

Ecology and Sustainable Development.

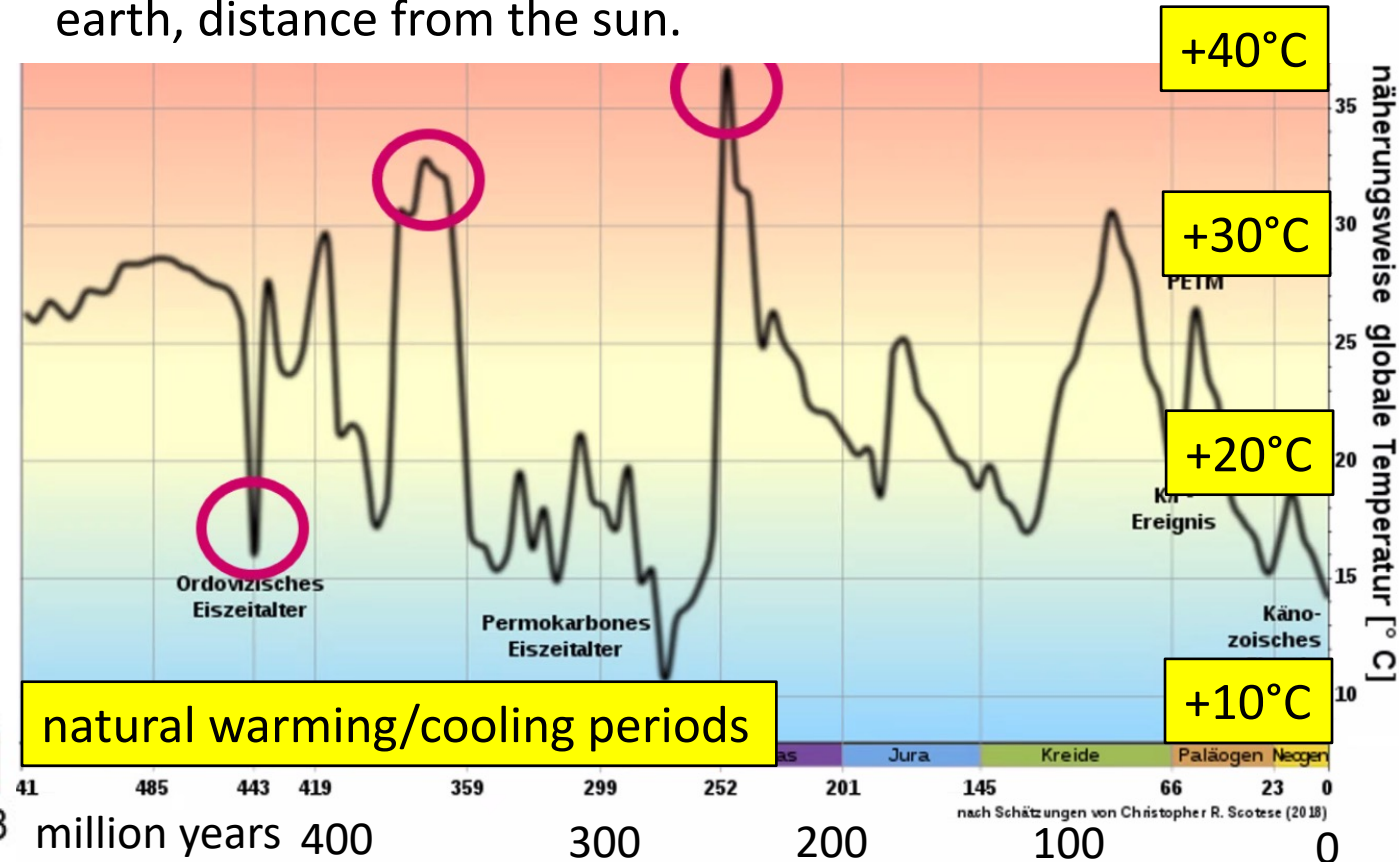
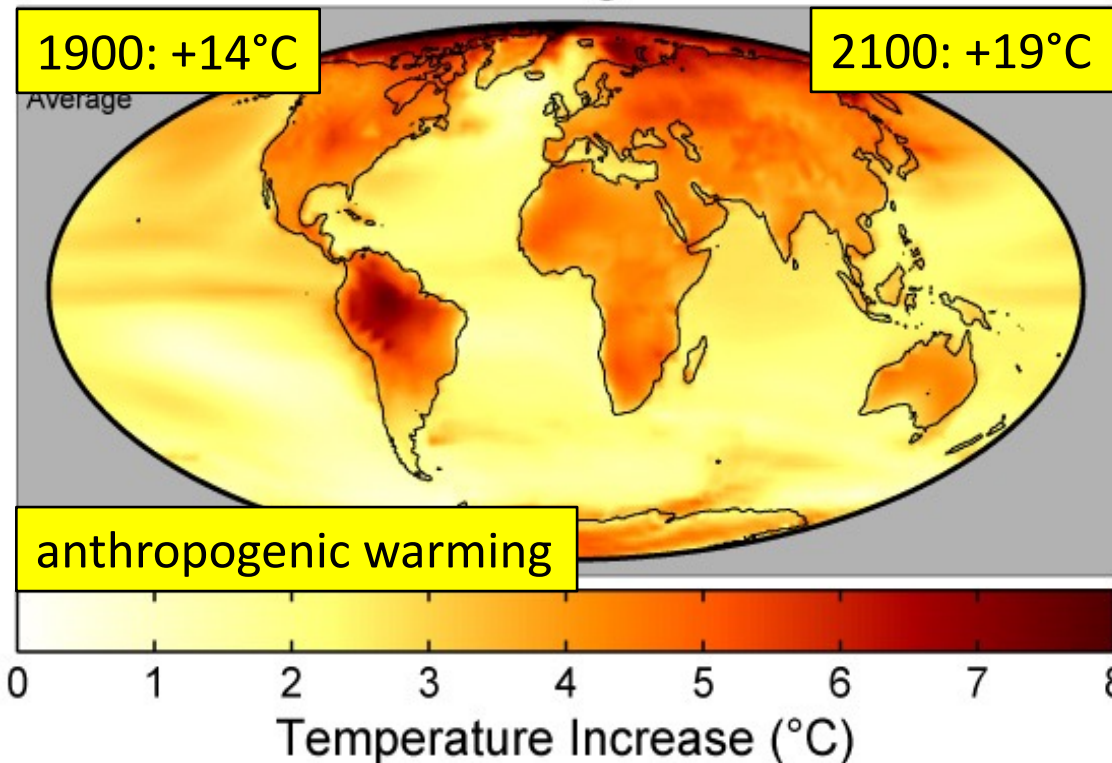
7. Climate Change:

- Basic findings
- Causes and trends
- Impacts
- Mitigation
- Adaptation

IPCC Fifth and Sixth Assessment Report (AR5 und AR6) 2013 und 2023

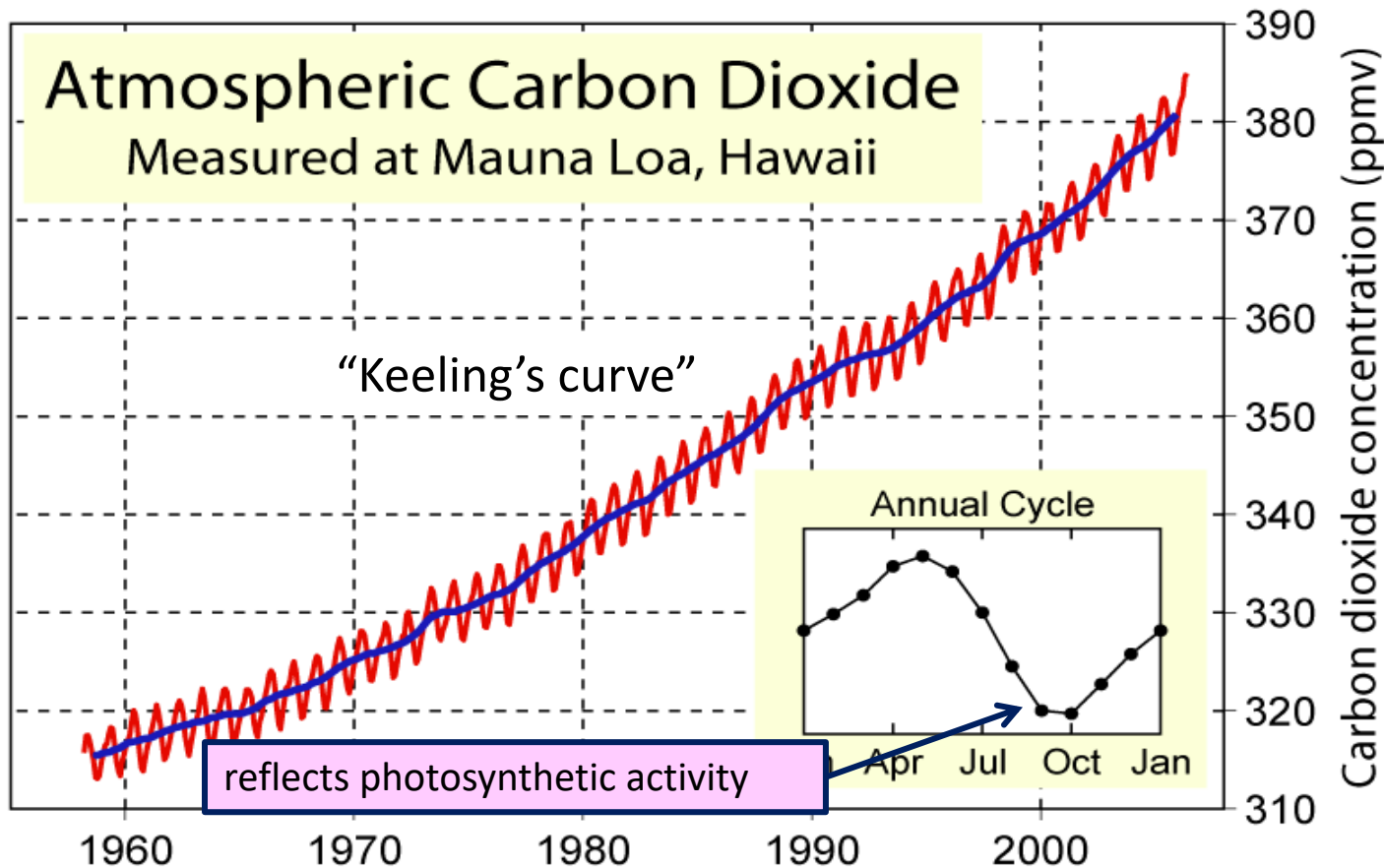
- **Historical record of average surface temperature:**
 - Average global surface air temperature of the earth showed a great variability in the past: from + 10 to + 40 °C.
 - These variations were caused by natural phenomena like inclination of the earth axis, changes in the orbital of the earth, distance from the sun.

Global Warming Predictions



Anthropogenic Global Warming: Initial Findings.

- Discovery of the atmospheric enrichment of the Green House Gas CO₂ by Charles David Keeling.



- Keeling made regular accurate measurements of the atmospheric CO₂ concentration, taking readings at the South Pole and in Hawaii from 1958 onwards.

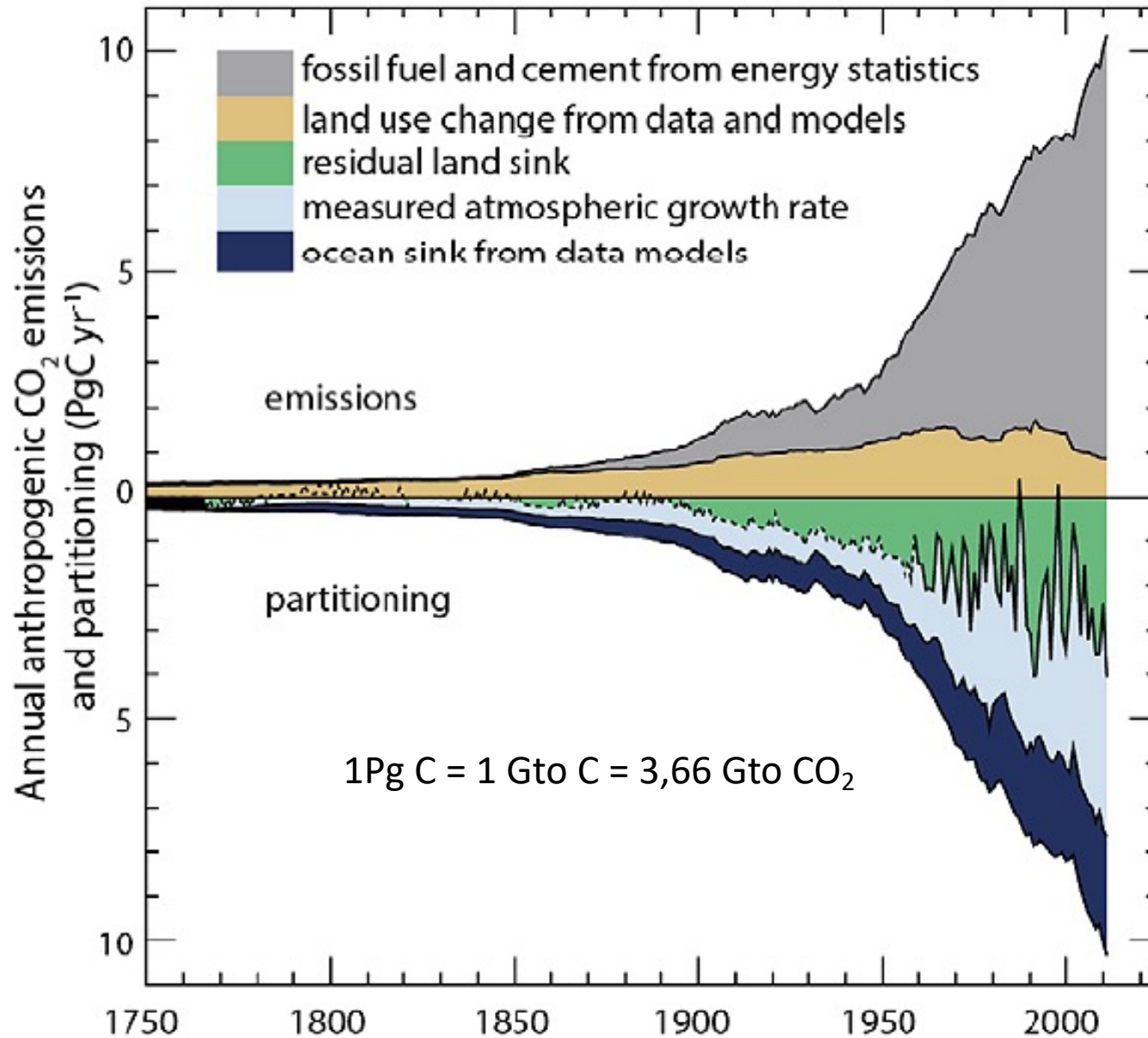


- The year-on-year increase roughly matched the amount of fossil fuels burned per year.

First "scientific observations" of global warming made in 1980s by J. Hansen in a hearing of the US Senate: "US heat waves due to global warming".

CO₂ is stable in atmosphere:
residence time 100 years.
Thus it is continuously enriched there.

Annual Anthropogenic CO₂ Emissions and Partitioning: Period 1750 to 2011.



- **Major Sources:**

- Fossil fuel consumption and cement production (total 365 Gto carbon).
- Land use change - mainly biomass burning (total 60 Gto carbon).

- **Major Sinks:**

- Uptake by oceans – dissolved in water, precipitated as carbonates.
- Uptake by plants (photosynthesis, storage in soil).

- **Accumulation in atmosphere:**

- 240 Gto carbon.

Atmosphere loaded with 185 Gto carbon (677 Gto CO₂).

Source: IPCC AR5 (2013)

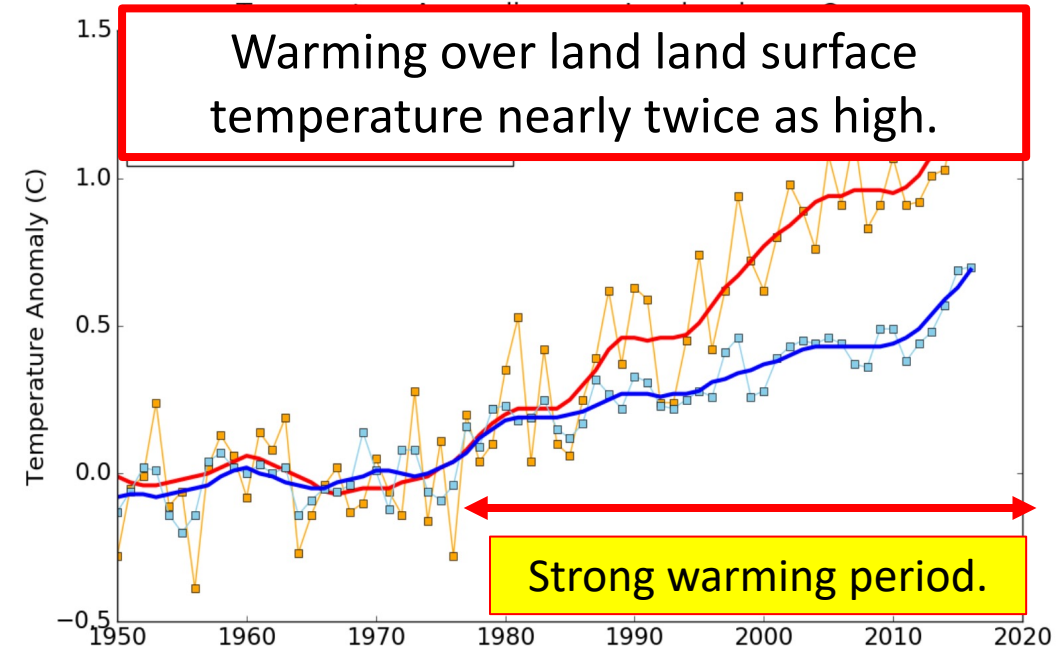
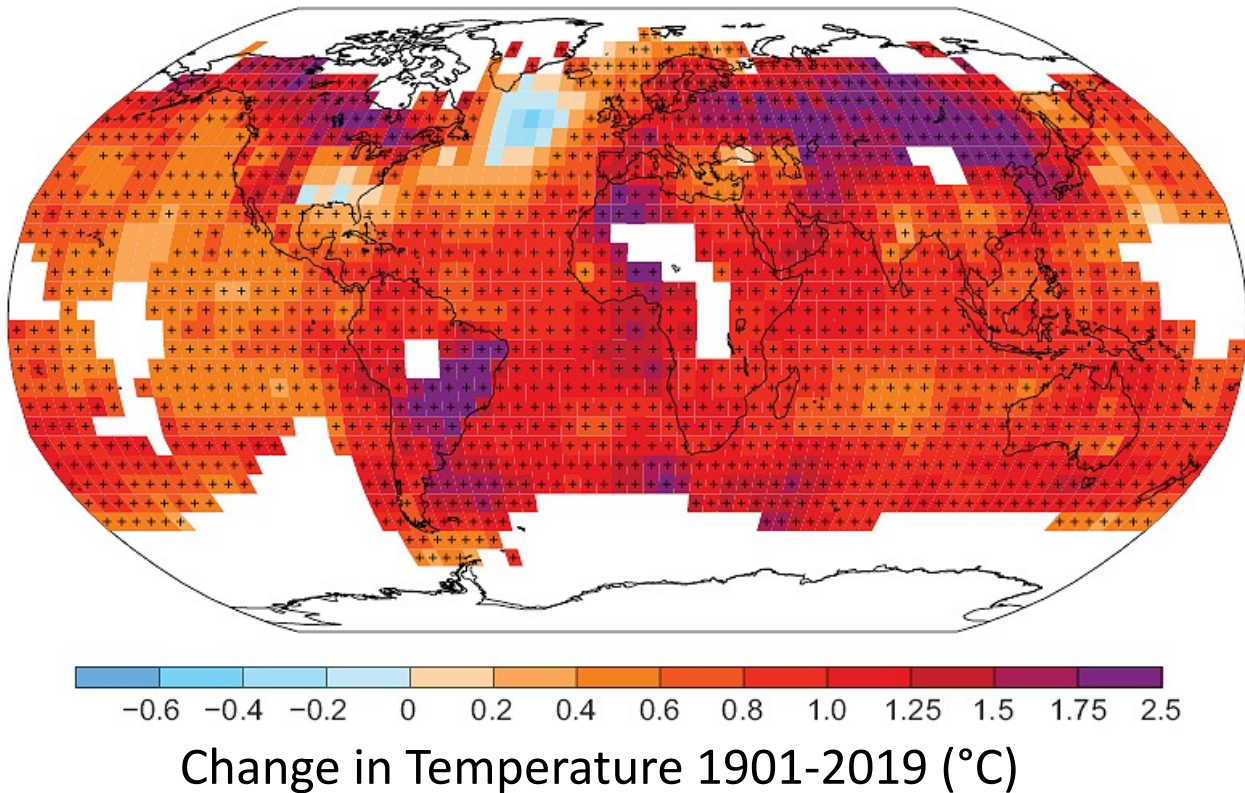
Evolution of Atmospheric Concentrations of GHGs.

• Evolution since preindustrial times (1850 - 2022):

- CO₂ 280 - 417 ppmv (climate forcing factor 1): fossil fuels, biomass burning
- CH₄ 730 - 1.912 ppbv (factor 25): agriculture, gas and oil exploration
- N₂O 270 - 336 ppbv (factor 30): fertilisers, fossil fuels

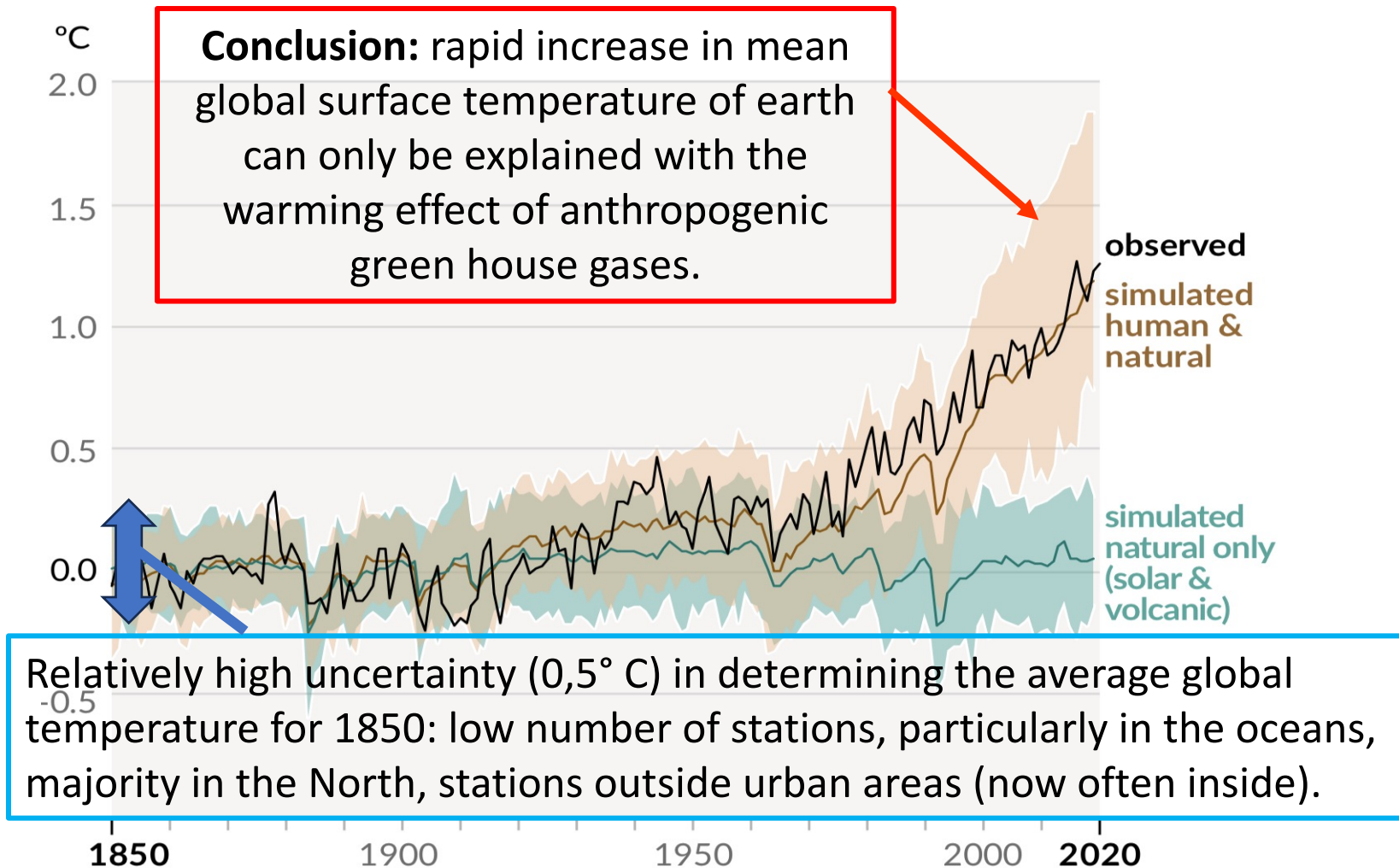
- Rise of the GHG-concentrations 2% per year.
- GHGs have strongly enhanced the natural warming and led to an overall increase of the global mean air temperature by 1.1°C [0.8–1.3].

1850 - 2022 CO₂eq: 280 - 508 ppmv (weighted sum)



Source: IPCC, NOAA (2023)

Natural and Anthropogenic Components of Global Warming.



- **Possible other influences of seasonal temperatures and anomalies:**

- Historical cold periods – Little Ice Age in Flanders.
- Regional heat waves in summers 2023 and 2024.
- Regional warm periods in winter months.
- El Nino?
- La Nina?
- Albedo changes?
- Submarine volcanoes?
- Changes in solar activity?

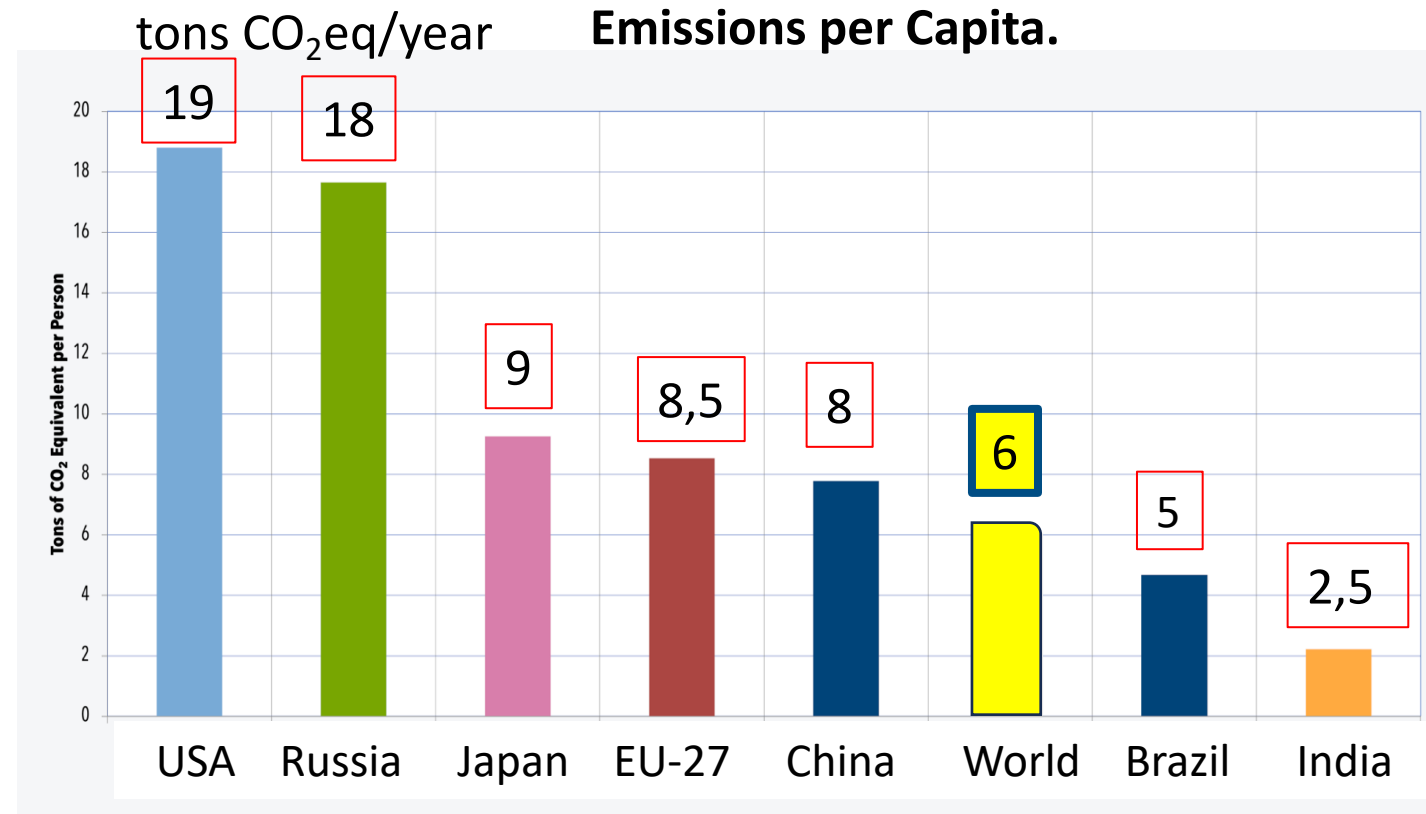
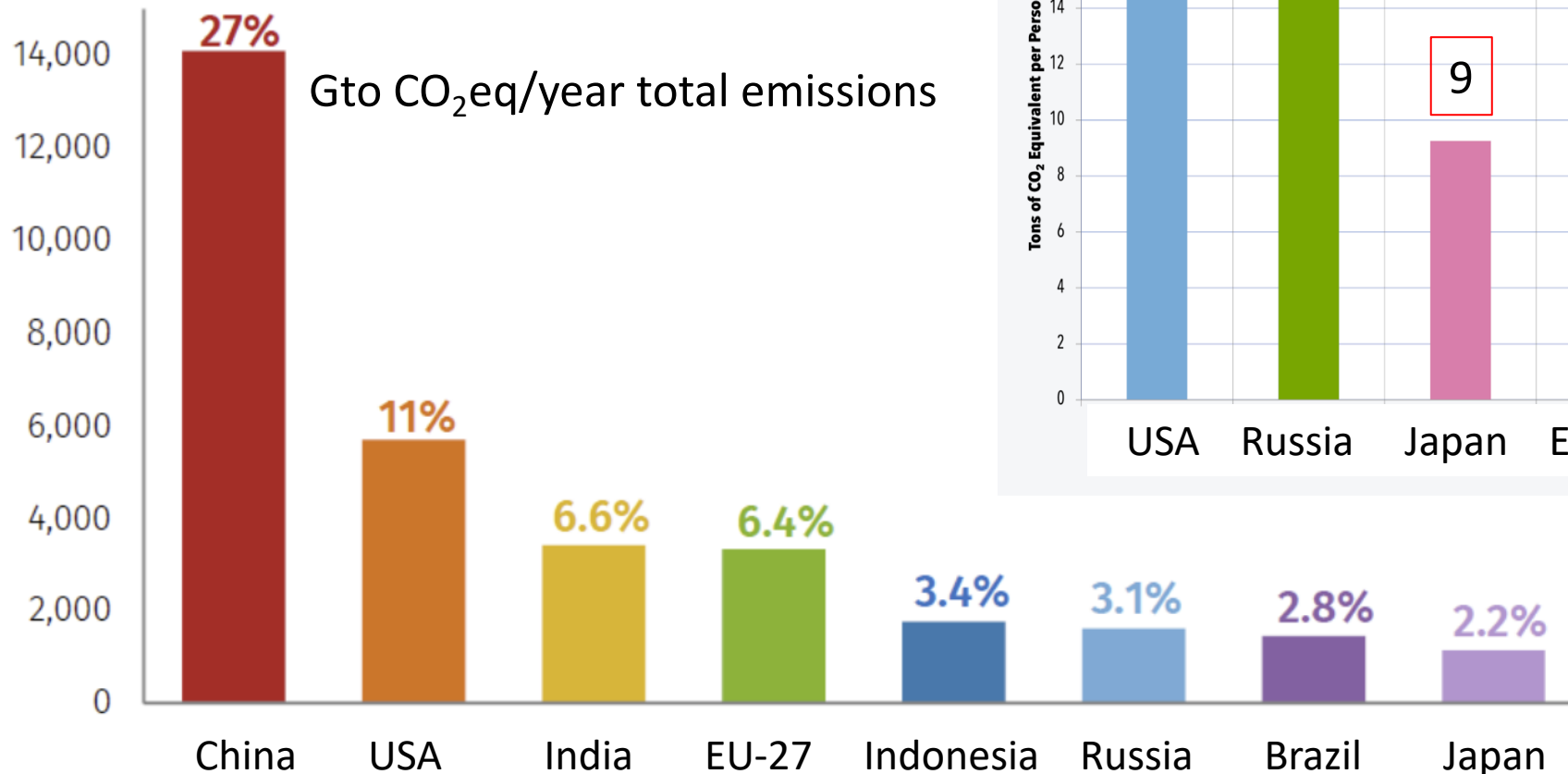
IPCC AR6: „It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.“

Source: IPCC AR6 (2023)

Global Green House Gas Data 2019.

Total global emissions:
36 Gto CO₂/year
50 Gto CO₂eq/year

Emissions per Country/Region and Share.

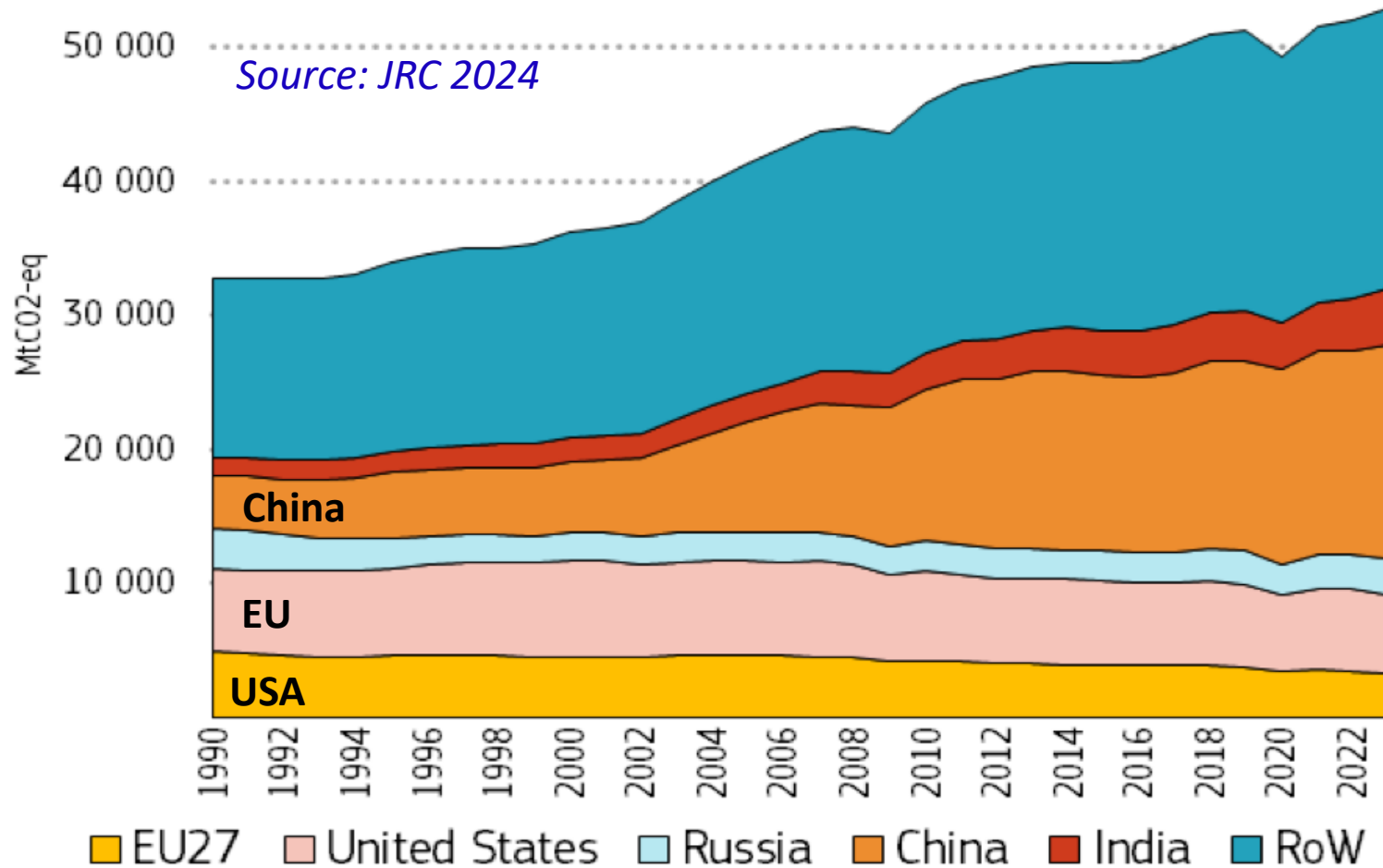


Note: figures vary somewhat from data source to data source due to different calculation approaches, e.g. China 27 - 30%, USA 11 - 15%, EU 6,4 - 8%.

Trends in Global GHG (CO₂eq) Emissions 1990 - 2023.

Emissions EU are 3,25 Gto/yr = 6,1% of global emissions.
37% decrease of emissions in EU from 1990 till 2023.

Source: JRC 2024

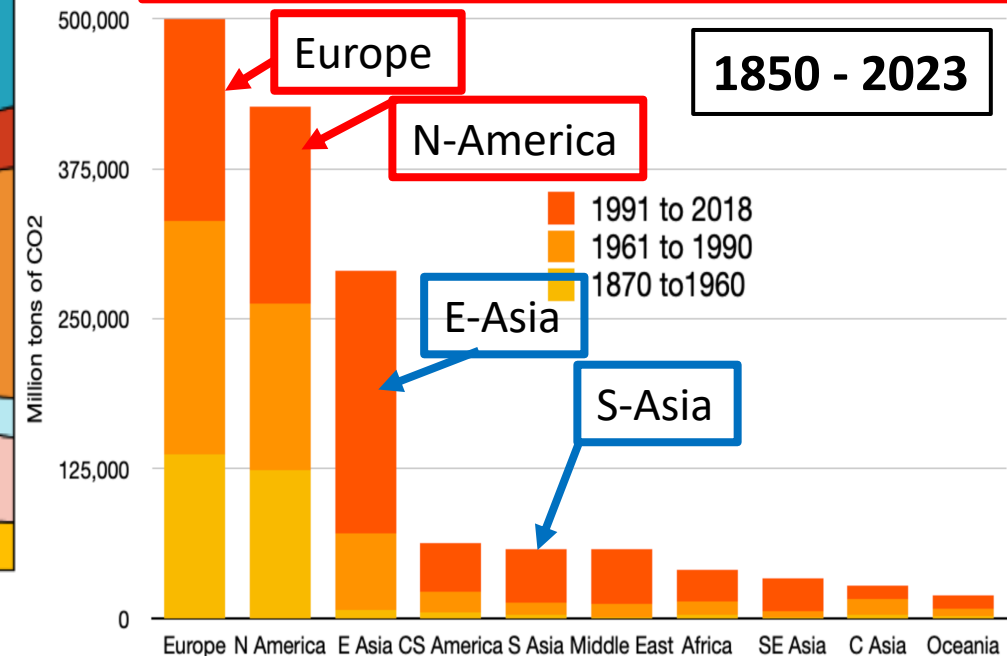


Causes for reduction of EU CO₂ emissions: restructuring of CEE, deindustrialisation, economic crisis of 2009, mitigation measures.

Global total emissions in 2023:
53 Gto.

Annual increase: + 1-2%
China, India: + 5%

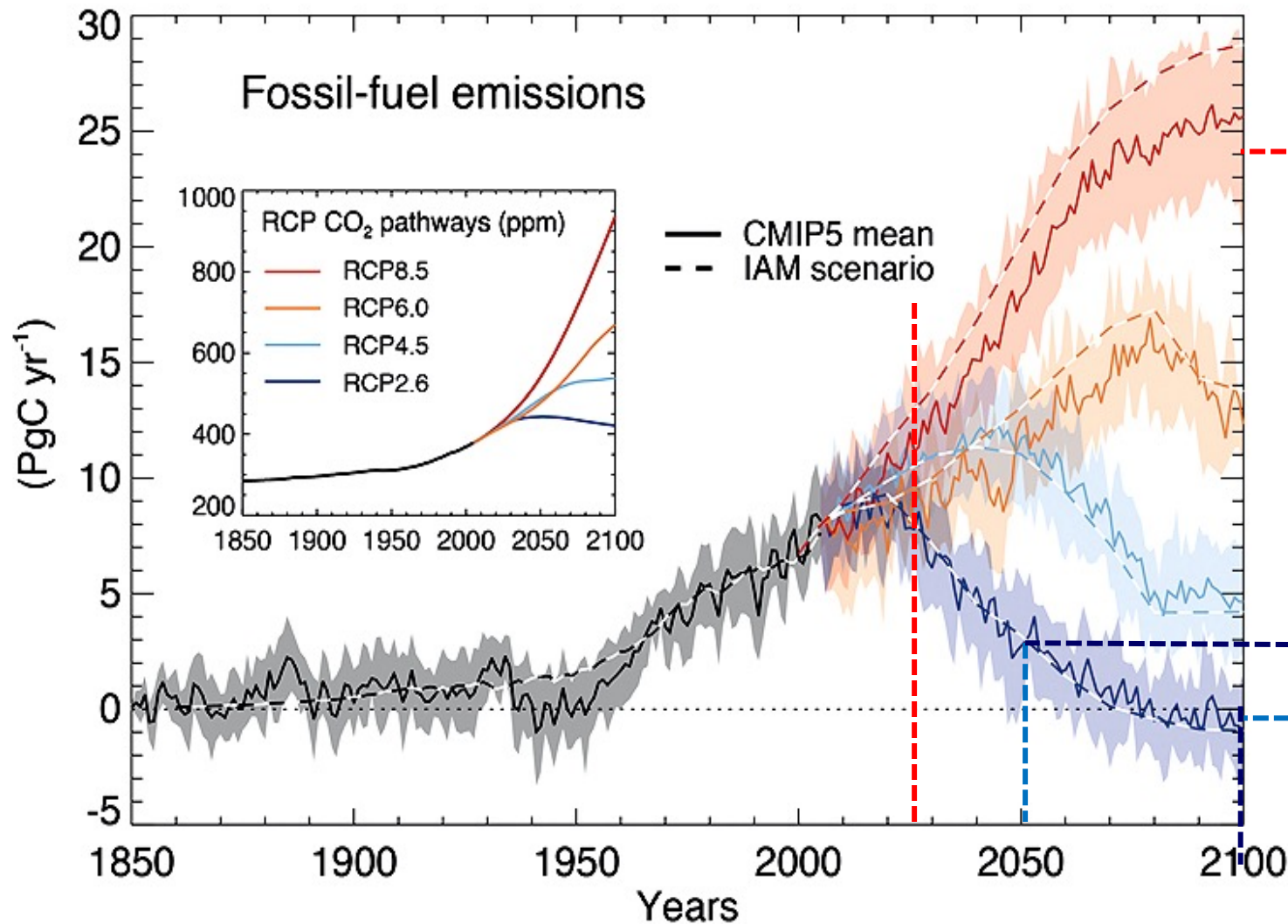
Cumulative CO₂-emissions by regions.



Industrialised regions (Europe, N-America) have emitted roughly 3x the amount of the emerging and developing economies.

The Evolution of GLOBAL Fossil Fuel Emissions.

IPCC Scenarios for 2100:



“Business as Usual”:

Doubling of annual CO₂ emissions till 2100 mainly due to rising global energy consumption.

- **RCP 8,5:**
 - Excess energy is 8,5 W/m²
 - Overall temperature increase 4,7°C.

“Stabilisation Scenario”:

Annual CO₂ emissions strongly reduced dropping to 50% by 2050 and zero by 2100.

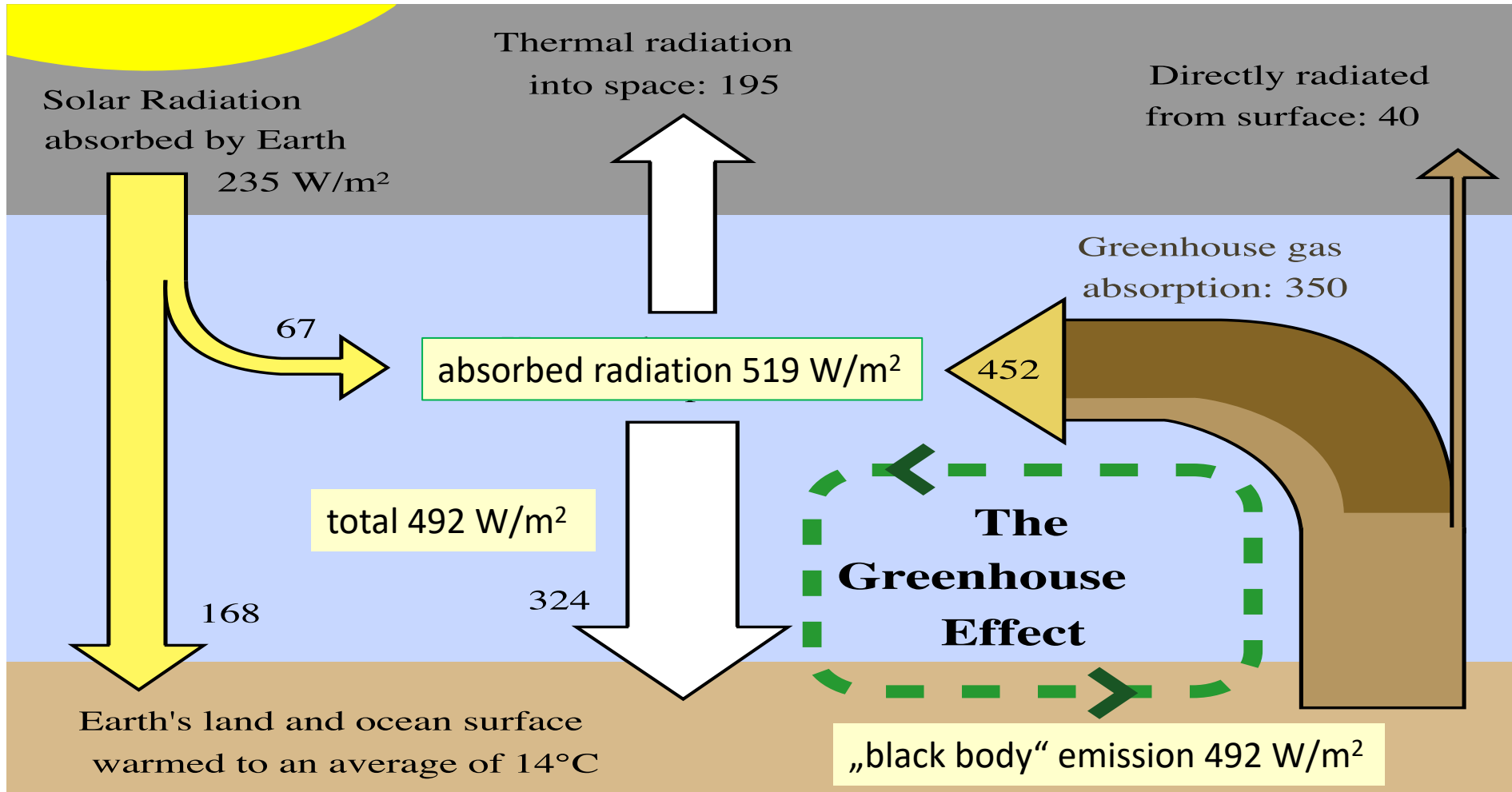
- **RCP 2,6:**
 - Excess energy is 2,6 W/m²
 - Overall temperature increase 2°C.

RCP = Representative Concentration Pathway

Conversion carbon to CO₂: PgCx44/12; 1 Pg = 10¹⁵ g = 10¹² kg = 1 Gto.

Source: IPCC AR5 (2013)

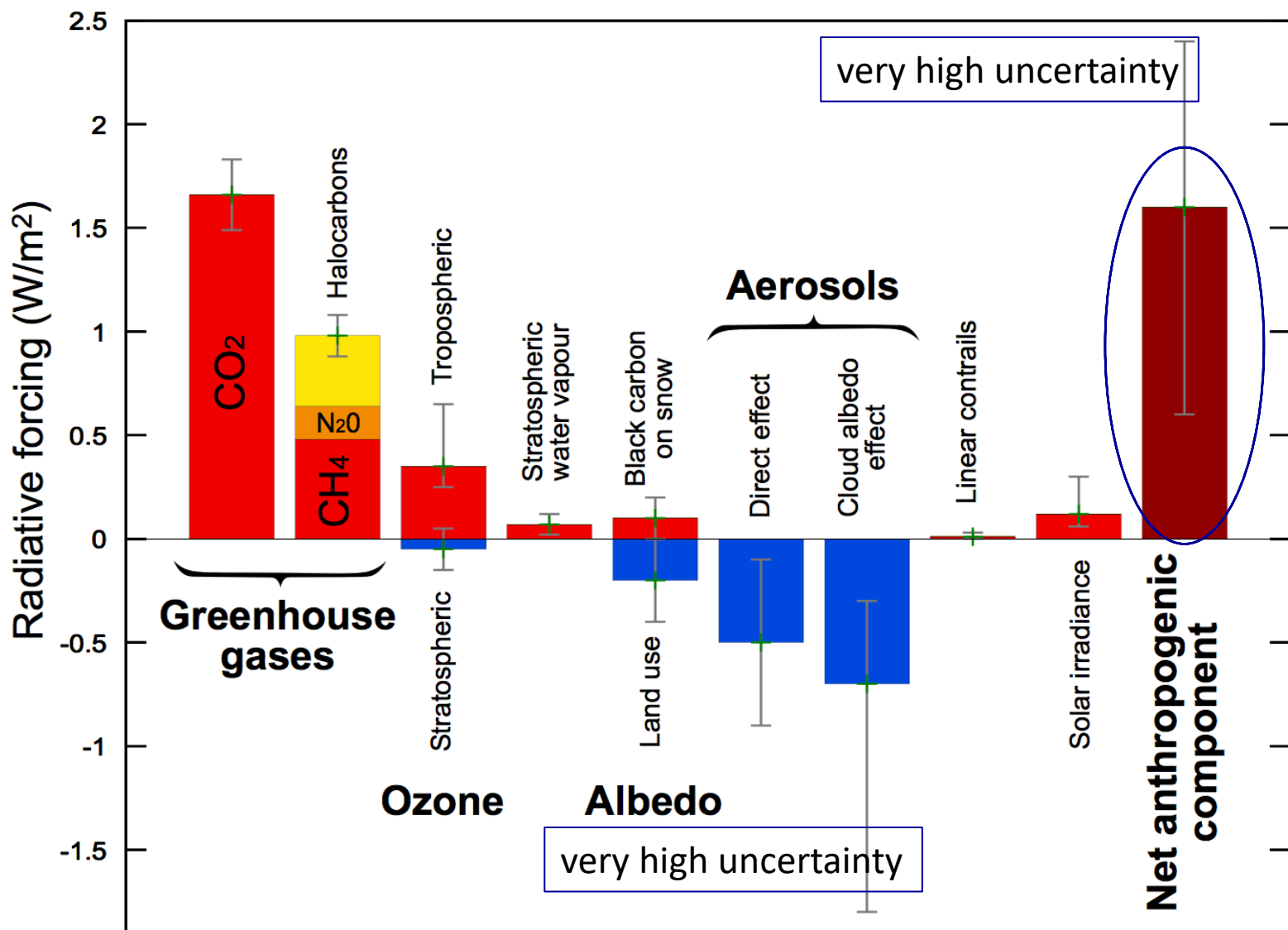
Impact of GHG in Atmosphere on Temperature: Radiation Transfer Processes.



- **GHG effects:**
 - H_2O conc. 10.000 ppm, share in warming 70%.
 - CO_2 conc. 400 ppm, share in warming 20%.
 - Others conc. 2 ppm, share in warming 10%.
 - T_{surface} without effect of GHGs would be minus 18°C .

Earth absorbs radiation from the sun. Absorbed radiation is re-emitted as „black body“ radiation in IR range. GHGs absorb IR radiation and re-emit a fraction back to the land surface causing warming of the surface.

Radiative Forcing Components of Anthropogenic GHGs.

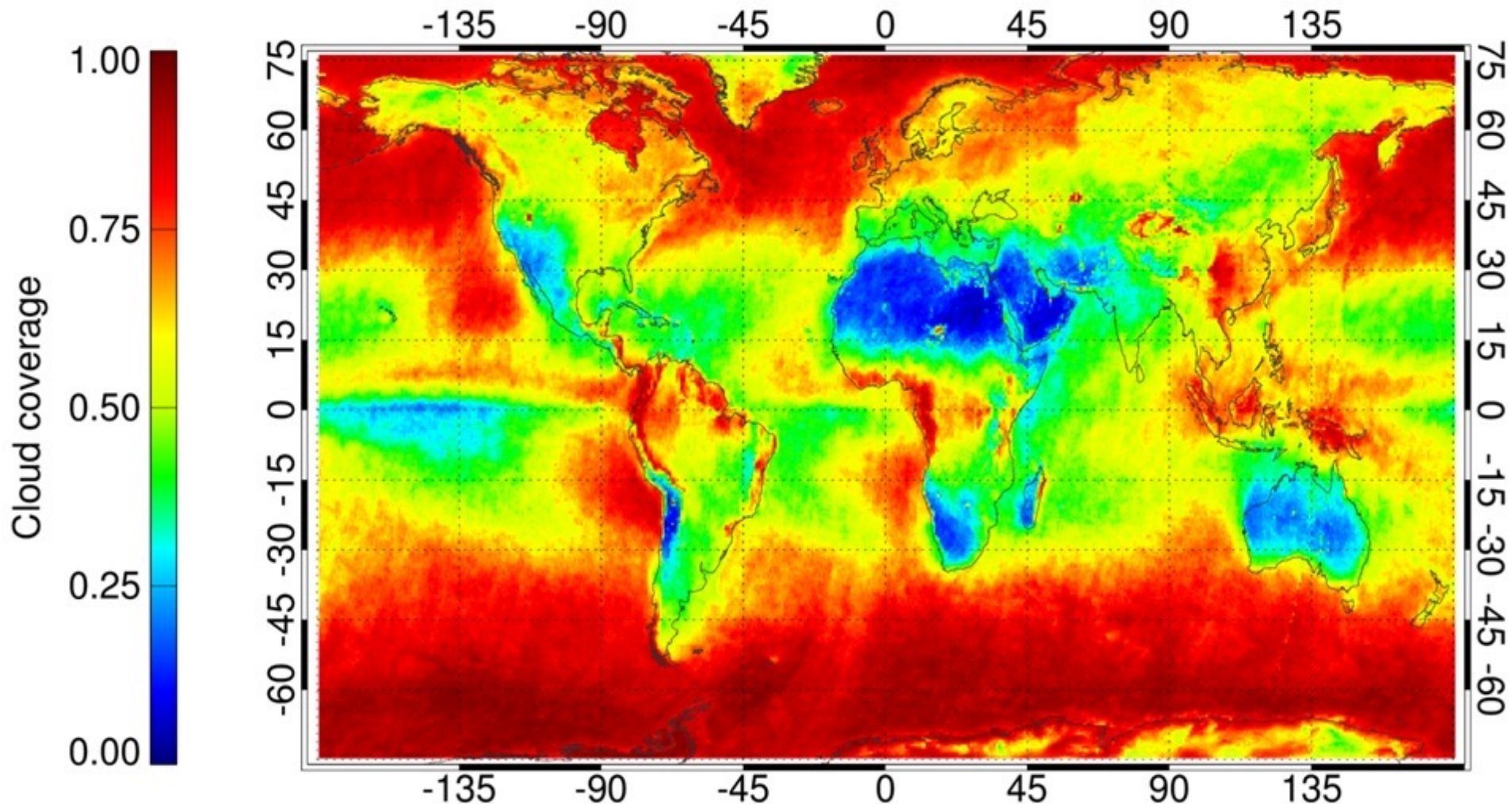


- **GHGs with warming effect:**
 - carbon dioxide (65%)
 - methane (16%)
 - tropospheric ozone (10%)
 - dinitrogen oxide (6%),
 - halocarbons (1%)
 - black carbon on snow fields (2%)
- Percentages relate to the share in warming.*
- **Components with cooling effect:**
 - stratospheric ozone
 - aerosols
 - cloud albedo

Net radiative forcing + 27% from 2002-2018 = 2% per year, mainly due to CO₂

Cooling Effect of Clouds.

Global annual mean cloud cover derived from three years (2007–09) of Envisat data.



The map shows areas with little to no cloud coverage (blue) as well as areas that are almost always cloudy (red).

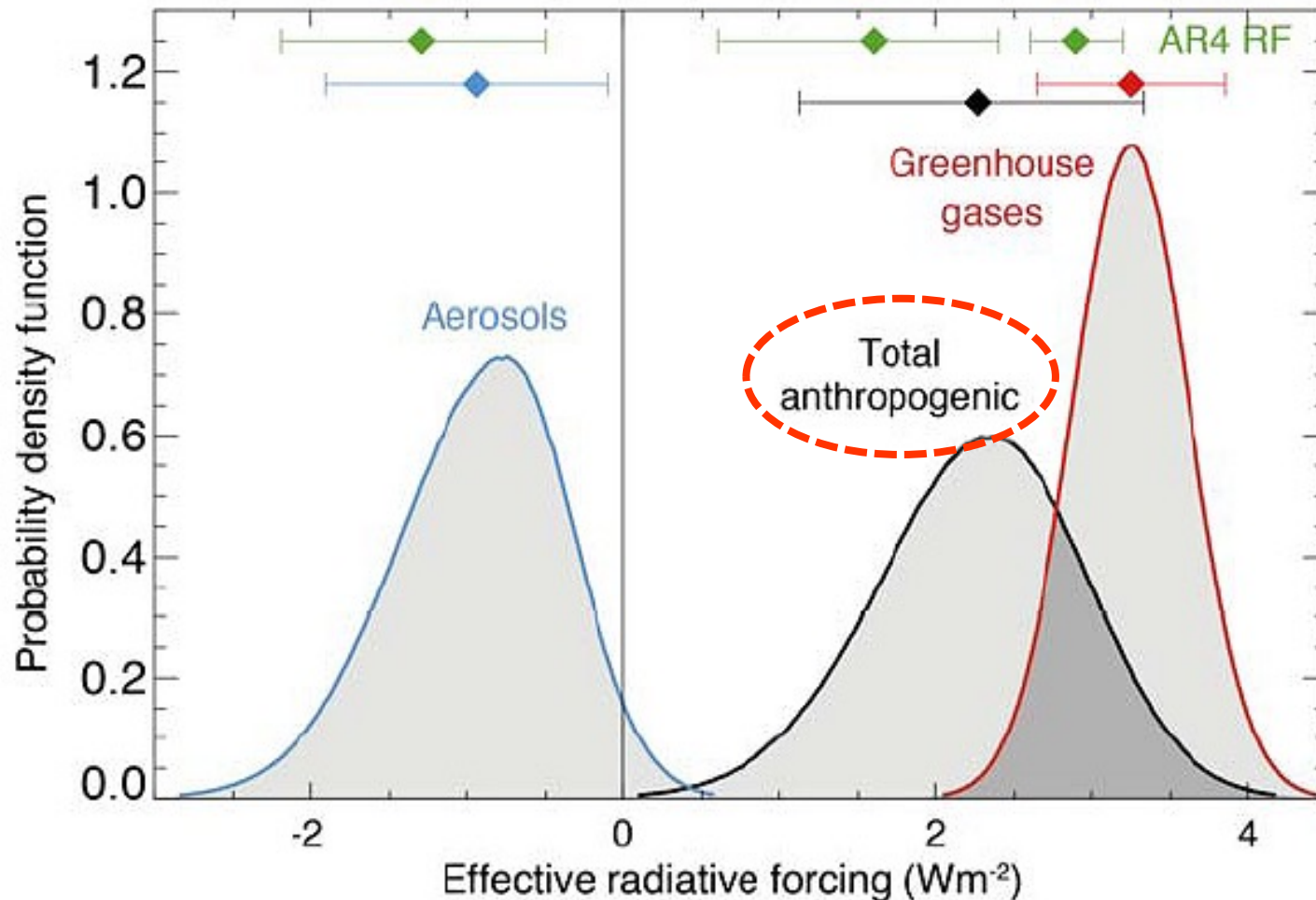
Very inhomogeneous distribution.

High uncertainty in calculating the cooling effect.

Source: ESA 2013

Effective Radiative Forcing (ERF) of GHGs.

Source: IPCC AR5 (2013) and AR6 (2023)



Total anthropogenic RF increasing:

2013:

1,1- 3,3 W m^{-2}

2019:

1,96 - 3,48 W m^{-2}

2050:

3.0 - 4.8 W m^{-2}

2100:

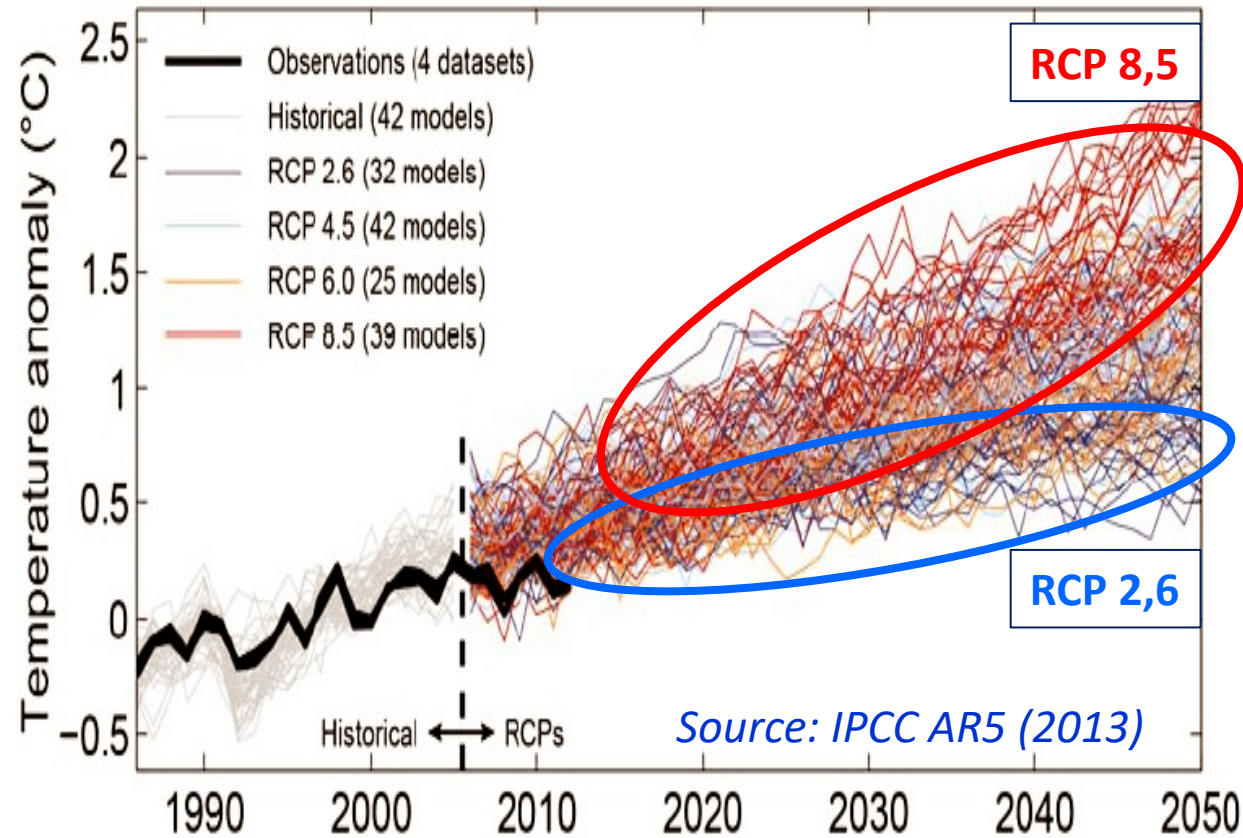
4.7 - 8.4 W m^{-2} .

**Trend clear,
but high uncertainties!**

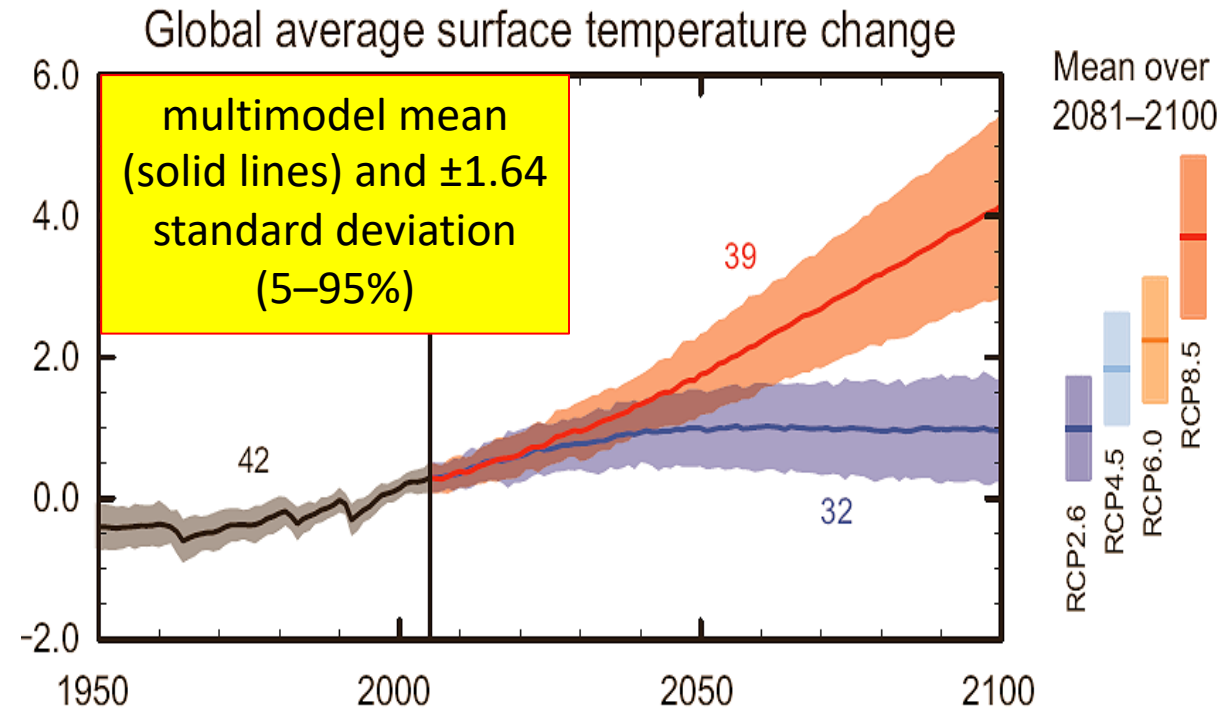
Probability Density Functions for the ERF, for the aerosol, well-mixed greenhouse gas (WMGHG) and total. The green lines show the AR4 RF 90% confidence intervals and can be compared with the red, blue and black lines which show the AR5 ERF 90% confidence intervals (uncertainties increased!).

Modelling Temperature Evolution till 2050.

- For conversion of atmospheric GHG concentrations into a climate forcing effect (air temperature increase) many different models are used.



Significant uncertainty in the prediction even for the same scenario due to complexity of the warming and cooling processes. Therefore rather low accuracy of the models to convert GHG concentrations into temperature changes.



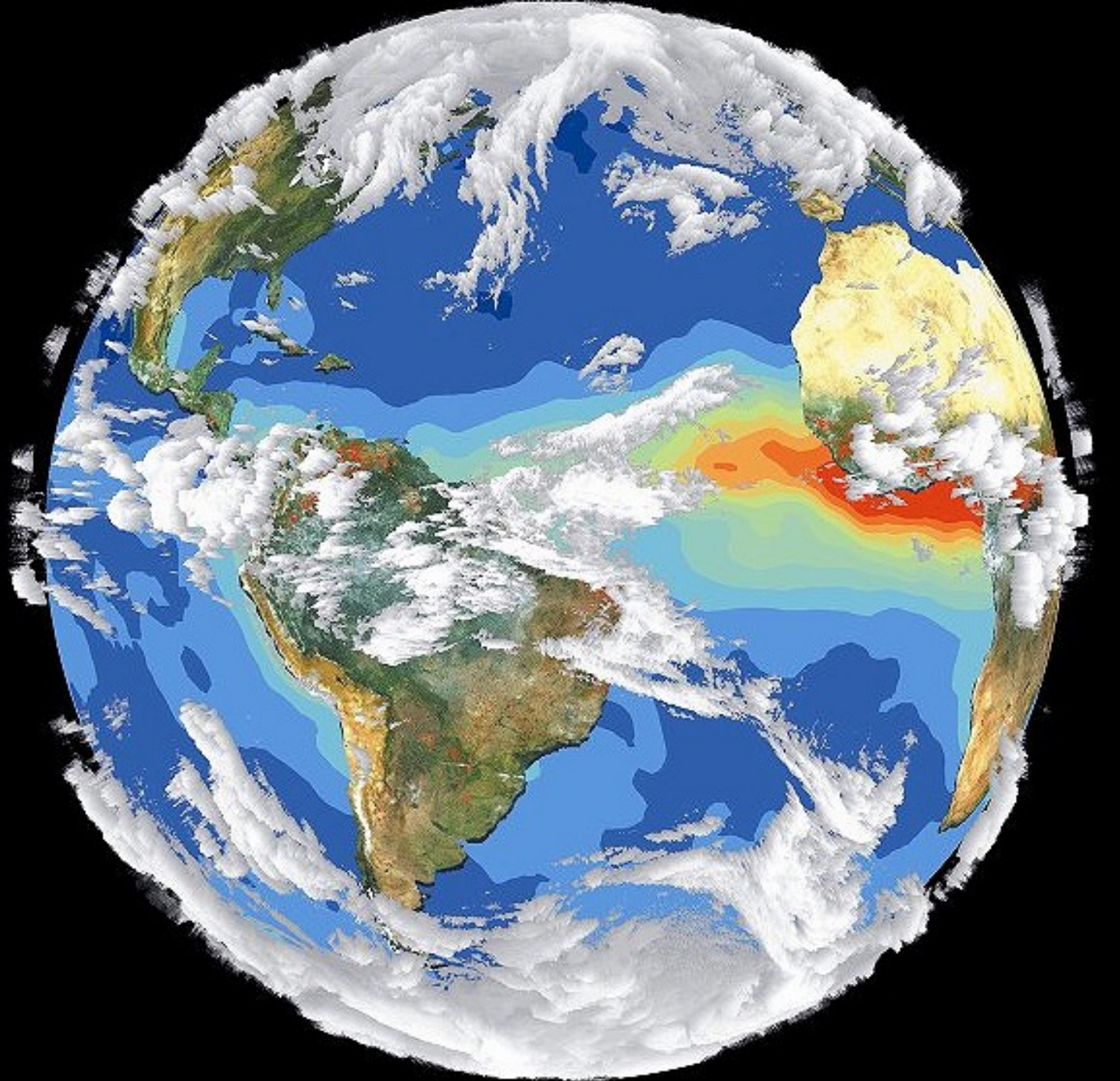
RCP 8,5 (BAU):

Overall* temperature increase
4,7°C (range 3,6 - 5,8°C).

RCP 2,6 (stabilisation of climate):

Overall* temperature increase
2°C (range 1,3 - 2,7°C).

*since
1850



Earth's Interrelated Systems and Climate.

Accurate prediction of global and regional temperature rise extremely difficult due to complexity of the system.

IPCC raised its conviction that man is causing global warming as near to 100% as scientifically responsible.

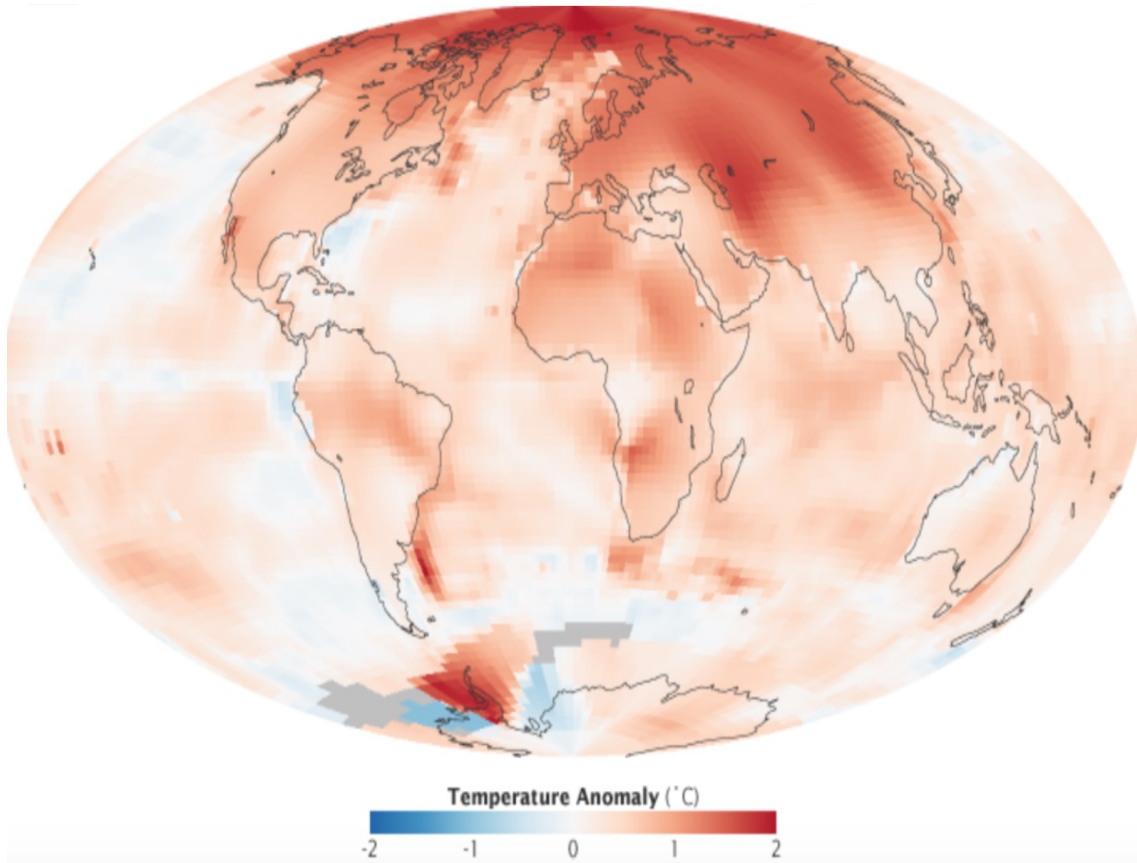
Natural effects possibly leading to global warming are still subject to further scrutiny as many questions are still open.

Source: NASA 2012

Impact of Global Warming on the Environment.

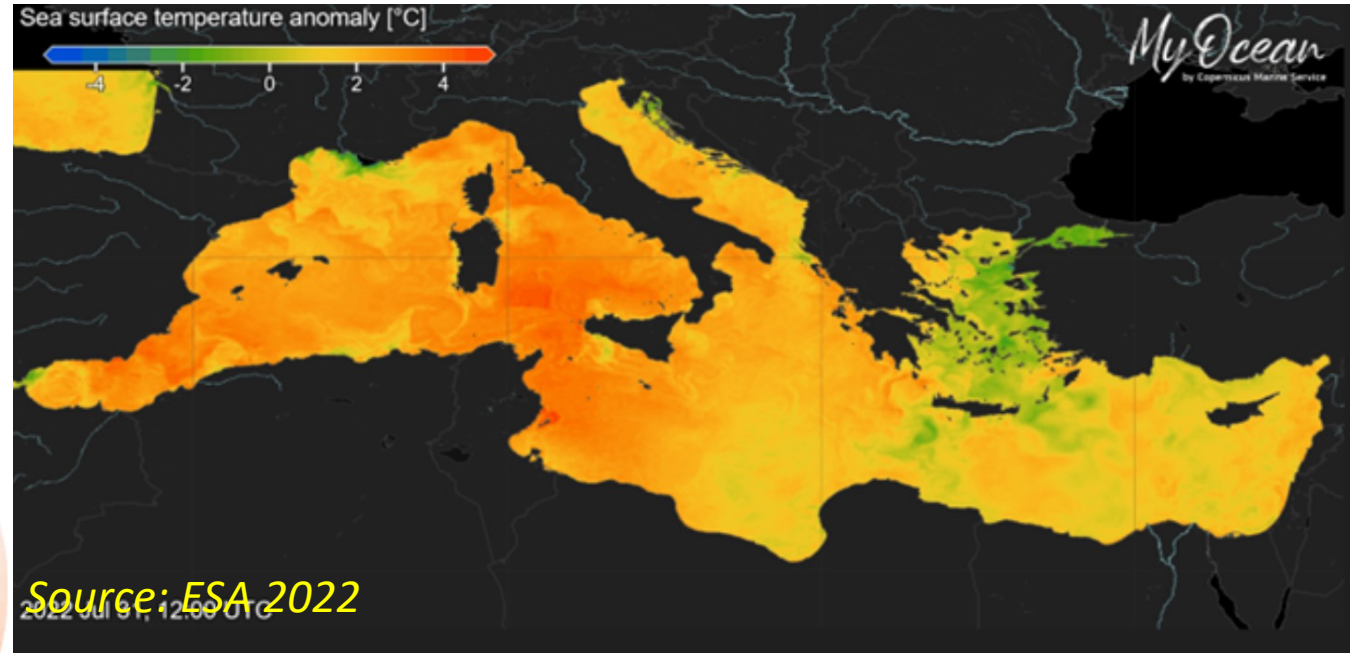
- **Basic issue for Northern hemisphere:**

- Terrestrial warming twice as high as global average plus „Arctic Amplification.“
- Average temperature increase in Austria 2024 = 3,6 °C (compared to 1850).



- **Increased Temperature of European Water Bodies:**

- Mediterranean Sea temperature July 2022 up to +4,6°C.



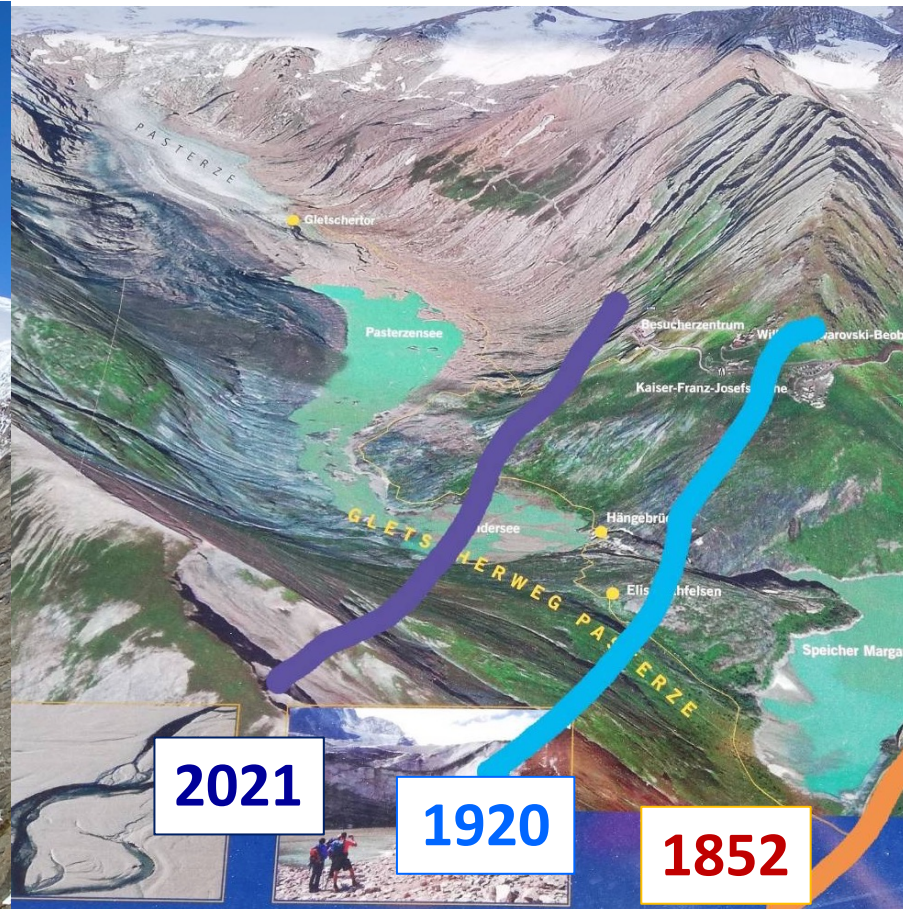
- **Possible consequences:**

- Increased evaporation of Mediterranean and Black Sea leading to higher water content in the air and enhanced precipitation (contributing factor to floods in August 2024).
- Higher temperatures of lakes and rivers affects biodiversity.
- Cooling problems for nuclear power plants.

Impact of Global Warming on the Environment.

- **Strong retreat of Alpine glaciers:**
 - Glacier of Großglockner in Austrian Alps already massively reduced.

Pasterze 8. Oct. 2020



Area of the glaciers in Austria:

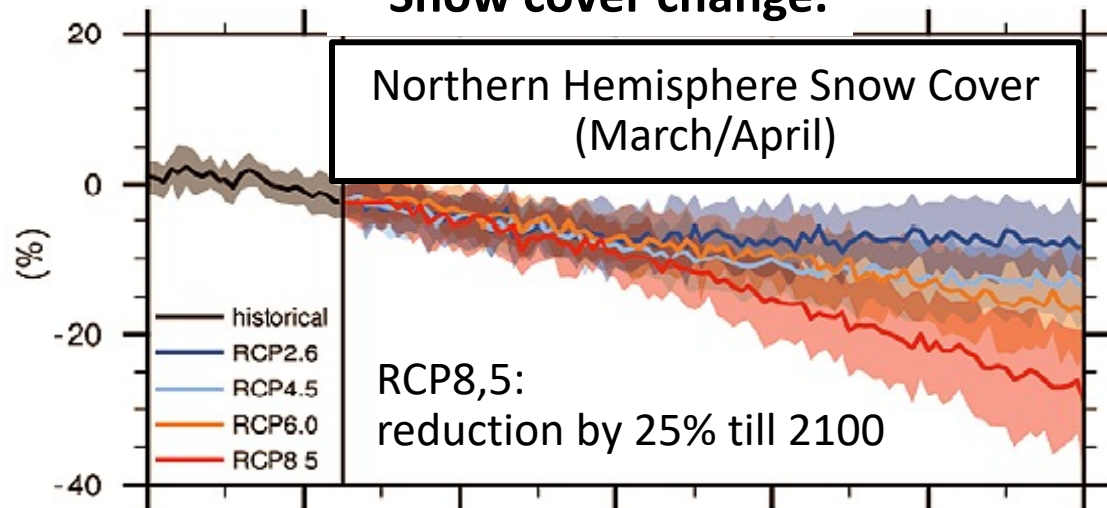
1852:	946 km ²
1920:	759 km ²
1969:	567 km ²
1998:	471 km ²
2010:	415 km ²
2020:	320 km ²
70% lost.	

**IPPC: By 2100, 35 to 85% of the Earth's glaciers will be eliminated under RCP 8,5.
(medium confidence)**

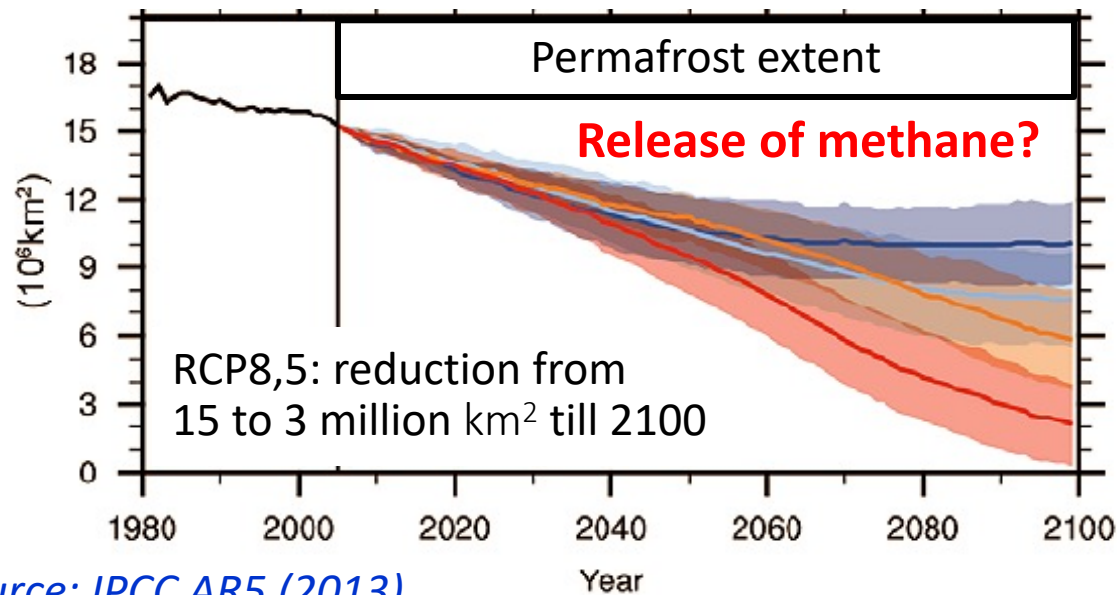
Source:
Nationalpark Hohe
Tauern 2022

Impact of Global Warming on the Environment.

- **Snow cover change.**

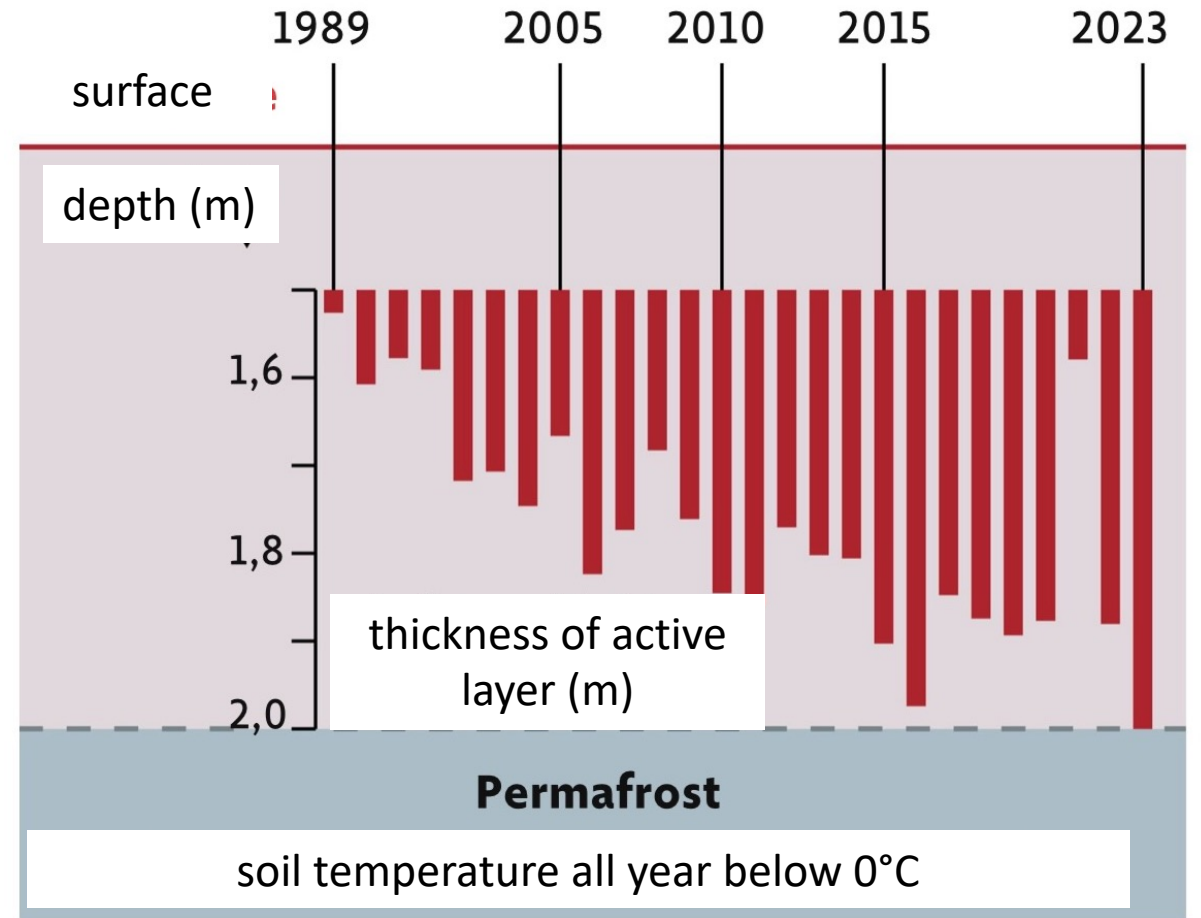


- **Reduction of near surface permafrost area.**



Source: IPCC AR5 (2013)

- **Melting of the permafrost.**

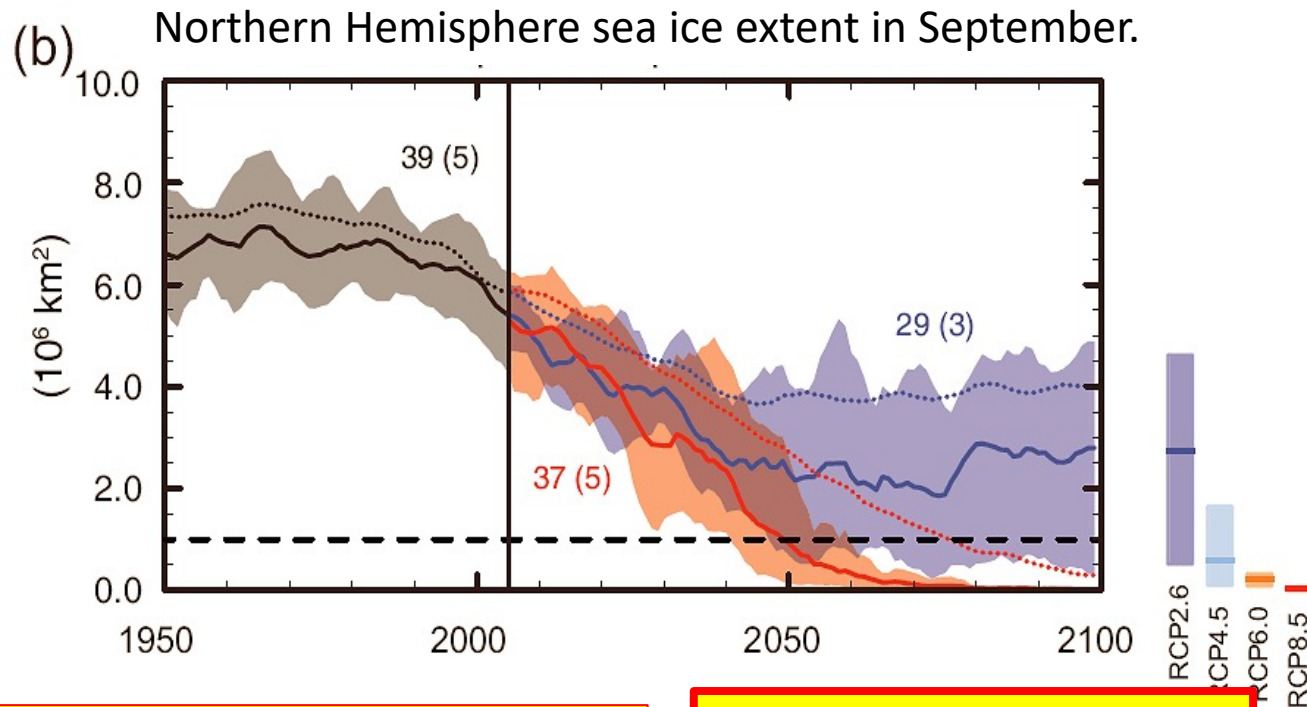


Measurements at Ny Alesund - warming very high:
1,4°C per decade!

Source: Metrological institute of Norway (2023)

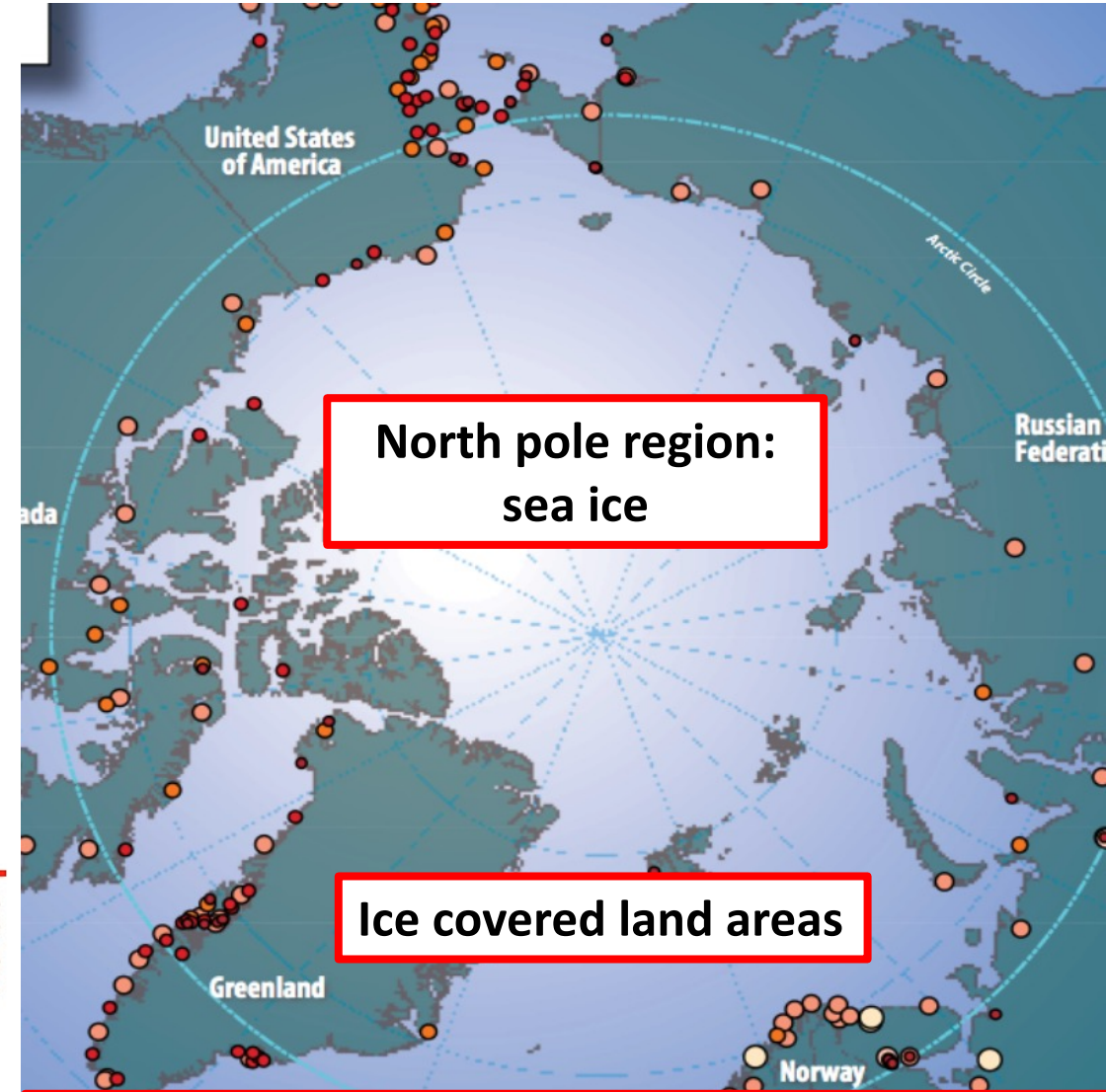
Impact of Global Warming on the Environment.

- **Loss of Arctic ice:**
 - Arctic sea ice: Already 40% lost.
 - Loss of sea and land ice will continue for all scenarios.



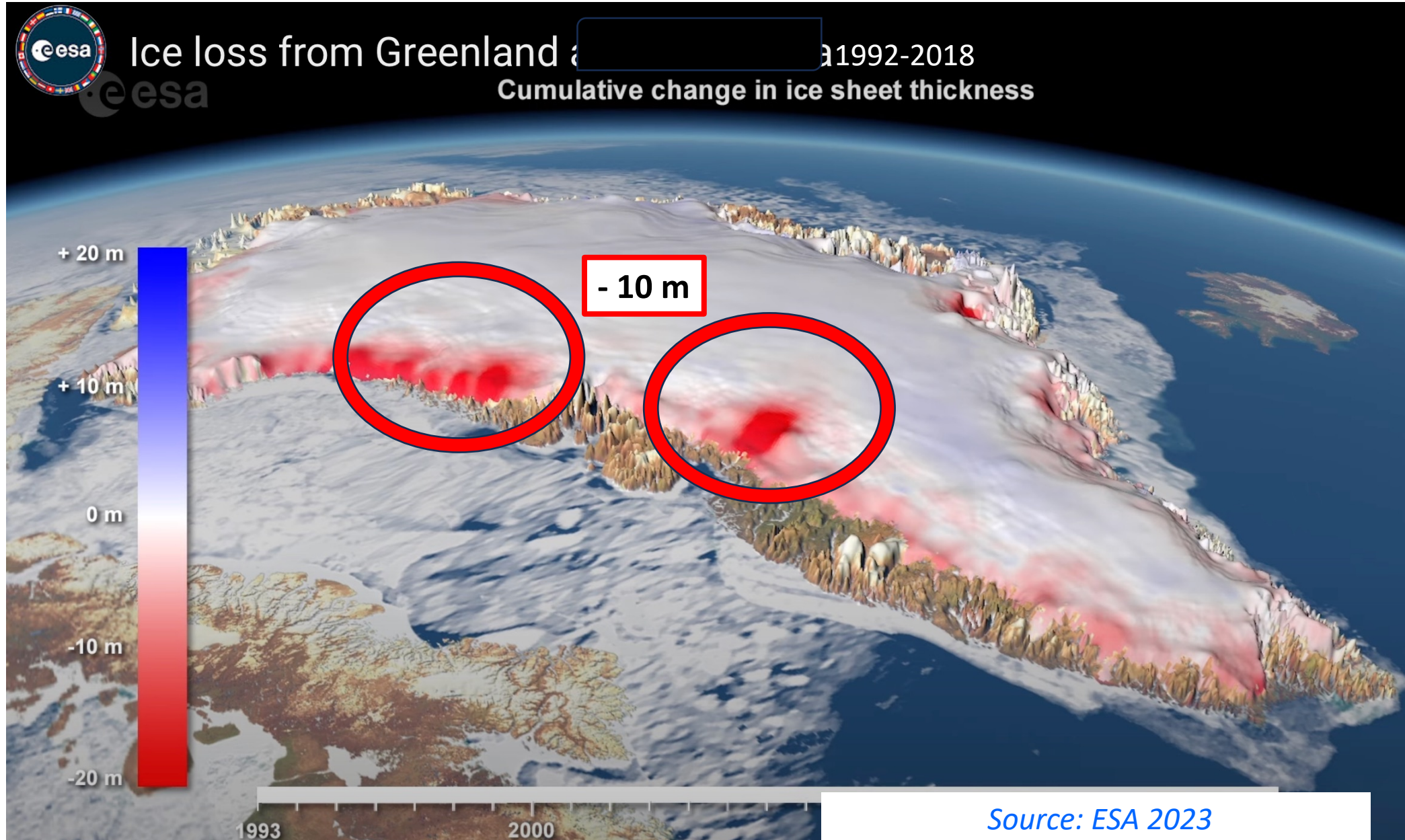
IPPC: By 2080, The Arctic sea ice will be completely gone under RCP 8,5.

**Possible sea level rise till 2100:
40 cm – 80 cm ?
(medium confidence)**



**Millions km^2 ice area affected.
Process is accelerating!**

Impact of Global Warming on the Environment.

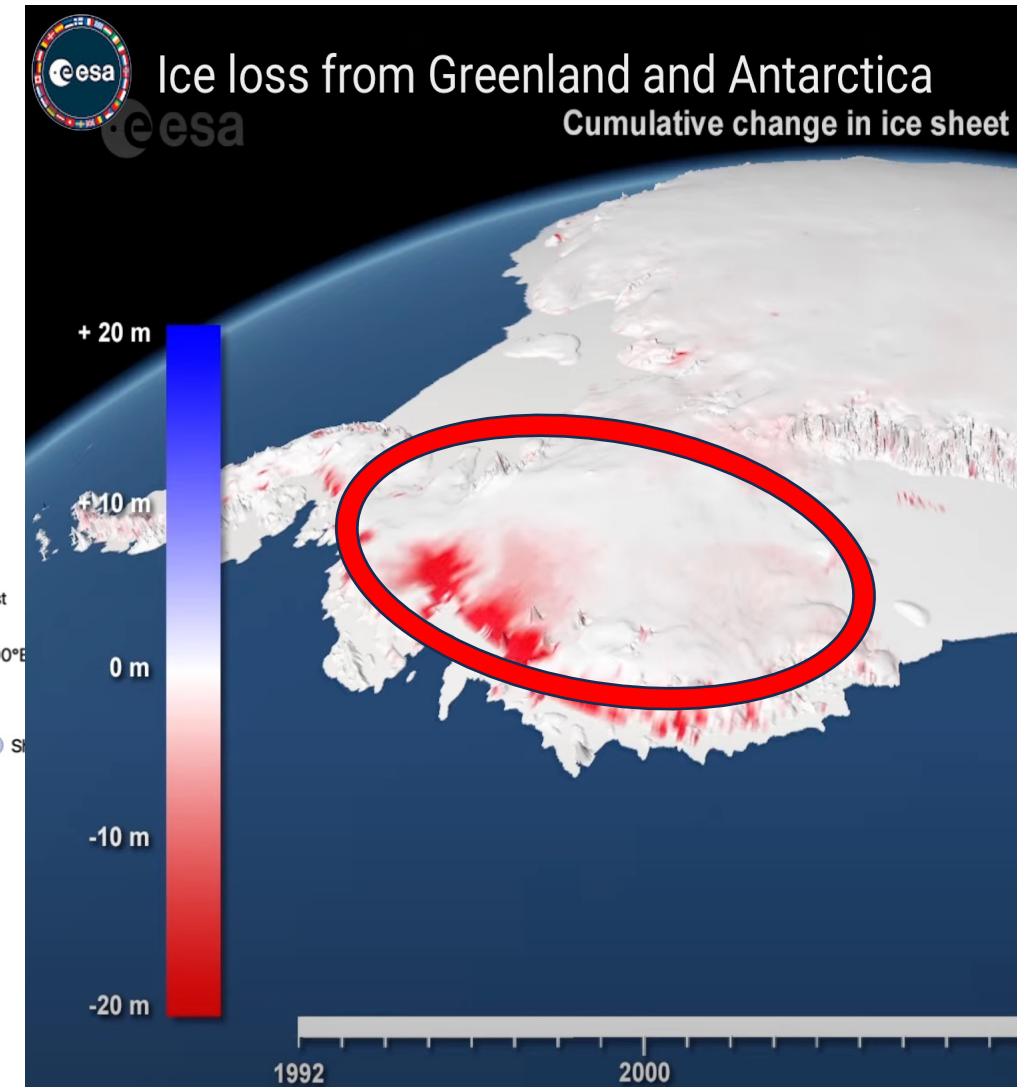
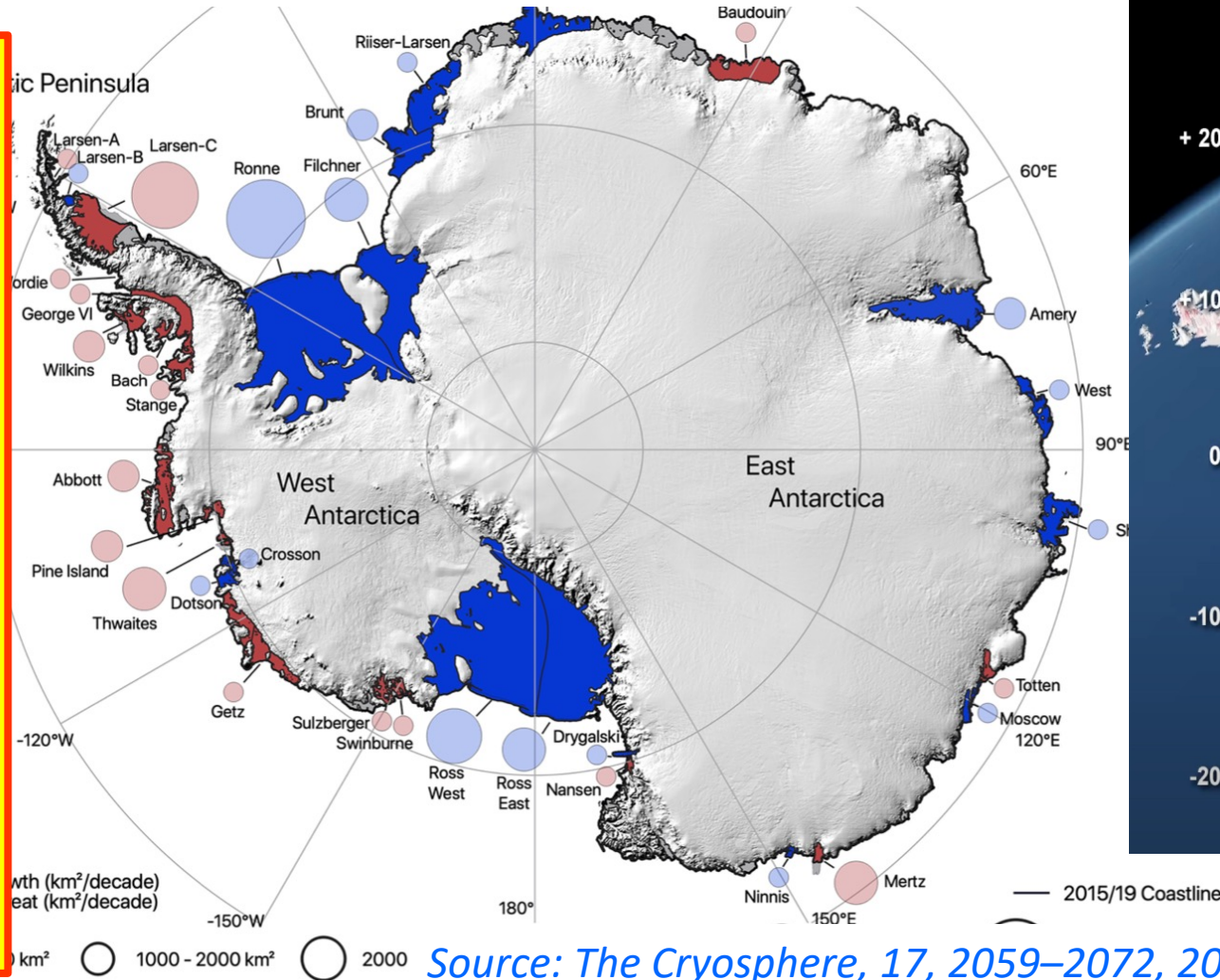


Impact of Global Warming on the Environment.

- **Antarctic ice:**

- Some areas lose ice.
- In other regions the ice area is increasing.

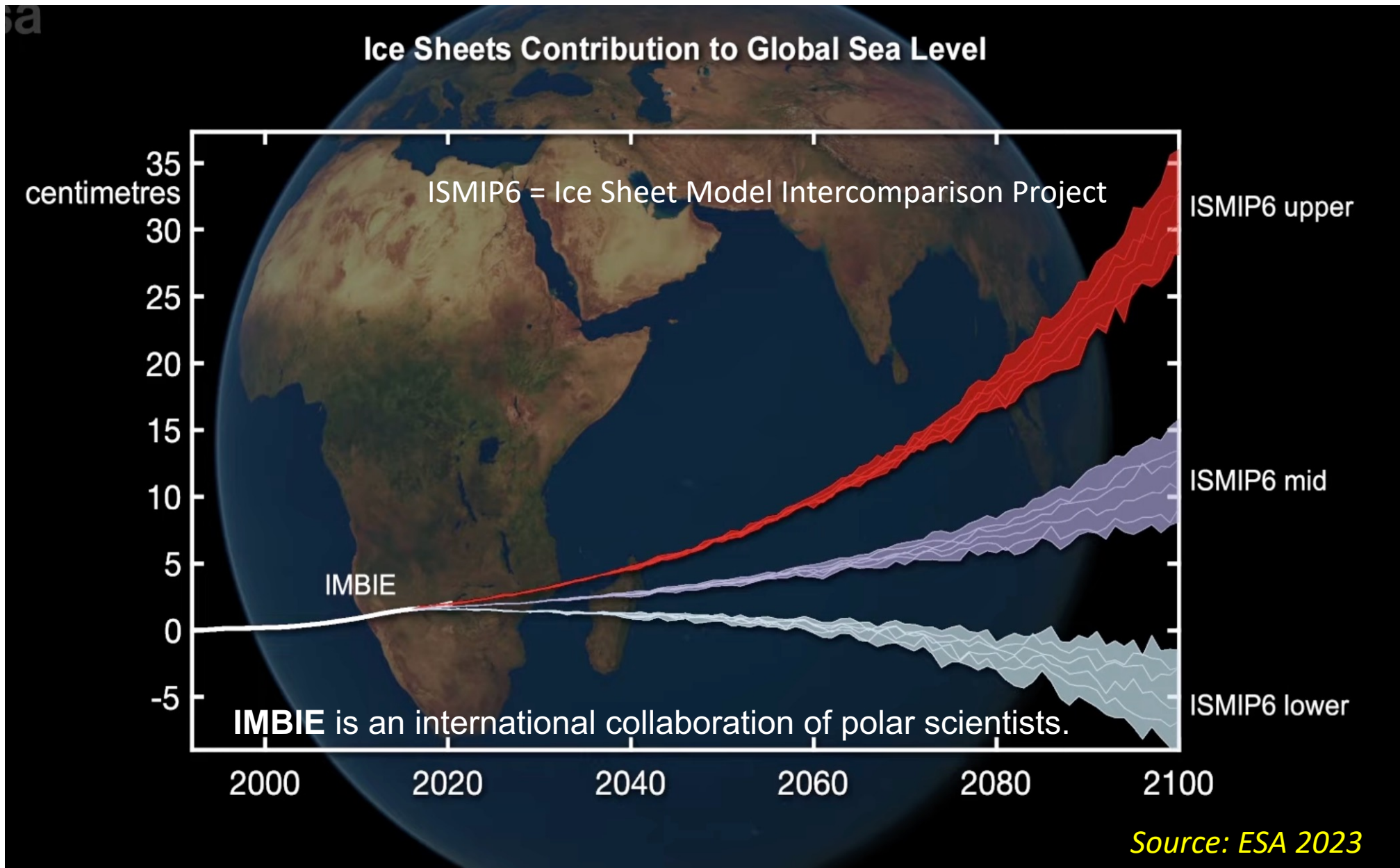
Antarctic ice shelf area has grown by 5.305 km² since 2009, with 18 ice shelves retreating and 16 larger shelves growing in area. 6.611 Gto ice mass gained.



Source: *The Cryosphere*, 17, 2059–2072, 2023

Source: ESA 2023

Possible Sea Level Rise due to Melting of Ice Sheets.



The Ice Sheet Model Intercomparison Project concludes that the maximum sea level rise would be 30 cm by 2100.

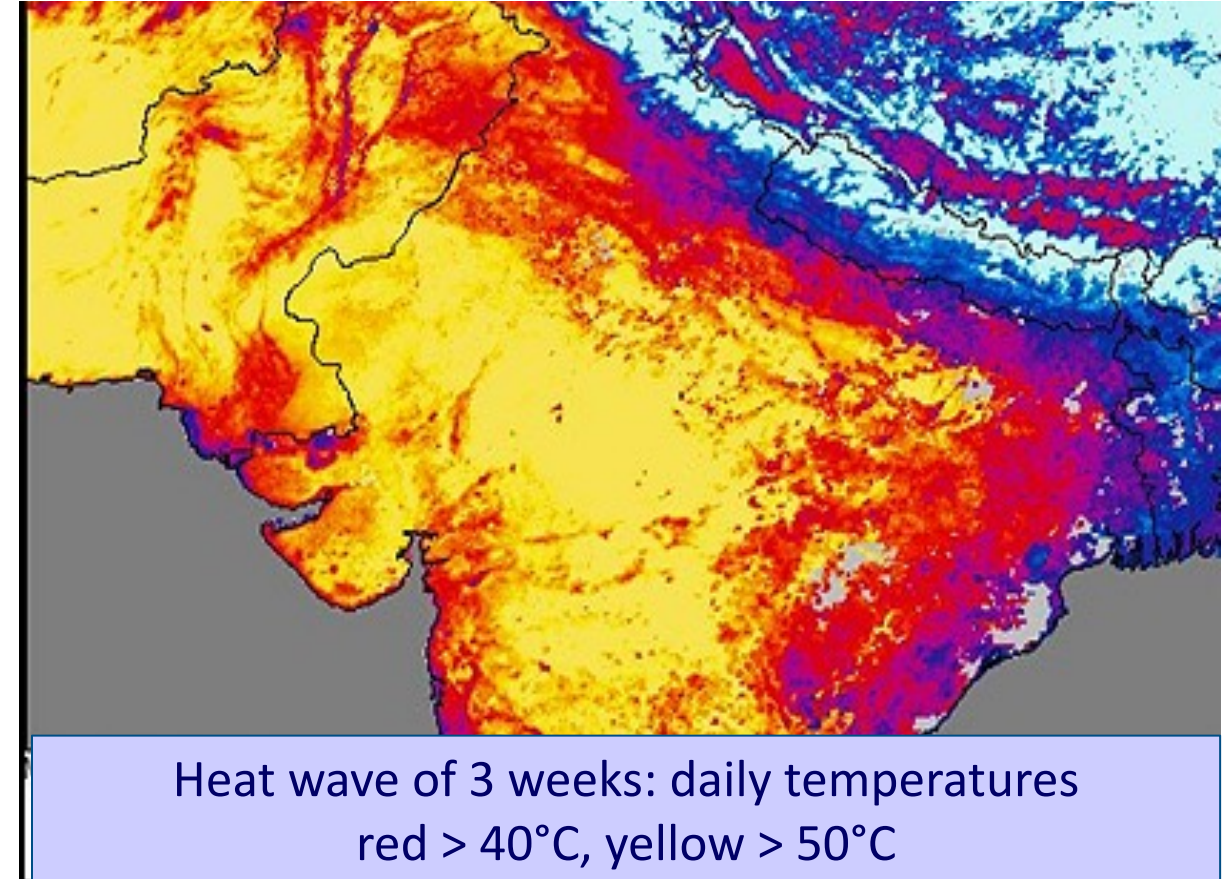
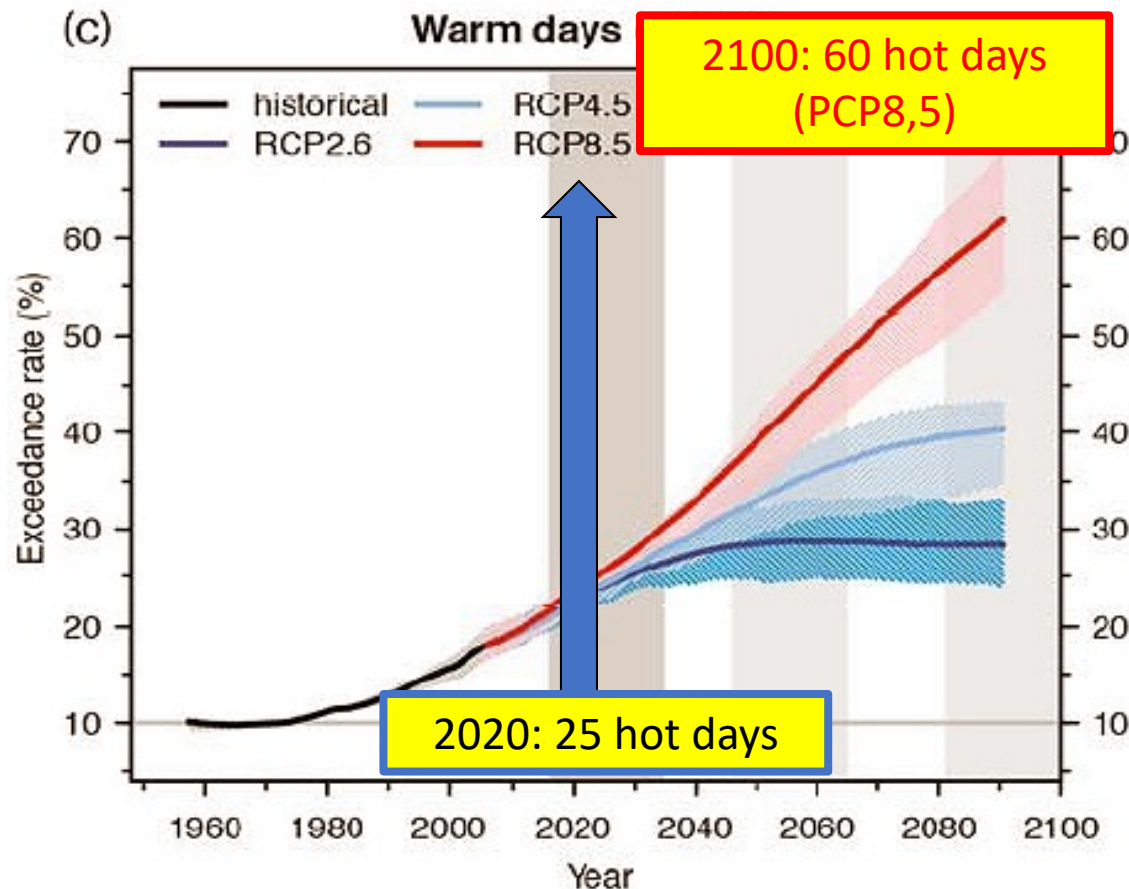
This is substantially less than modelled by the IPCC.

Massive discrepancies exist also in respect to other impact phenomena.

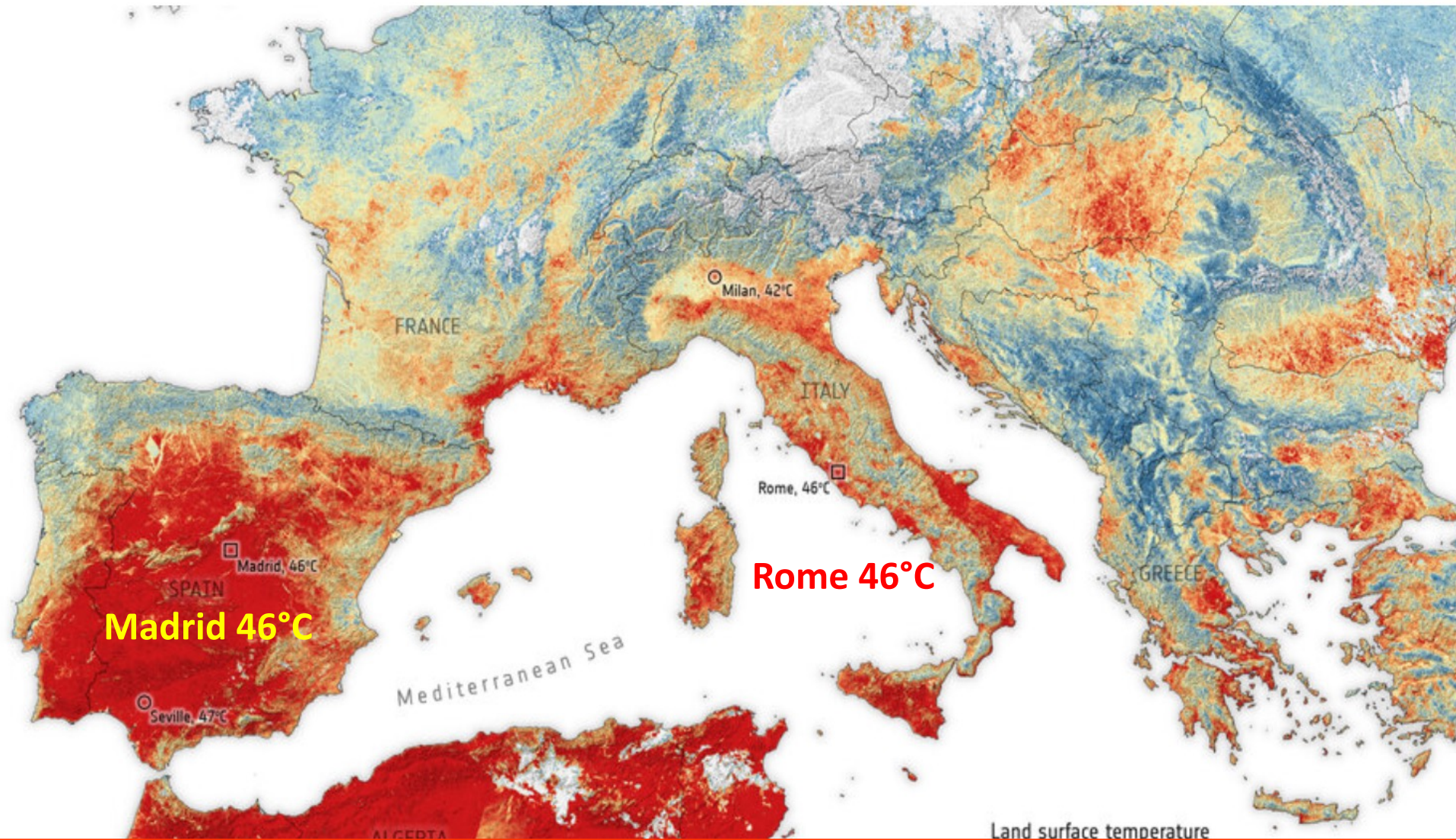
Impact of Global Warming on the Environment.

- **Increasing number of hot days ($T > 30^{\circ}\text{C}$) and intensity of heat waves:**
 - Longer periods of heat: number of hot days ($T > 30^{\circ}\text{C}$) doubling till 2100.
 - Under RCP8.5 the maximum temperature in big cities like Paris, New York could rise by up to 8°C .
 - Massive impact on well being and health of the people exposed.
 - Substantial reduction of agricultural yield.

India June 2005



Impact of Global Warming on the Environment.



Land surface temperatures during heat wave in July 2023 measured with Copernicus Sentinel 3A satellite.

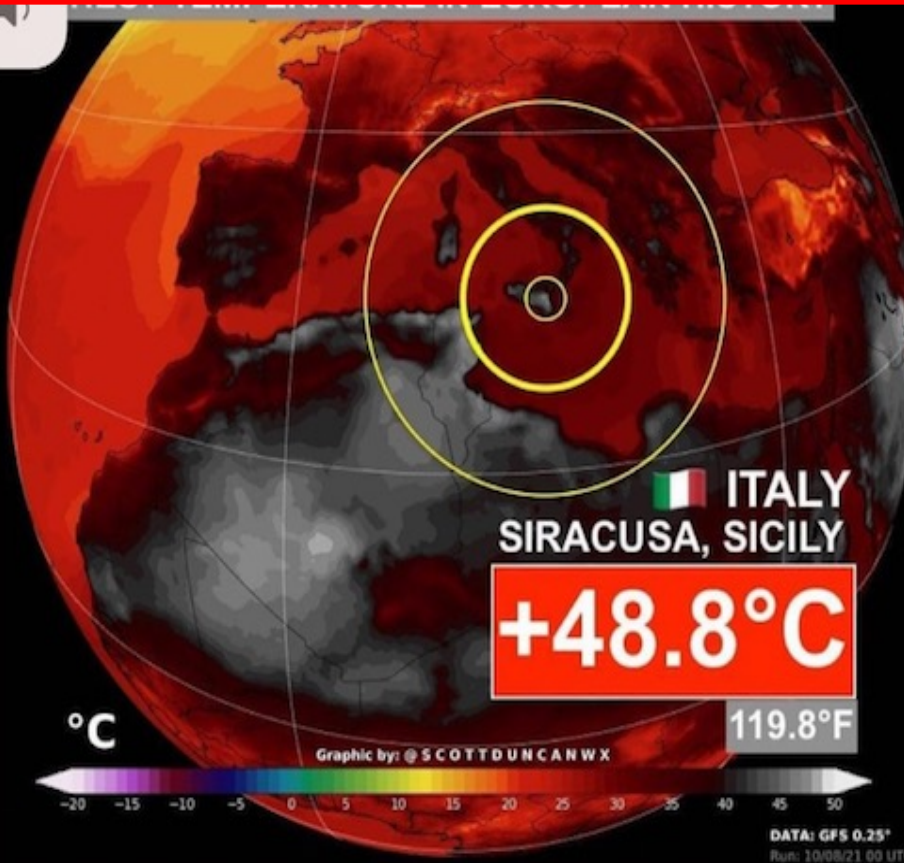
Source: ESA 2023

Land surface temperatures represent the air volume until about 10 cm above ground: usually much higher than meteorological air temperatures measured in shaded stations 2 m above ground level (Rome, Madrid 40°C).

Impact of Global Warming on the Environment.

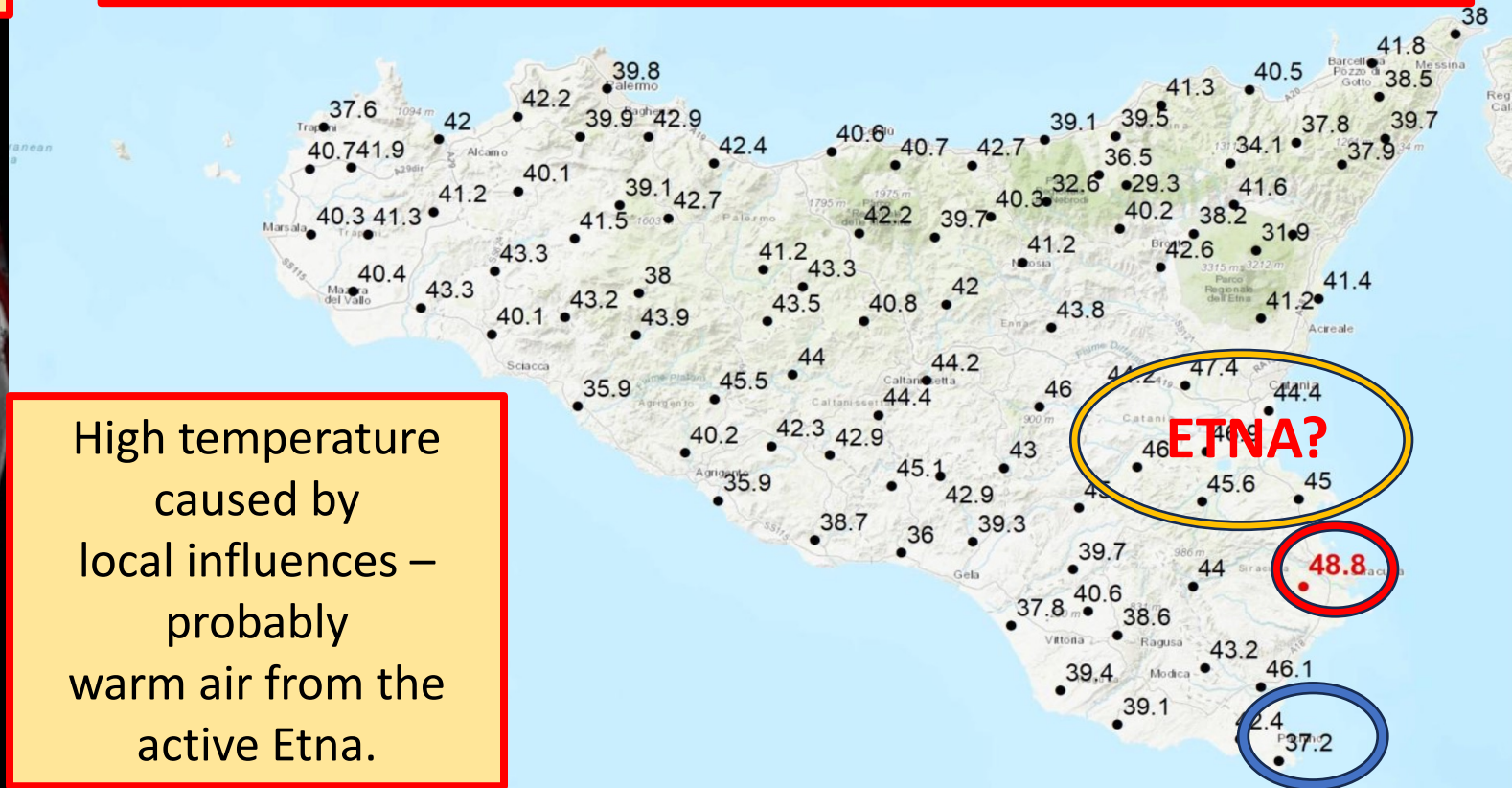
- **Siracusa 11 Aug. 2021:** highest air surface temperature in European history measured in one meteorological station in the city.

News on all TV stations:
Highst temperature in European history.



Representativity of Single Extreme Data?

Range of maximum temperatures reported in Sicily: 37 - 48,8°C.

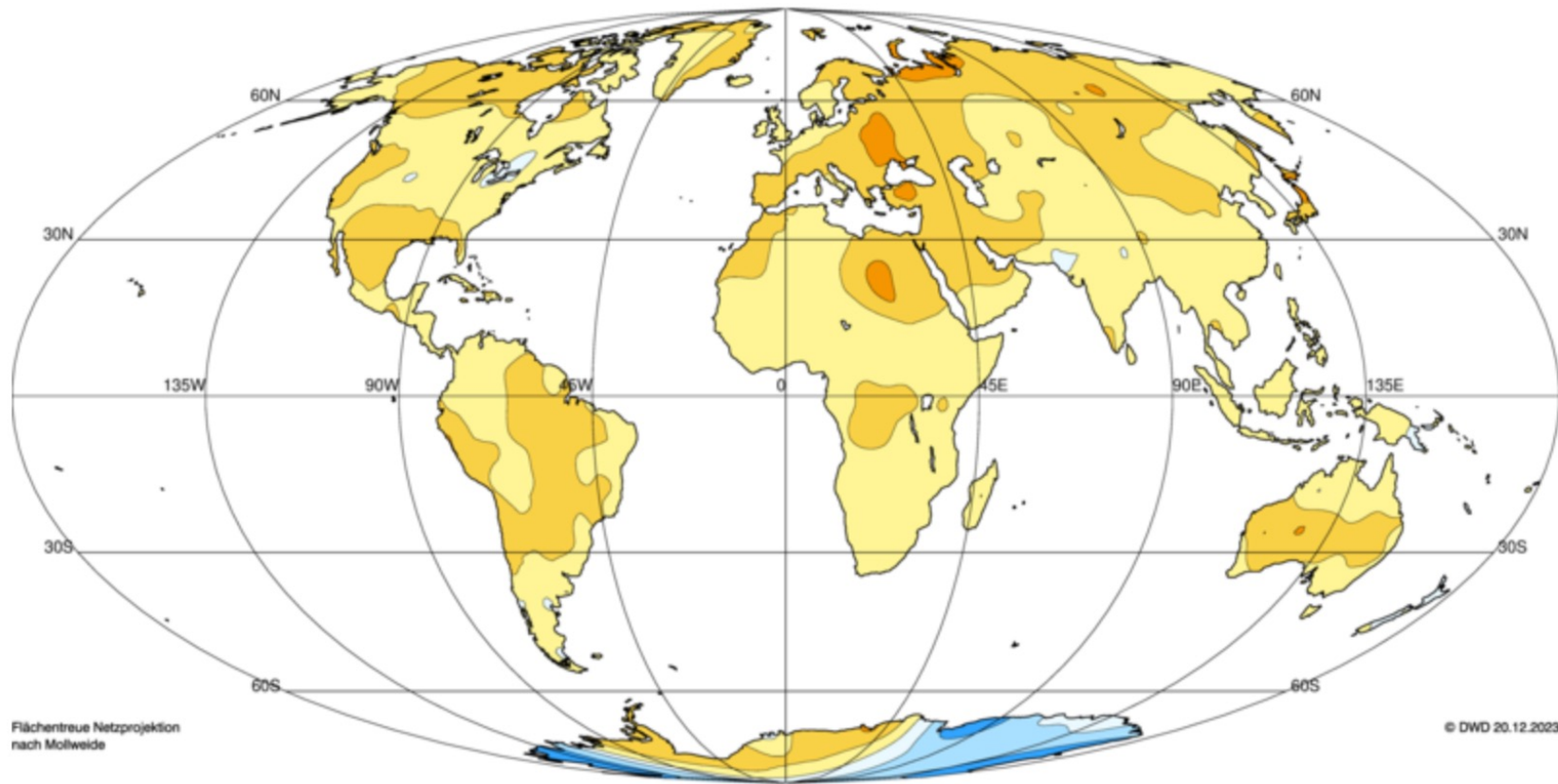


High temperature caused by local influences – probably warm air from the active Etna.

Air temperature at official meteorological station for the region of Siracuse in Cozzo Spadaro was much lower: 38°C.

Global Temperature Increase in Hot Summer 2023.

Air temperatures in August 2023 compared to mean temperature 1961-1990 obtained from from 2.800 metrological stations.



- The heat waves of summer 2023 (and 2024) cannot be explained with annual increase of GHG emissions, which 1-2%.
- There must be additional influences on the air temperature on earth.
- Possible effects:
 - Simple seasonal variations?
 - Albedo changes?



Source: DWD 2023

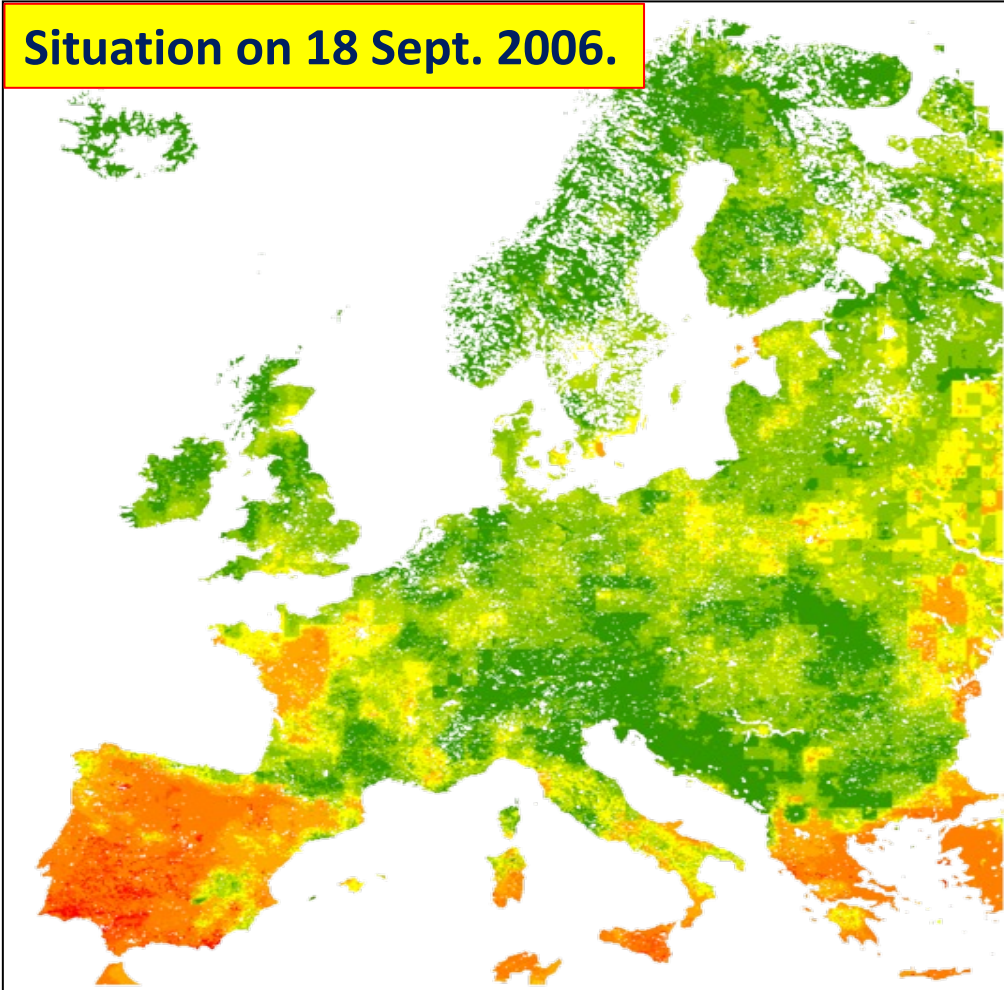
Impact of Global Warming on the Environment.

- **Reduction in soil moisture:**

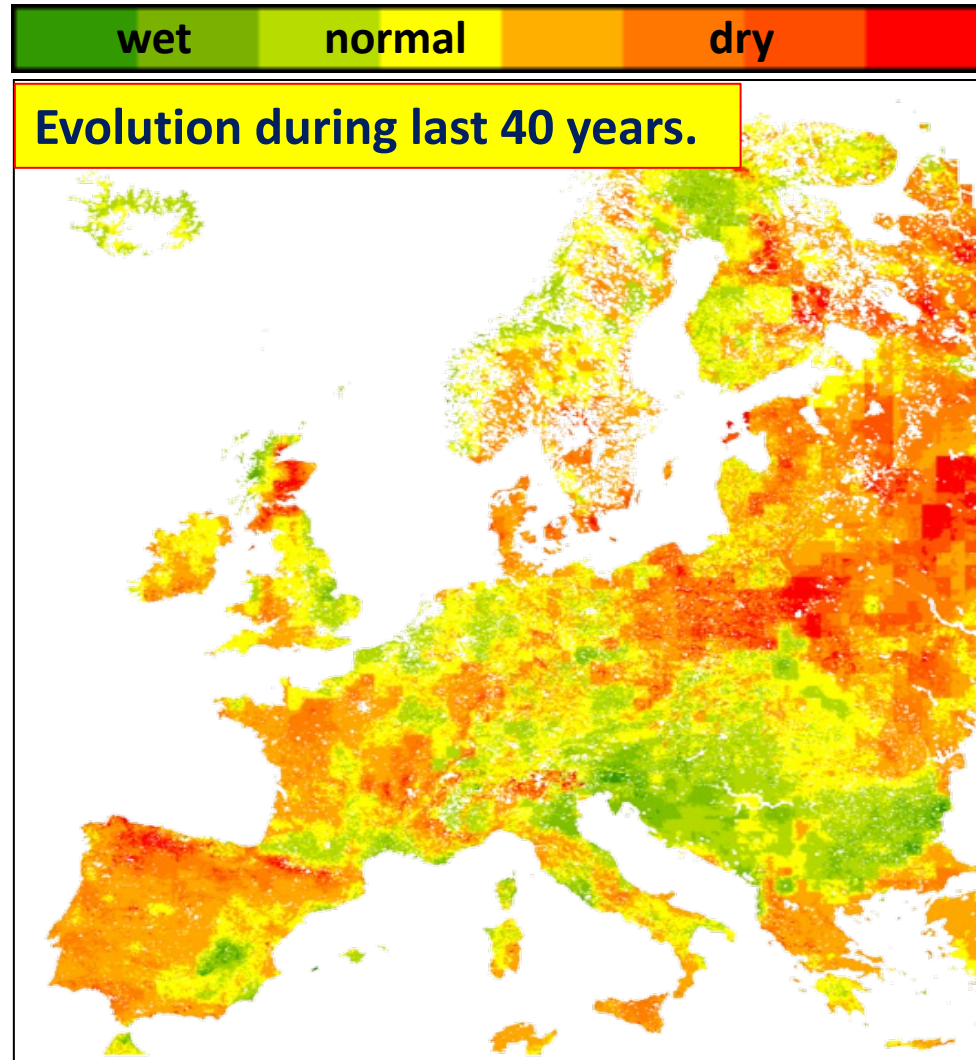
- Reduction of agricultural yields.
- Damages to forests.

European Soil Moisture Maps.

Situation on 18 Sept. 2006.



Evolution during last 40 years.



- **European soils have lost much soil humidity.**

- Reduction of plant growth.
- Damage to soil biodiversity.

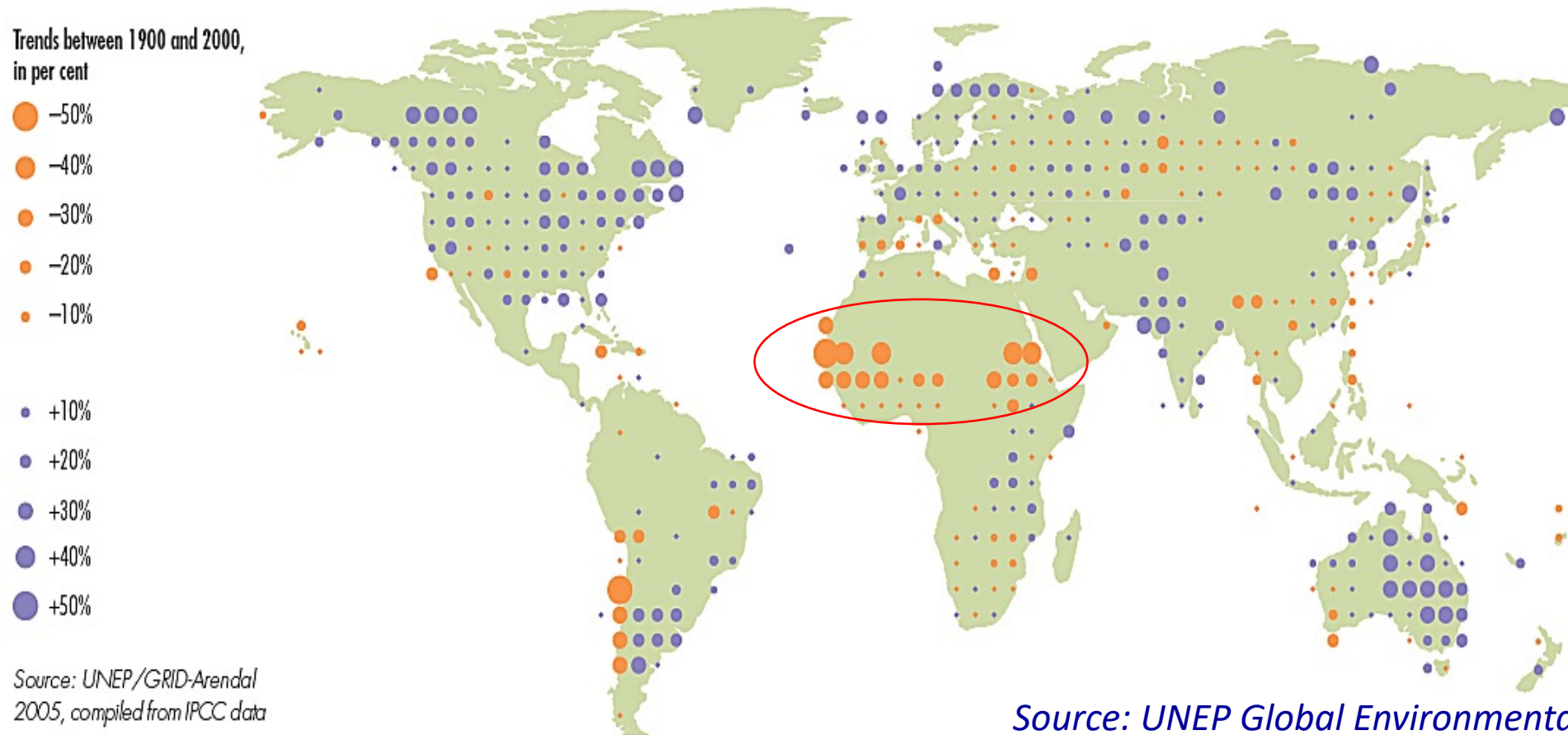
- **Critical areas:**

- Mediterranean land
- Pannonian region (Weinviertel)
- Eastern Europe

*Source: JRC-IES/
ECMWF*

Impact of Global Warming on the Environment.

- **Reduction in rain water supply:**
 - Reduction of soil moisture.
 - Reduced agricultural yield.
 - Necessity for irrigation for agricultural production.
 - Shortage of round and drinking water in Southern Europe and other arid zones.



**Annual
precipitation
trends
1900 – 2000.**

By 2050, water availability is projected to decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics.

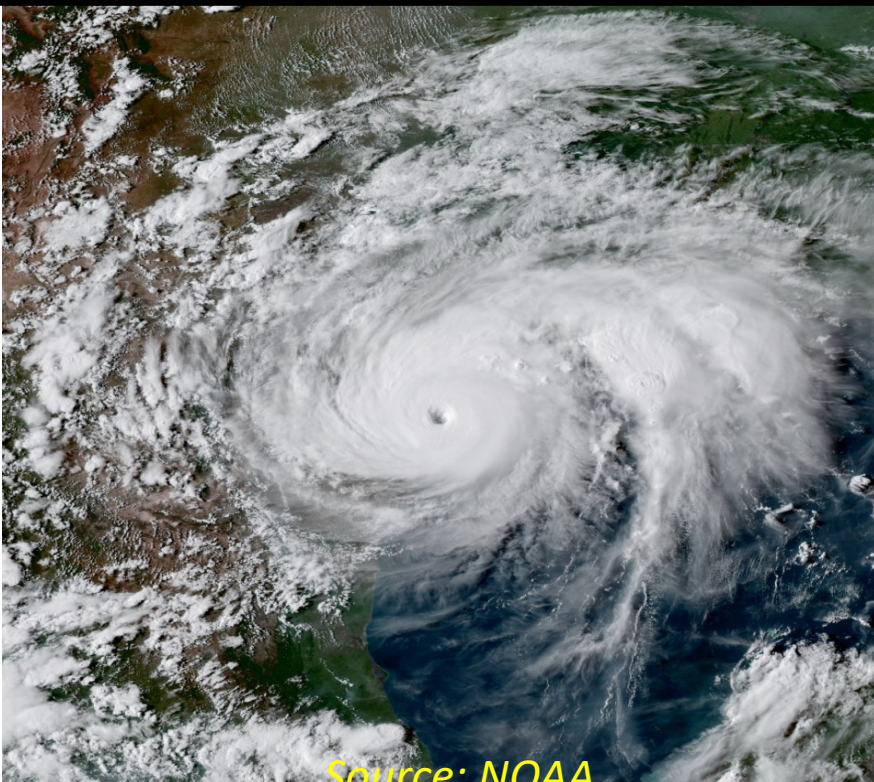
Source: UNEP Global Environmental Outlook (GEO-4), 2006

Impact of Global Warming on the Environment.

- Possible increase of number and strength of extreme weather events:

- Excessive rainfalls.
- Flood.
- Landslides.

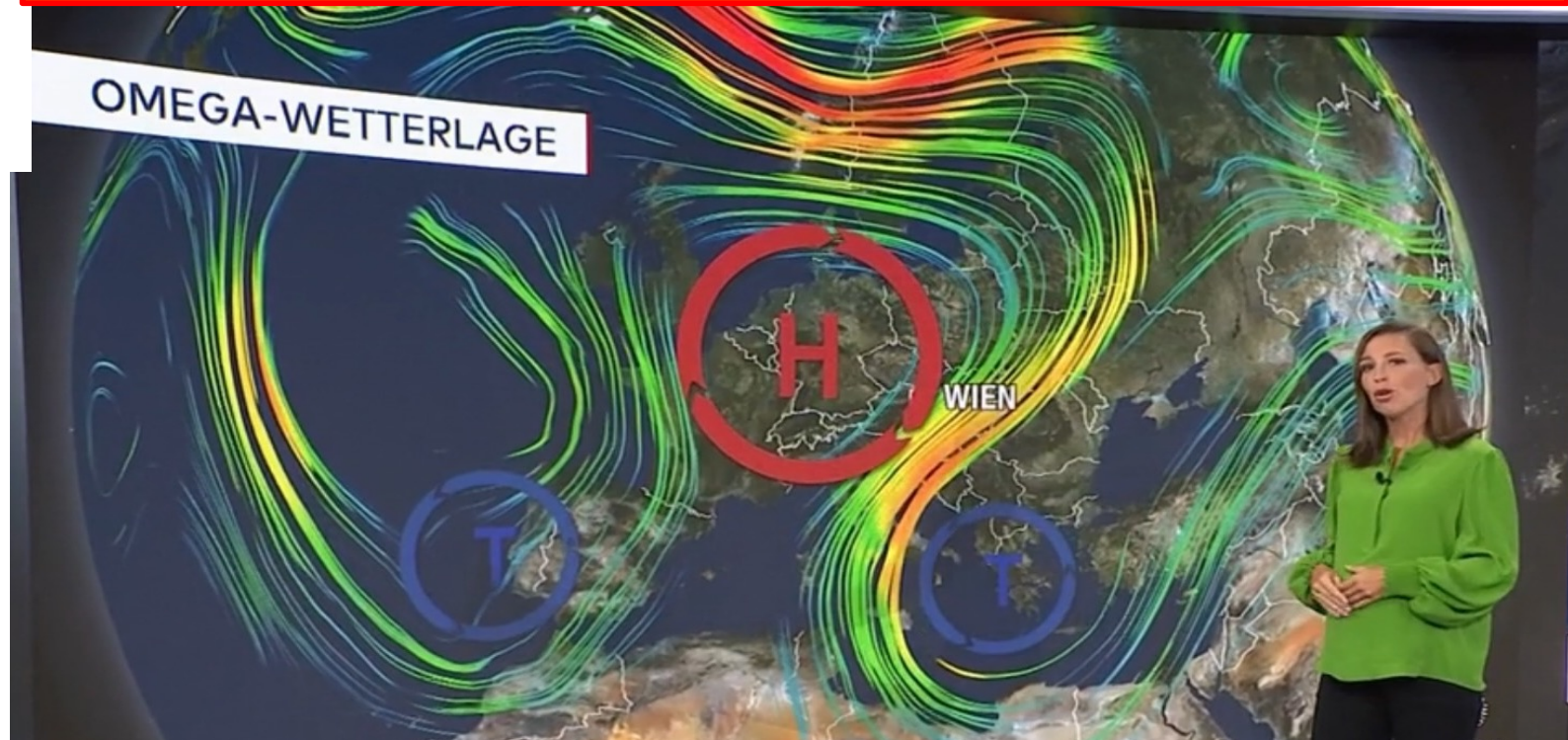
Hurricane Harvey Texas 25. Aug. 2017.



Source: NOAA

Unusual weather situation 4 Sept. 2023:

High pressure area squeezed between 2 low pressure areas with heat wave. Low pressure areas with high rainfall and storms (Spain, Greece). System stable, therefore heavy rainfalls for days.



General assumption now:

Global warming is enhancing the number and strength of extreme weather events: Hurricane Harvey provided most important evidence ("event attribution science").

Impact of Global Warming on the Environment.

- **Extensive floods in Europe:**

- Greece August 2023
- Valencia October 2024
- Austria September 2024
- Poland September 2024

Regional rainfall up to 500 L/m² within a few days.



Valencia, Spain

R



Kłodzko, Poland



Tullnerfeld, Austria

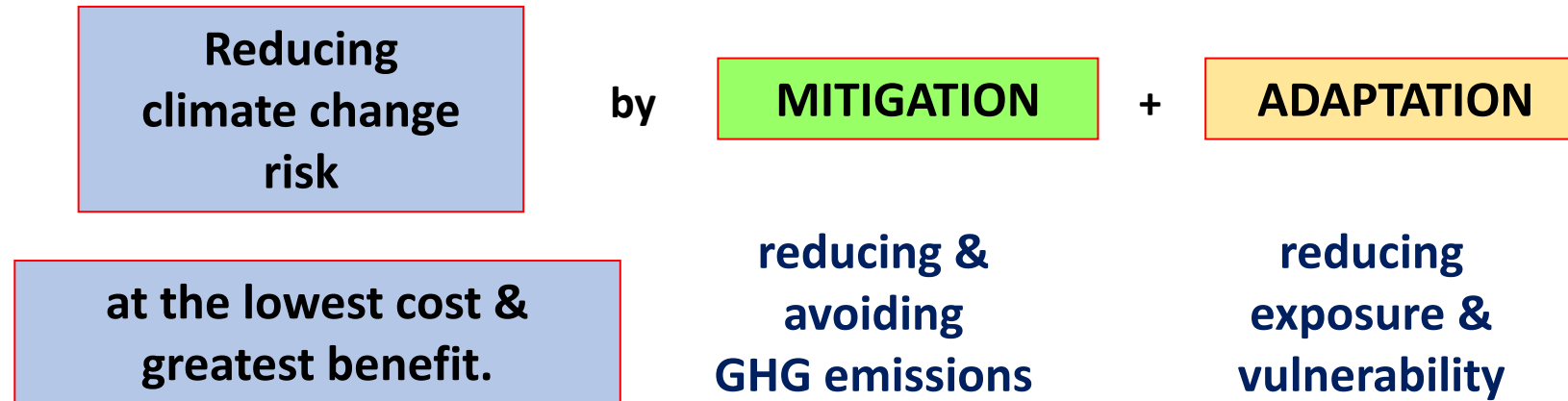
The Global Evolution of Climate Policies

- Intergovernmental Panel on Climate Change (IPCC) established in 1988 to evaluate the risk of climate change caused by human activity.
- **UN Conference on Environment and Development (“Earth Summit”) in Rio 1992:** The Framework Convention on Climate Change (UNFCCC).
- World Climate Conference 1997 Kyoto: (“Kyoto Protocol”): Agreement of industrialized countries to reduce emissions by 5% (2012 compared to 1990).
- The IPCC has so far published 6 comprehensive assessments of climate change and which are generally considered as the authoritative reports on the topic and therefore serve as the most important basis for policy making.
- Climate Agenda regularly discussed in Conferences of the Parties (COP1 Berlin 1997 - COP29 Baku 2024).
- COP21 (Paris 2015): Agreement between 196 countries to set a goal of limiting global warming to **"well below 2°C"** (aiming at **1,5°C**) compared to pre-industrial levels and to develop national action plans to achieve this goal. Ratification by 181 countries.
- **COP24 (Katowice 2018): limit global warming to 1,5°C:**

Emissions of the Green House Gases minus 90% compared to now.

EU Climate Policy.

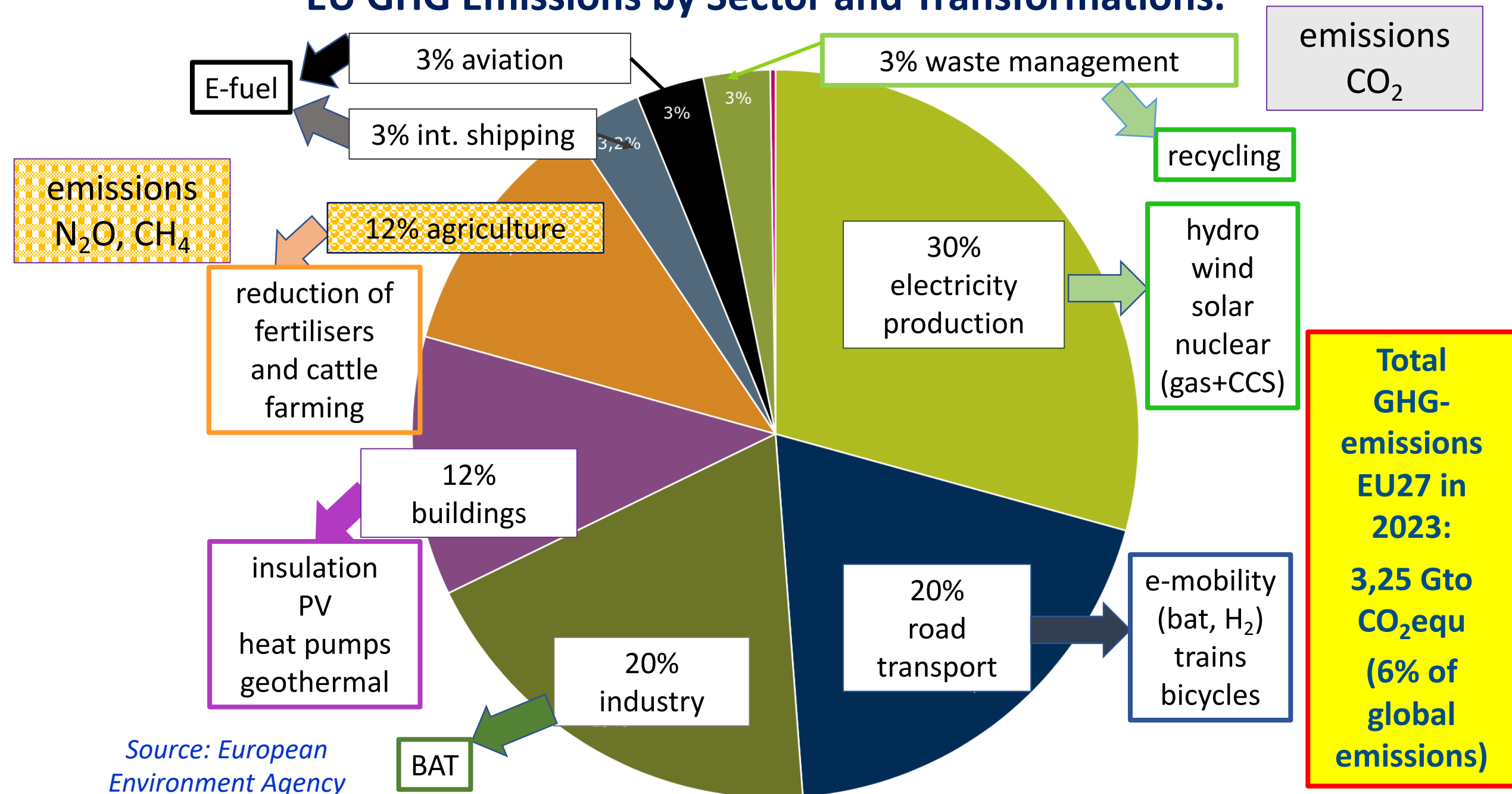
Principles established 1990:



European Council 2019:
Decision on Green Deal „A Carbon Neutral Europe by 2050“.

Legal targets for emission reduction of GHGs (base year 1990):
2020: minus 20% (achieved)
2030: minus 55% (measures in implementation, - 37% achieved in 2023)
2050: minus 90% (roadmap in development)

EU GHG Emissions by Sector and Transformations.



Towards a Climate Neutral Europe till 2050:

Implementation Tools

- **Emissions Trading System (ETS) to stimulate investments in clean technologies:**
- The EU-ETS sets maximum allowable CO₂ emissions (tons/year) for large scale installations covering 11.000 plants emitting together 45% of the EU GHGs. Aviation has been included 2012.
 - Emission rights allocated by European Commission on an individual basis.
 - Unused emission rights can be sold, for exceedance rights must be bought.
 - Price 2023: 80 EUR/ton – too low and ineffective.
 - In the future the number of certificates will be reduced making CO₂ certificates much more expensive (up to 300 EUR?).
 - Delicate balance between too many and too few emission certificates!
 - Impact on global competitiveness of important European industrial sectors (steel, chemistry) unclear.
 - CO₂ import tax (1. Oct. 2023) for cement, iron, steel, aluminum, fertilisers, hydrogen: bureaucratic monster, against present WTO rules ?

Towards a Climate Neutral Europe till 2050:

Implementation Tools

- **Effort Sharing Decision:**
- Covers GHG emissions from transport, buildings, agriculture, non-ETS industry (small entities) and waste, accounts for 55% of total domestic EU emissions.
- The [Effort Sharing Regulation](#) adopted in 2018 foresees binding annual GHG emission targets for each Member State for the period 2021–2030.
- Austria has a legally binding reduction goal of 48% (reference year 2005).
- **National reduction path has to be established based on tools like:**
- CO₂ taxation: now 35 EUR/to. No effect! If 300 EUR/to increase of gasoline price +1 EUR/lit. Politically acceptable?
- Subsidies for implementation of technologies with low carbon emission (RE, electrical cars, heat pumps....).
- Subsidies for measures to reduce energy consumption (passive houses....).
- Legal measures (reduction of primary energy use, prohibition of oil and gas heating, reduction of road traffic...).

Towards a Climate Neutral Europe by 2050: Critical Issues and Challenges.

- Transition pathways not mature - implementation demands much further R&D.
- Estimated transition costs: 1.000-2.000 billion EUR (5-10% of GDP) annually*?
- Energy costs will rise: 15% of GDP in 2050 (now 10%).
- Impact of these measures on industrial structure of the EU, the economic and social standards?
- Will the politicians follow a “reasonable” implementation path, or will they be driven by “Climate Panic”?
- Will the population go along?
- Replacement of current liberal “eco-social-market economy” by a rigid “eco-socialism”?
- Perhaps a “Mission Impossible”?

*Boston Consulting Group (2023):
global investments needed till 2030 are
30.000 billion EUR (8% of global GDP).



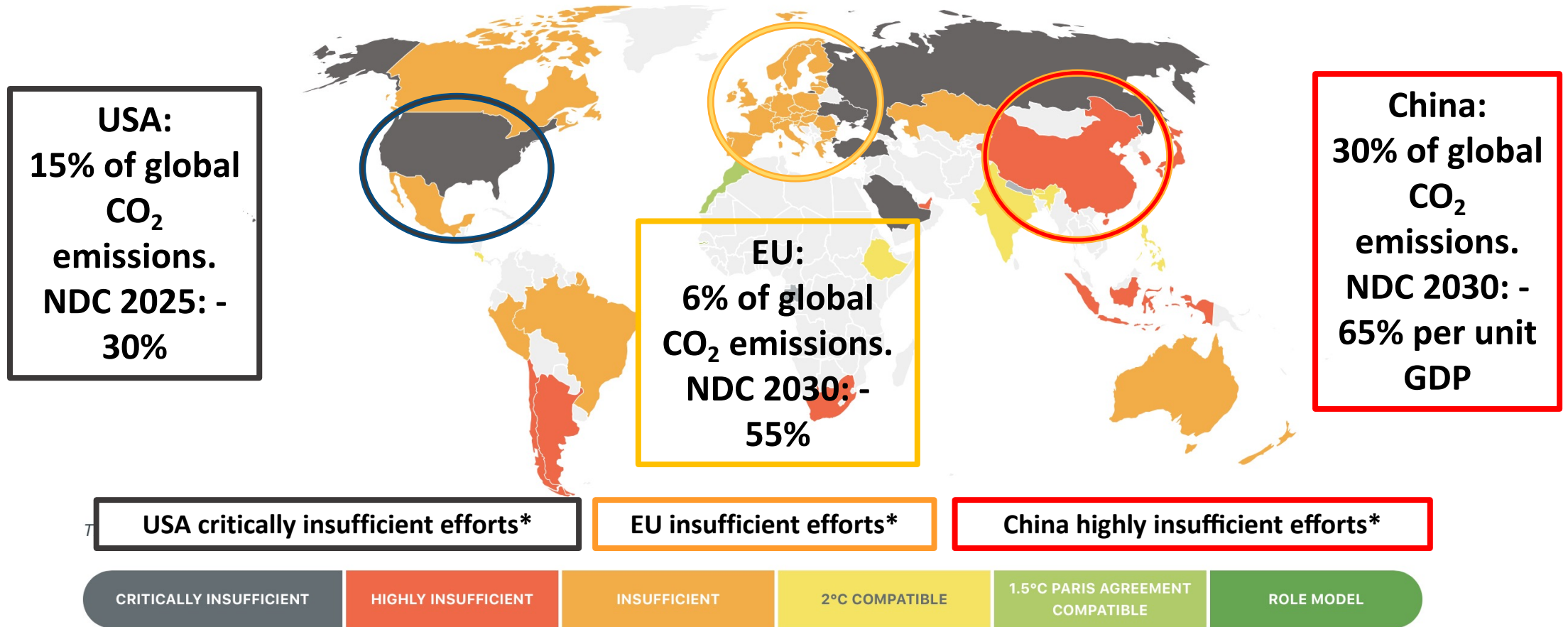
EU-27 are responsible for only 6% of the global GHG emissions.

Europe alone will not stop GHG induced global warming.

The global mitigation agreement (Paris 2015) must be implemented with high ambition!

Implementation of Paris Climate Agreement (State 2020).

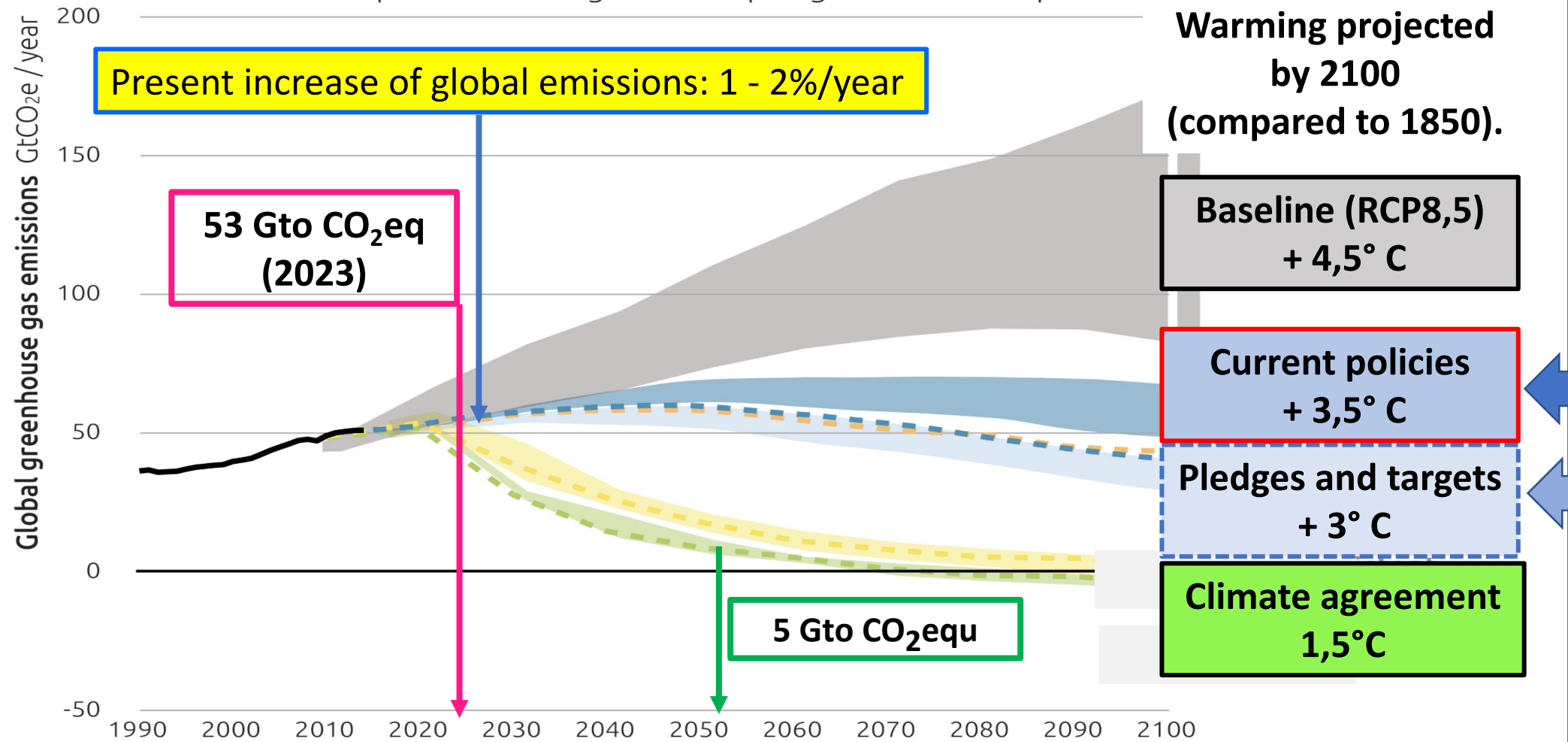
Based on pledges and targets (NDC) for 2030.



- **Major criticism of the Paris climate agreement:**
 - Each country is to set a target for emission reduction or limitation, called a "nationally determined contribution", but the amount will be voluntary.
 - No sanctions foreseen for inaction or violation of commitments.

Implementation of Paris/Katowice Climate Agreement (State 2024).

Green House Gas Emission and Temperature Scenarios.



Extensive adaptation measures necessary since global warming will be progressing.

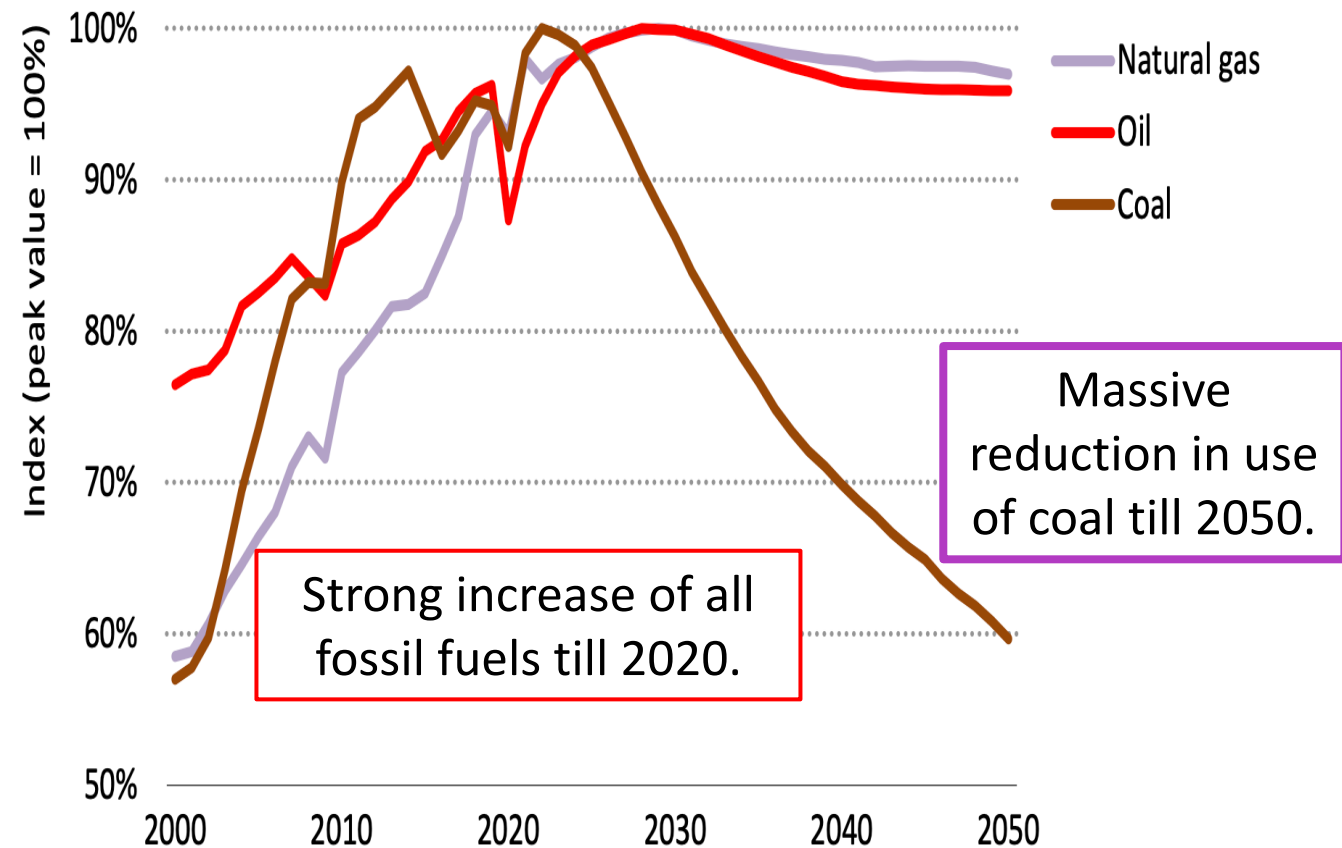
Implementation of Paris/Katowice Climate Agreement.

Can we reach the goal of limiting global warming to 1,5°?

- **Evolution of mankind till 2050:**
 - Global population will grow by 2 billion (25%).
 - Per capita economic output will increase by 85%.
 - Massive increase in energy consumption in Asia and Africa.
- **Impact of technological transformations on GHG emissions:**
 - Often overestimated due to lack of a complete life cycle analysis:
“Zero emissions” for wind power, PV-electricity, E-cars is wrong.

Source: *International Energy Agency*
2024

Figure 1.1 ▶ Fossil fuel consumption



Conclusion: The expected CO₂ emissions in 2050 will still be 25 Gto/a and not 5 Gto/a as required to achieve the 1,5 degree warming limit.