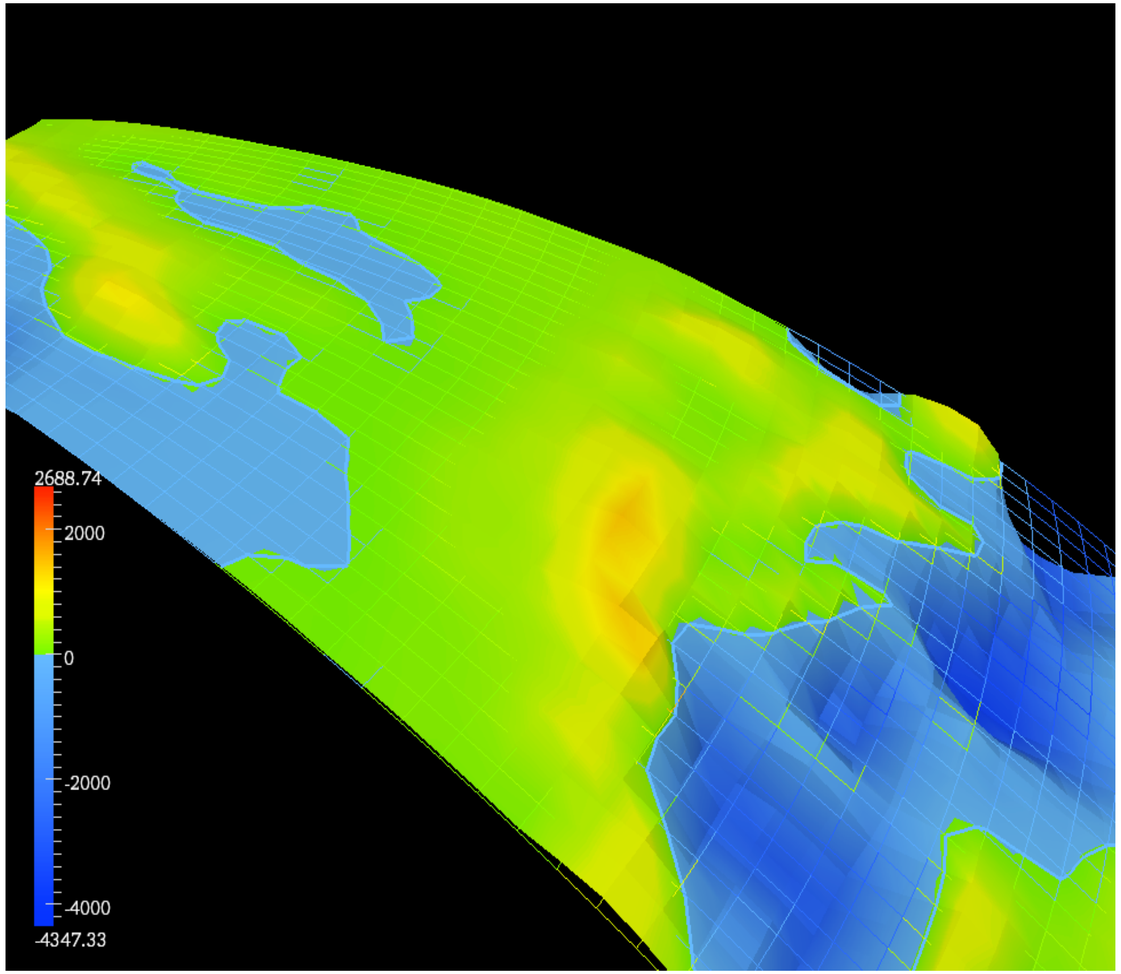


Divide the global atmosphere in grid-cells

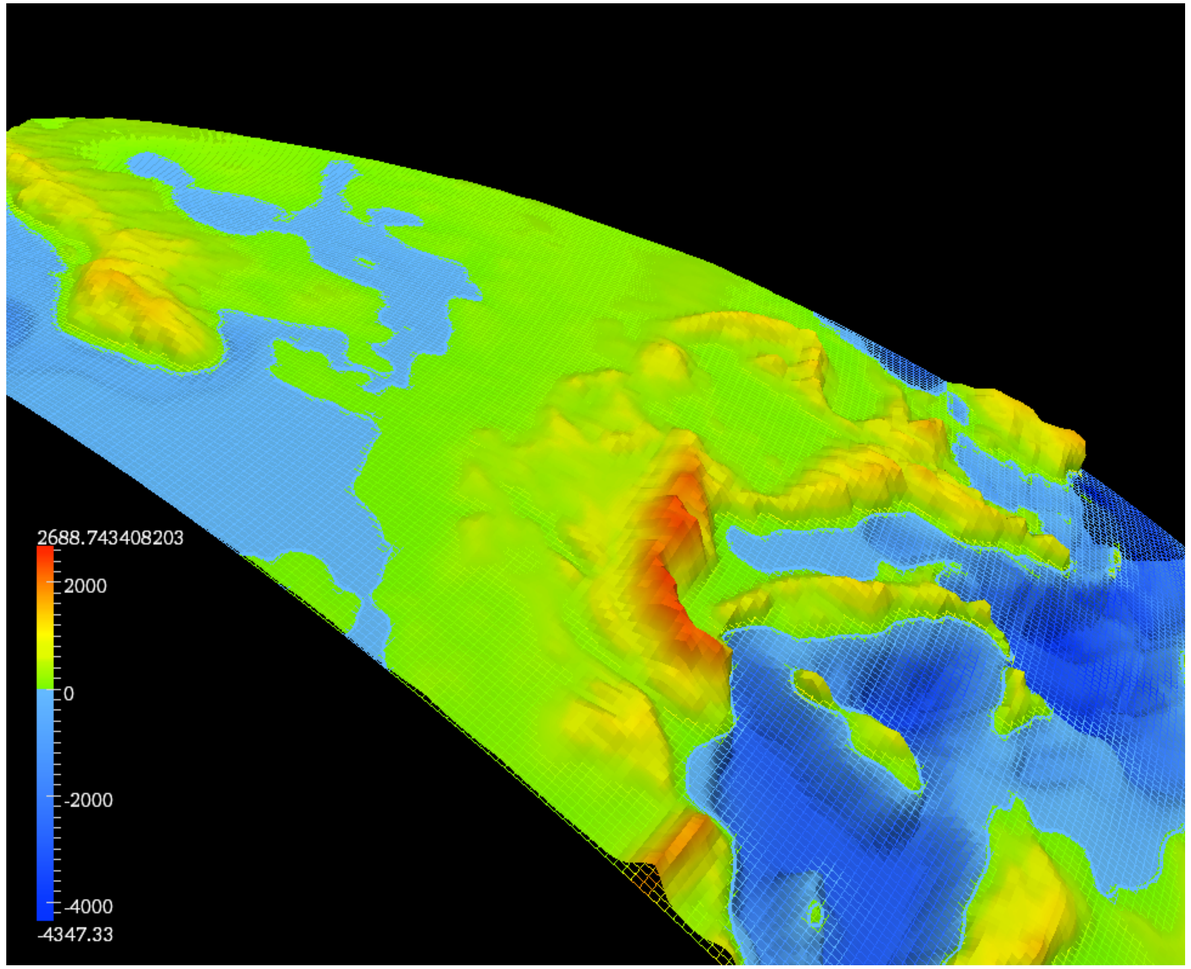
Only possible with powerful computers

Representation of land-sea distribution and mountains on the computational grid

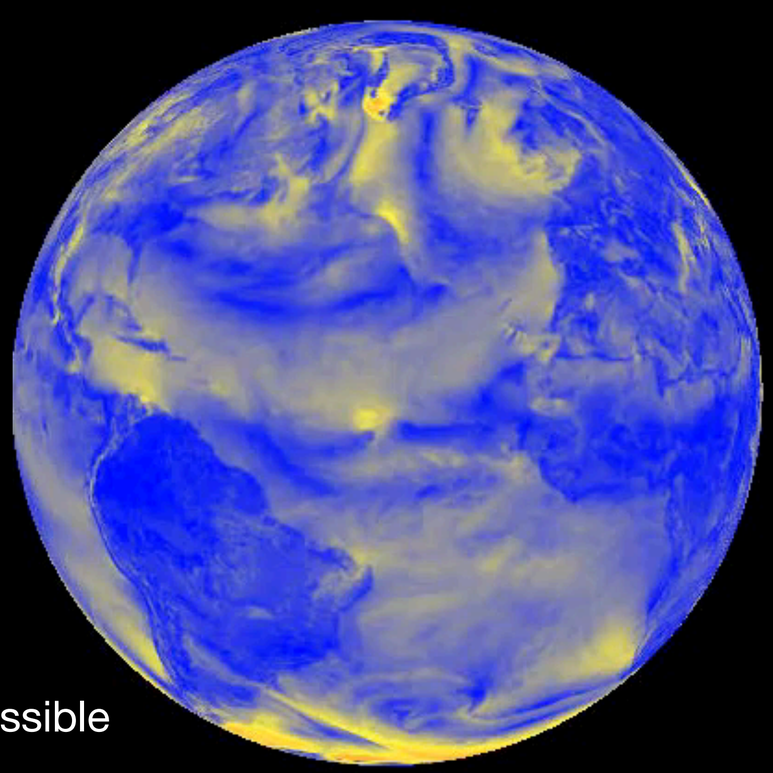
Present generation climate models

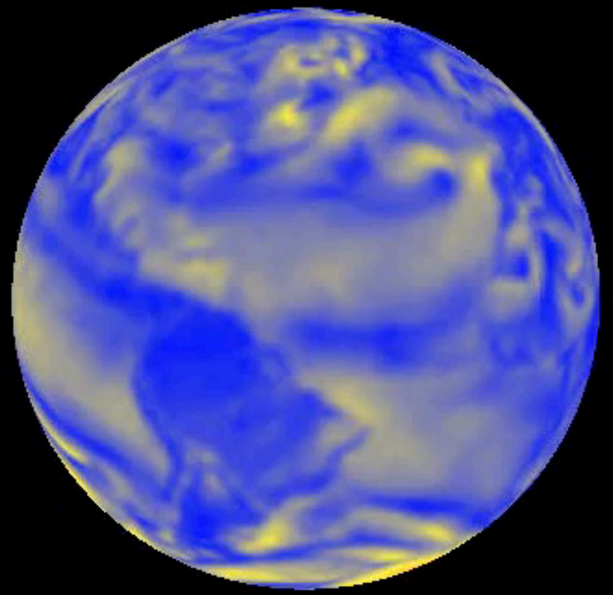


Next generation climate models



KNMI climate model simulates tropical cyclones

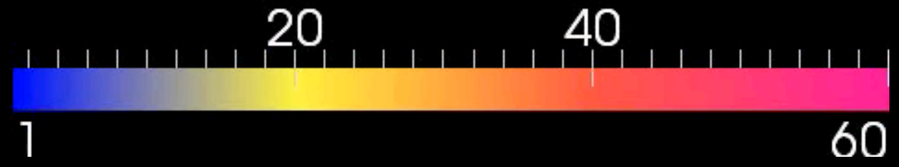




present resolution

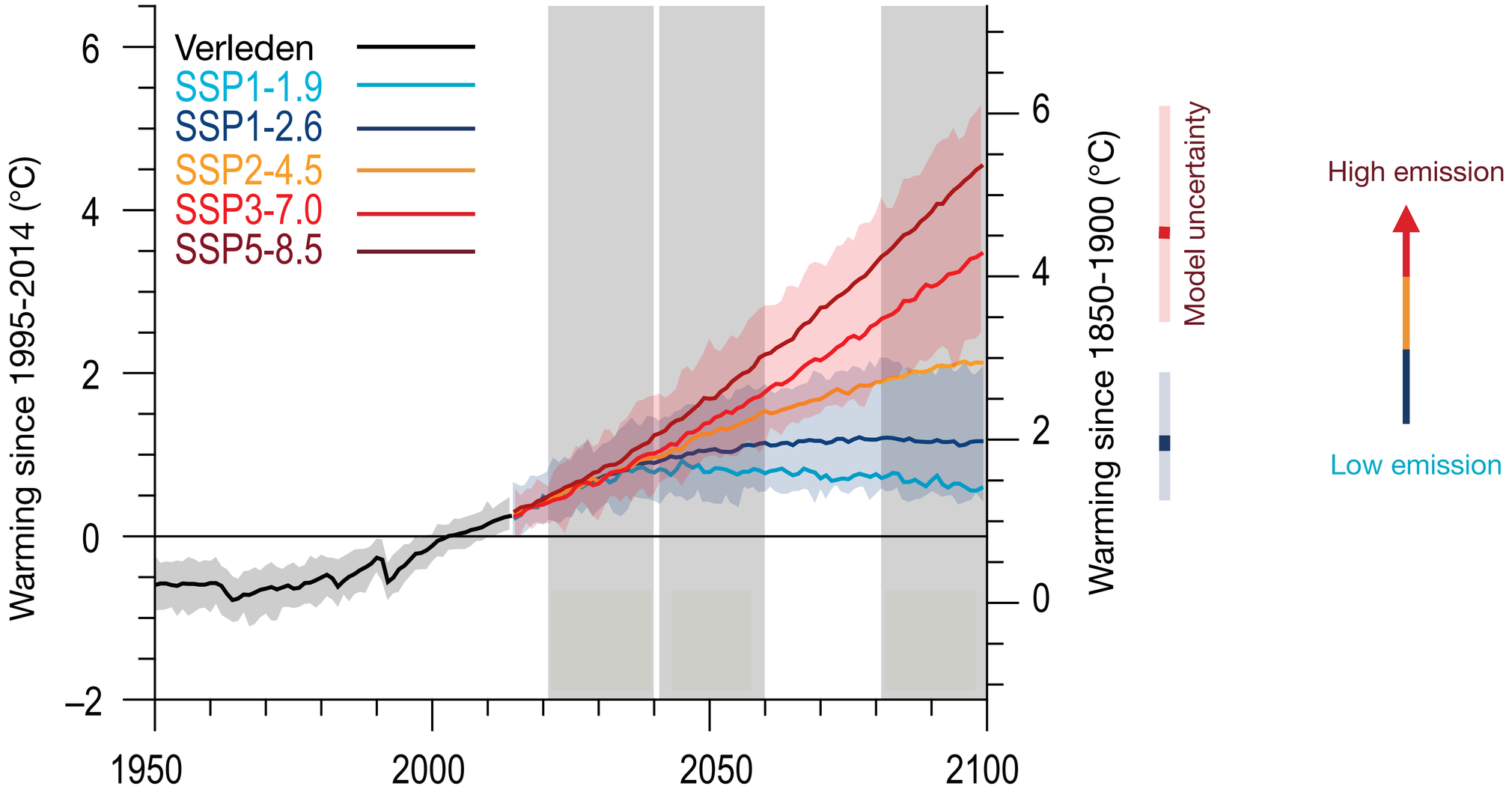
this is becoming possible

surface wind



The warming will continue, emissies should drop quickly soon to restrict warming to 2 degrees

Climate models are used to calculate the change for different scenarios of future emissions



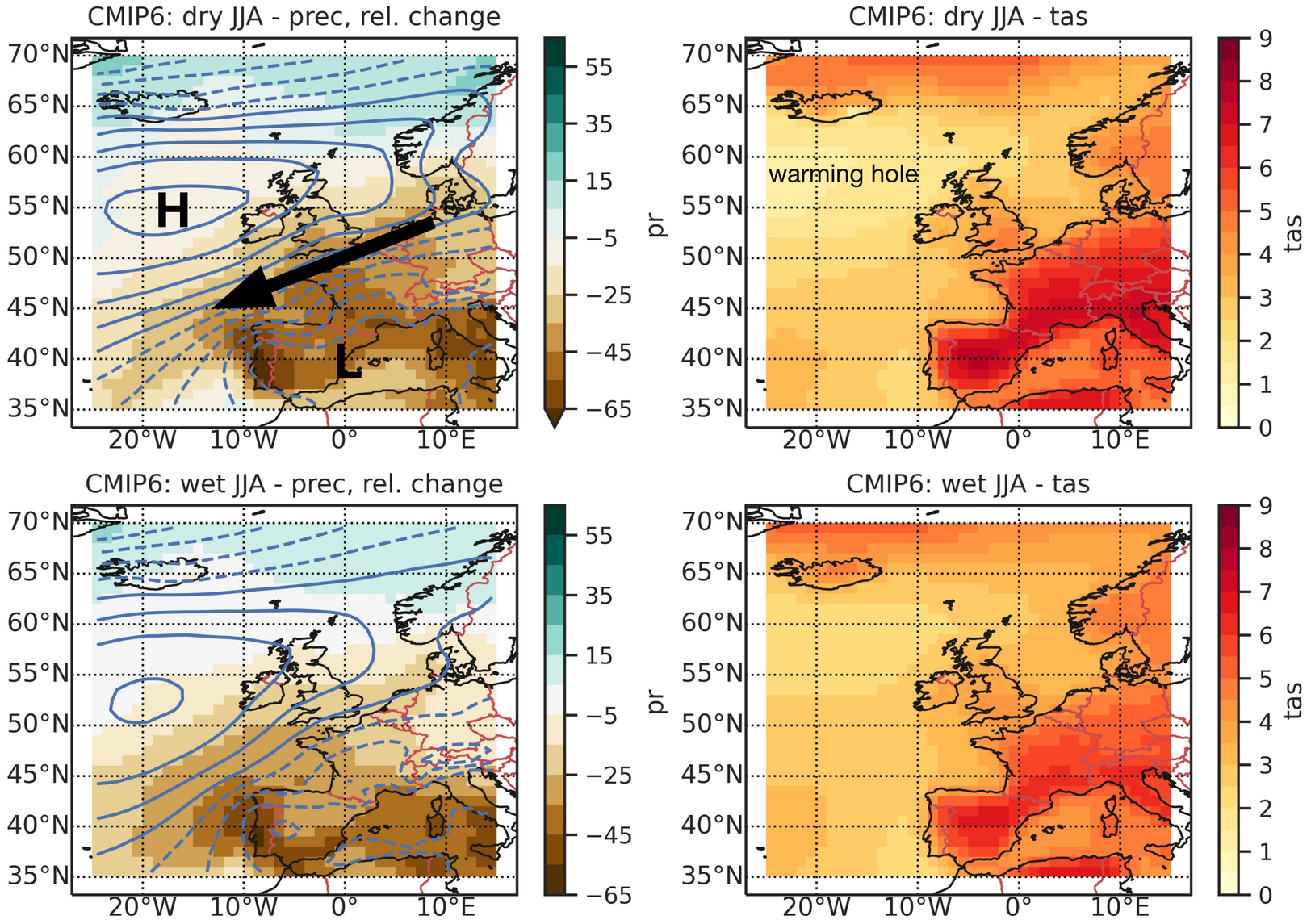
Climate models disagree on the amount of drying in summer: uncertainty due to land atmosphere feedbacks and ocean circulation

cooler subpolar gyre and related higher pressure west of Ireland

drying group

stronger heat low over warmer mediteranean

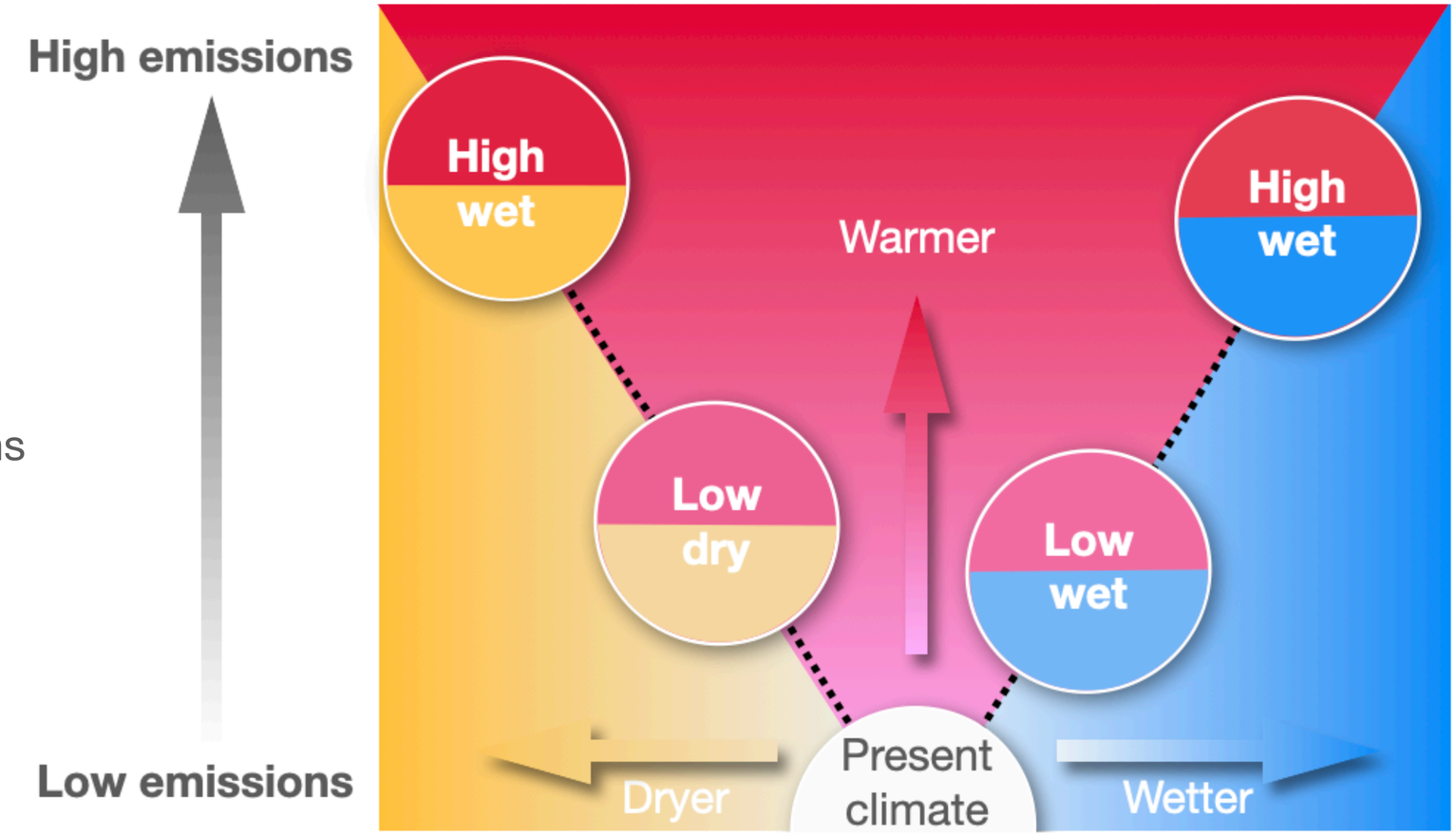
wetting group



The dry group projects a stronger cooling of the sub polar gyre which enhances easterly winds over summertime Europe

KNMI climate scenarios for the Netherlands

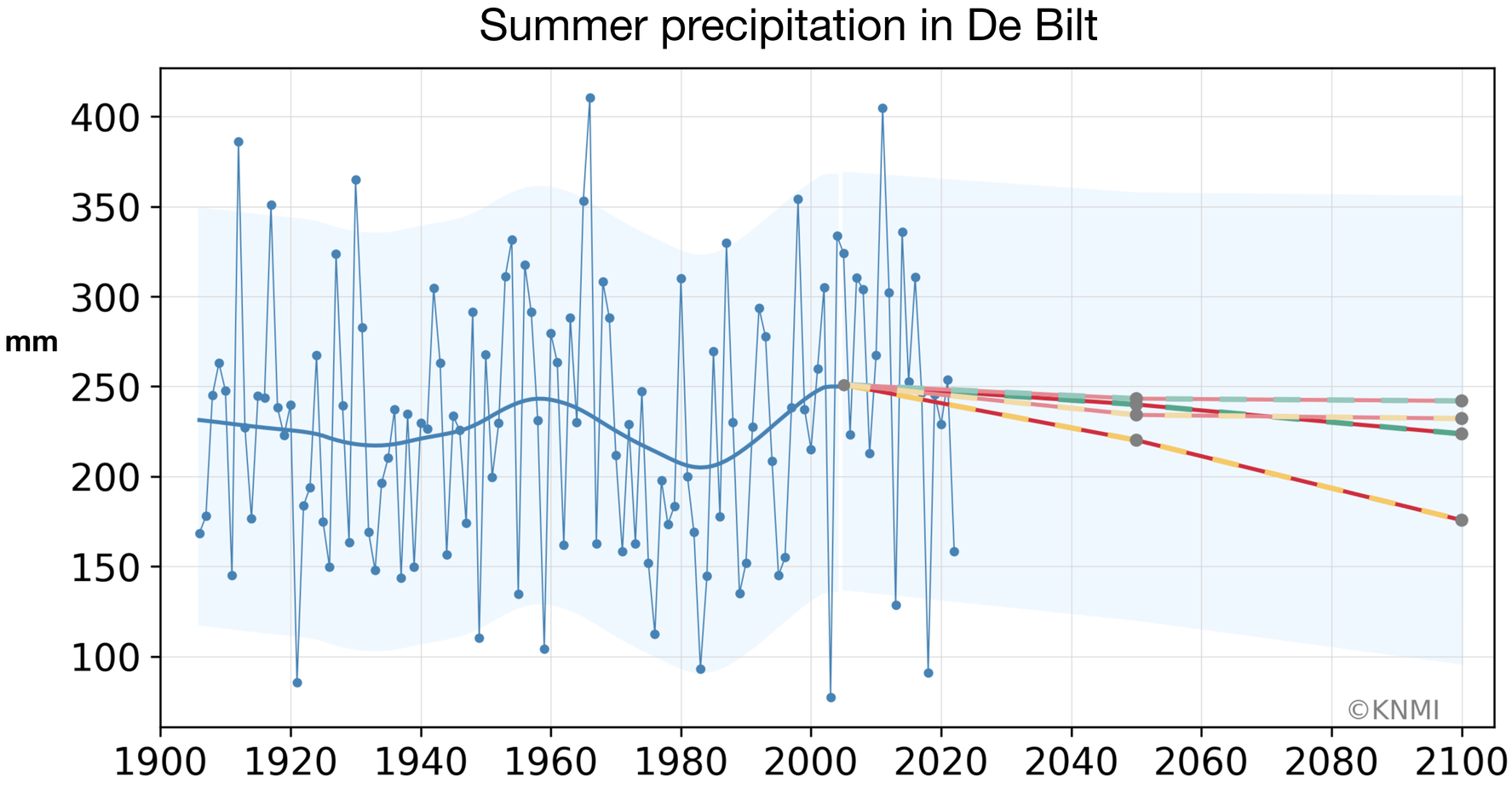
Climate will likely evolve within the range of these four scenarios

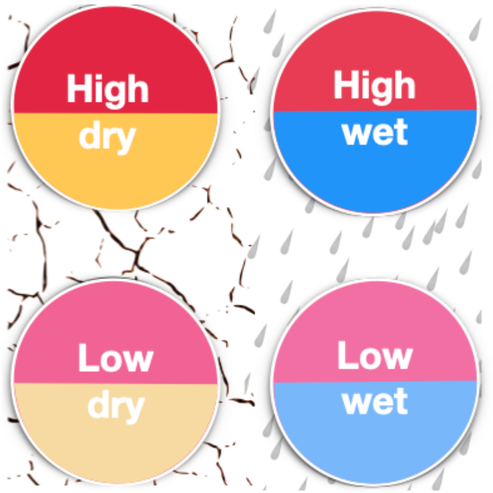


Annual precipitation can either decrease ór increase

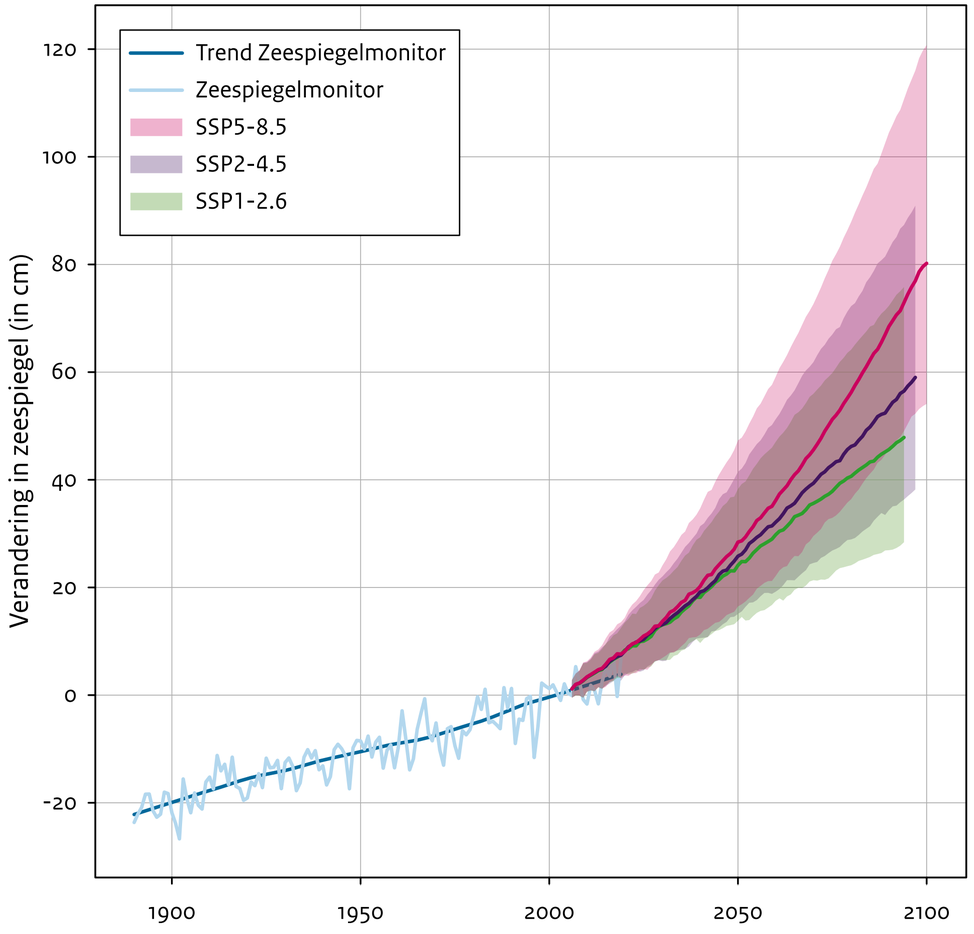
Uncertainty in regional climate response

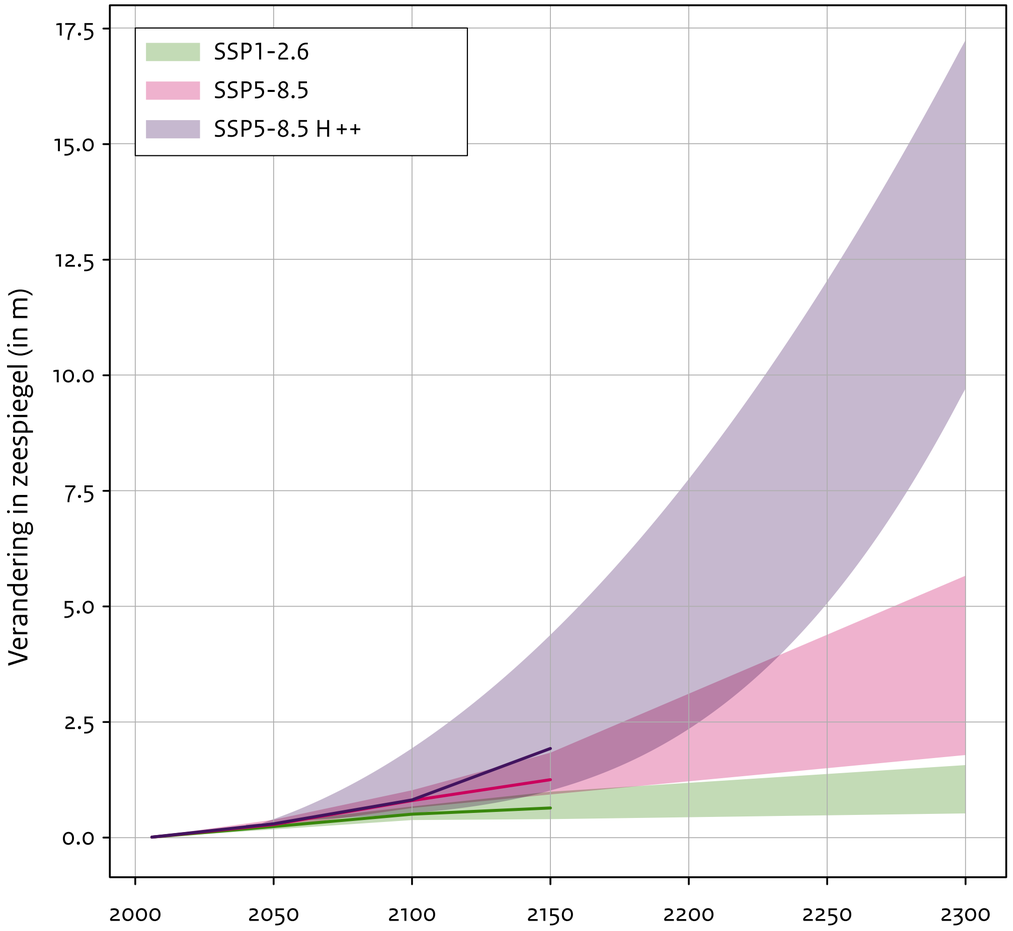
Example:

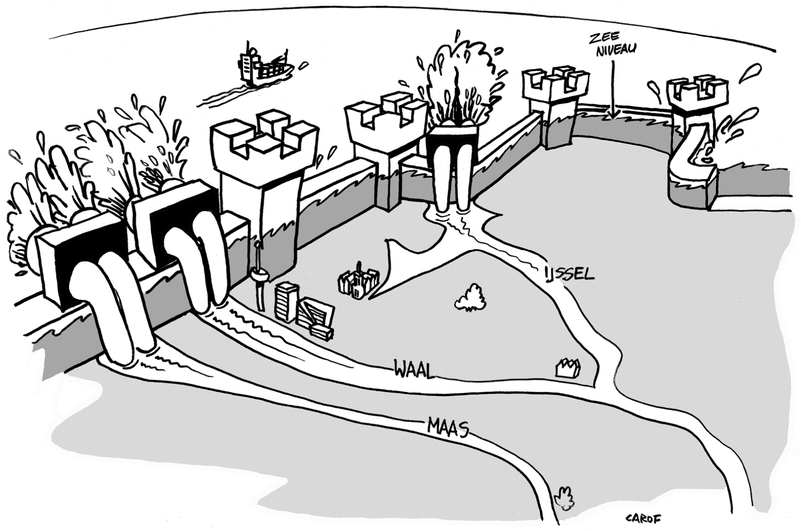

Summer precipitation in De Bilt
mm
400
350
300
250
200
150
100
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
©KNMI


High
dry
High
wet
Low
dry
Low
wet

Projections of sea-level rise







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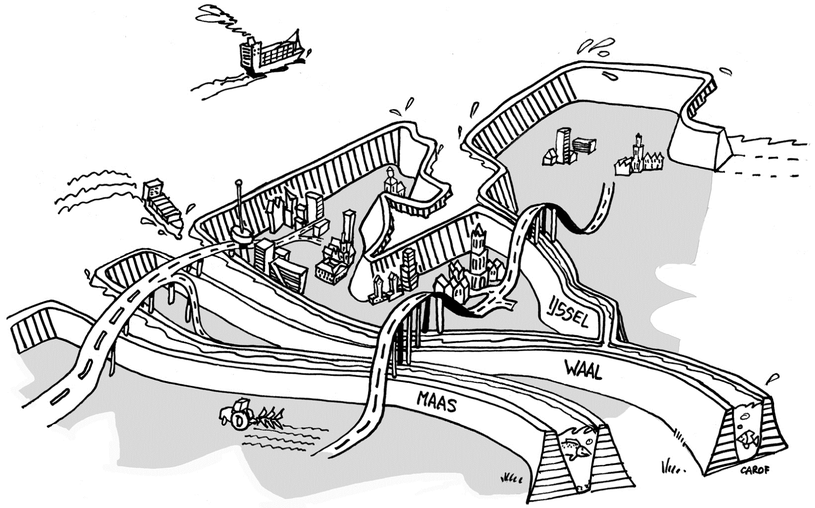

2

3

Three options to live in our delta in case of extreme sea-level rise:

1. protect like a fort and pump river water into the sea
2. protect low-lying areas with deep rivers
3. increase the height of the delta, as a whole or a collection of connected capes

CO2 removal from the atmosphere