ESA-7

Climate Change
A Brief Primer

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Energy Systems Analysis

A simple message – the world is warming

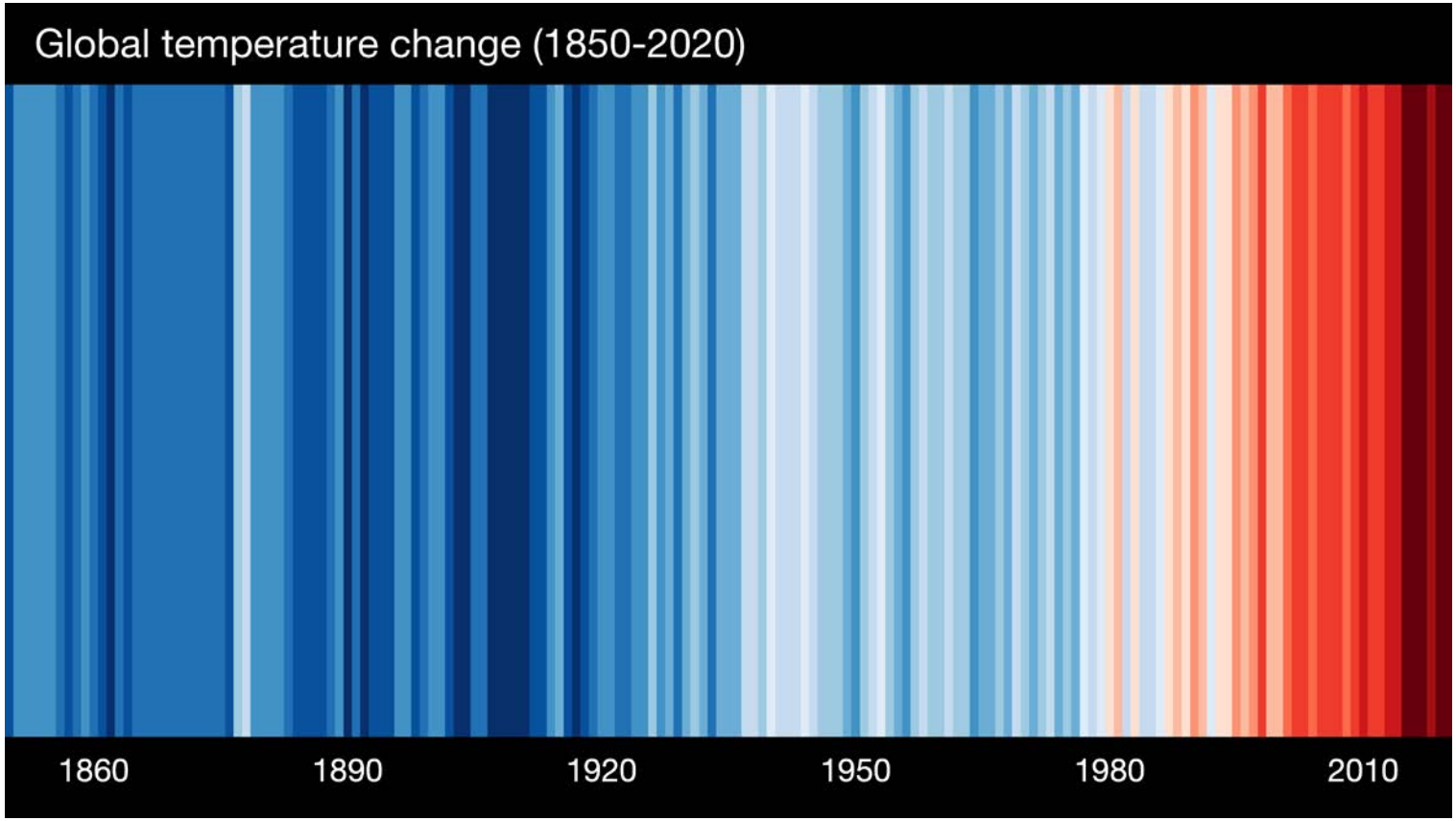
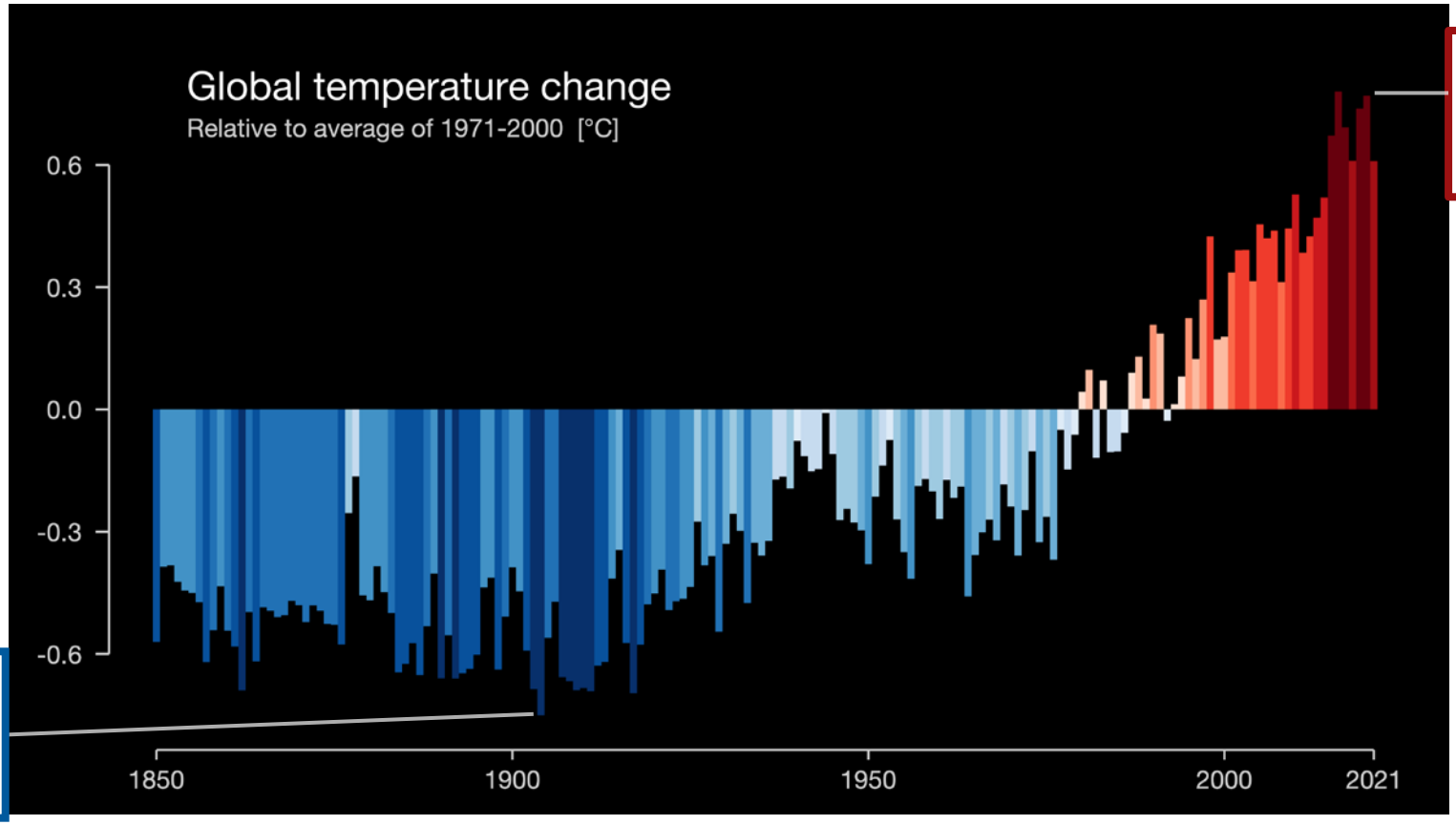


Image citation: Ed Hawkins, University of Reading, https://showyourstripes.info/

A simple message – the world is warming



+0.75°C of 1971-2000 average

-0.75°C of 1971-2000 average

Image citation: Ed Hawkins, University of Reading, https://showyourstripes.info/

Svante Arrhenius:

Climate change as attention management problem

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction : Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet§; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

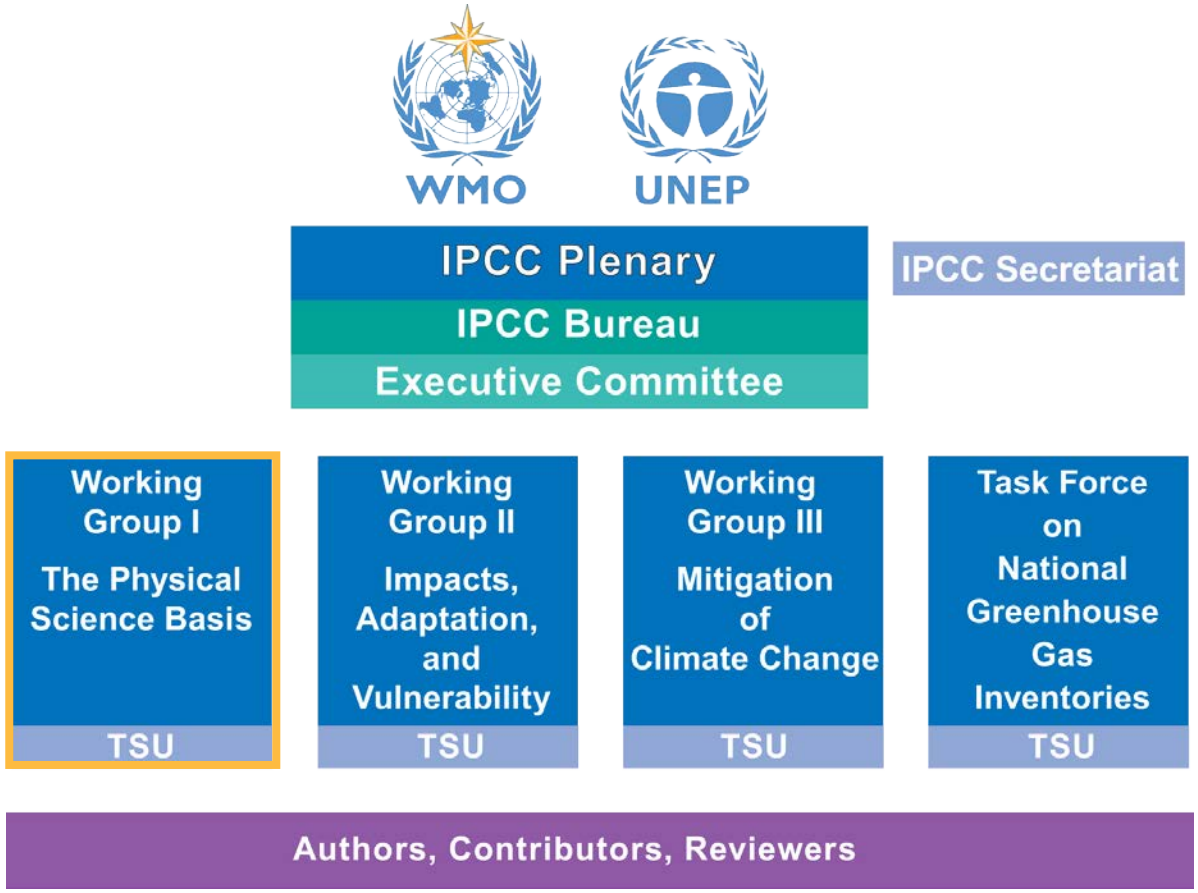
* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 406 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).


IPCC WORKING GROUP III
12TH SESSION
IPCC PLENARY
39TH SESSION
Berlin, 7 – 12 April 2014
are a key mitigation strategy in scenarios reaching atmospheric CO2eq concentrations of about 450 or 500 ppm by 2100 (robust evidence, high agreement). Near term reductions in energy demand are an important element of cost effective mitigation strategies, provide more flexibility for decarbonizing the energy supply sector, hedge against related supply side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. Integrated and sectoral studies provide similar estimates for energy demand reductions in the transport,

The IPCC

- Scientific body set up by WMO and UNEP
- Periodic Assessment Reports (AR6 in 2022)
- Hundreds of Scientists involved as Authors and Reviewers
- Does not conduct own research, but assesses the latest scientific, technical and socio-economic literature
- Elaborate Expert and Government Review
- Main findings summarized in “Summary for Policy Makers”
- Nobel Peace Price 2007 together with A. Gore

WGI: The Physical Science Basis of Climate Change



WGI: The Physical Science Basis of Climate Change

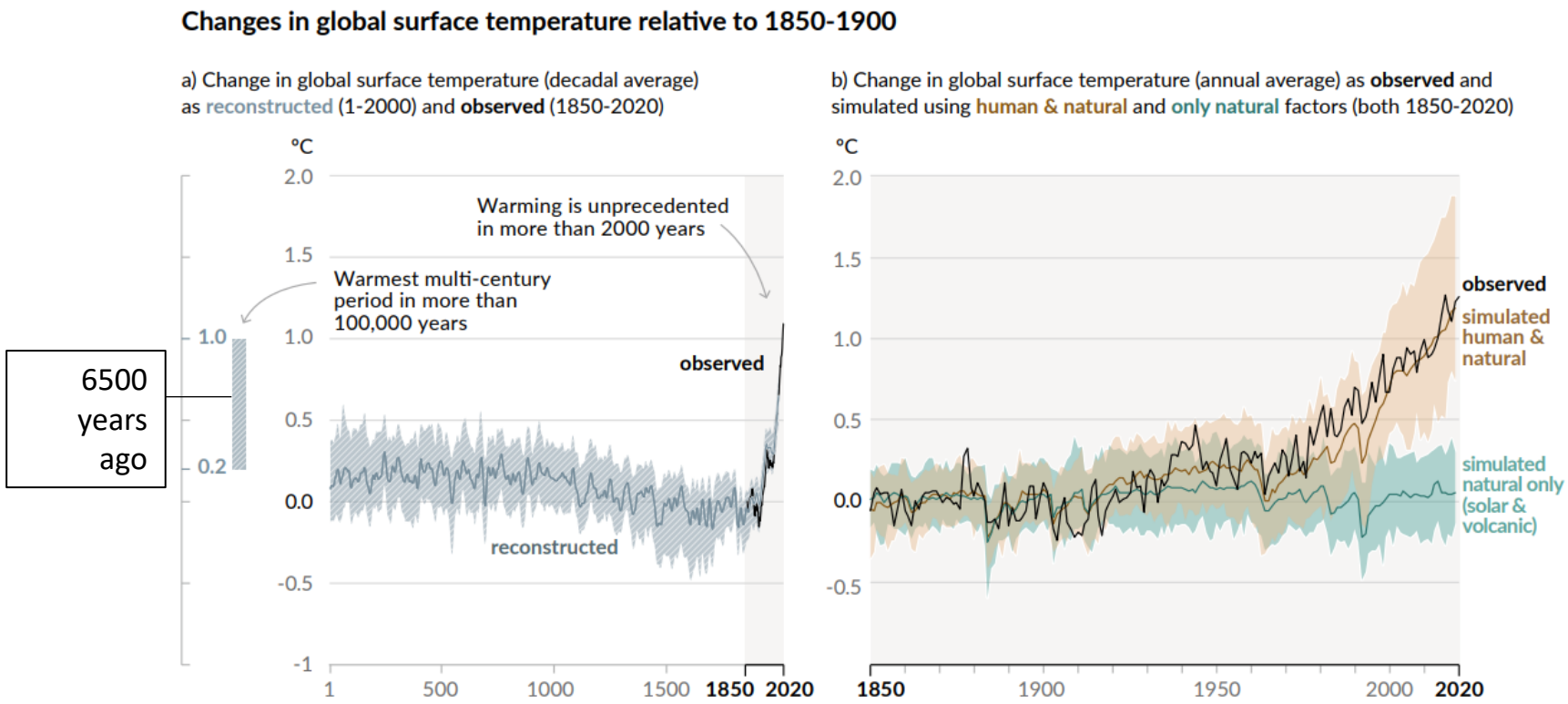
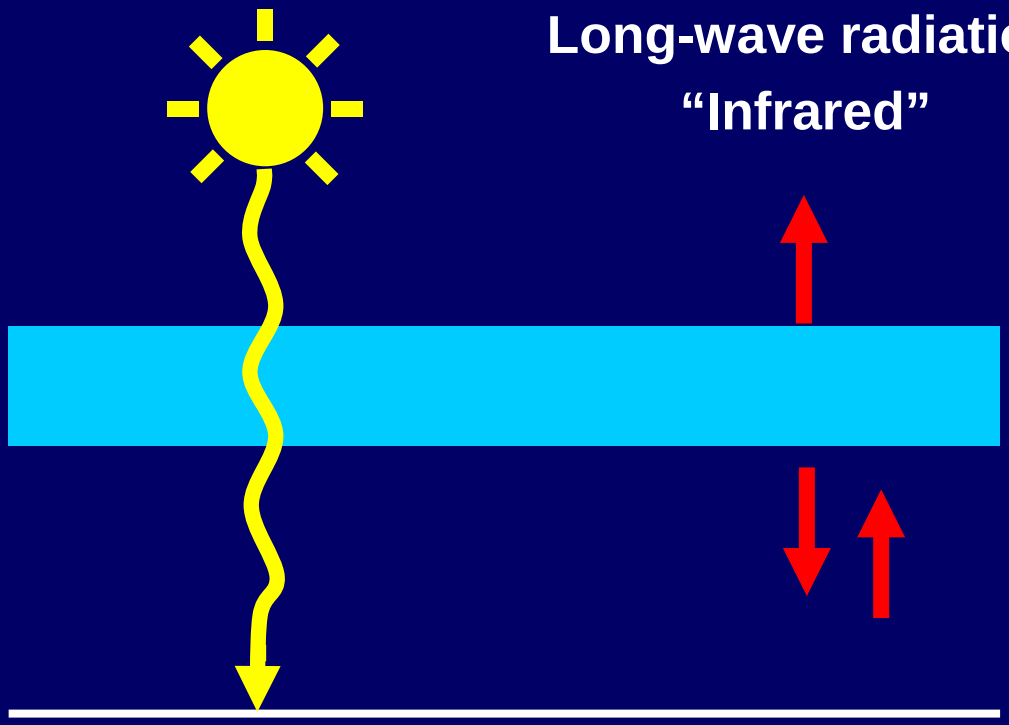


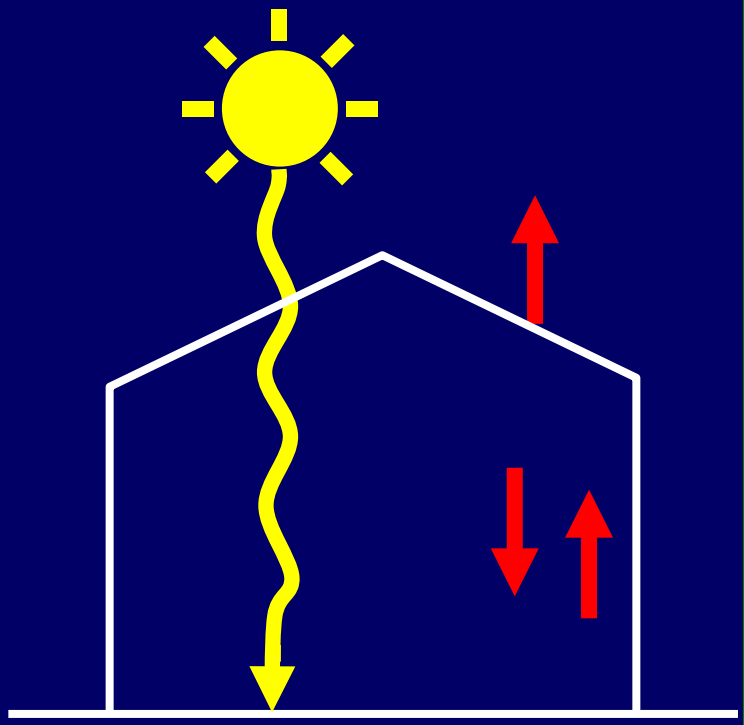
Image citation: IPCC, Climate Change 2021: The Physical Science Basis. Figure SPM.1

The Greenhouse Effect

Solar radiation

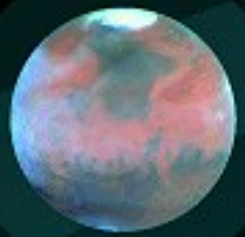
Long-wave radiation
"Infrared"





Planets and atmospheres

Mars
Thin atmosphere
(Almost all CO_2 in ground)
Average temperature : - 50°C



Earth
0,03% of CO_2 in the atmosphere
Average temperature : + 15°C

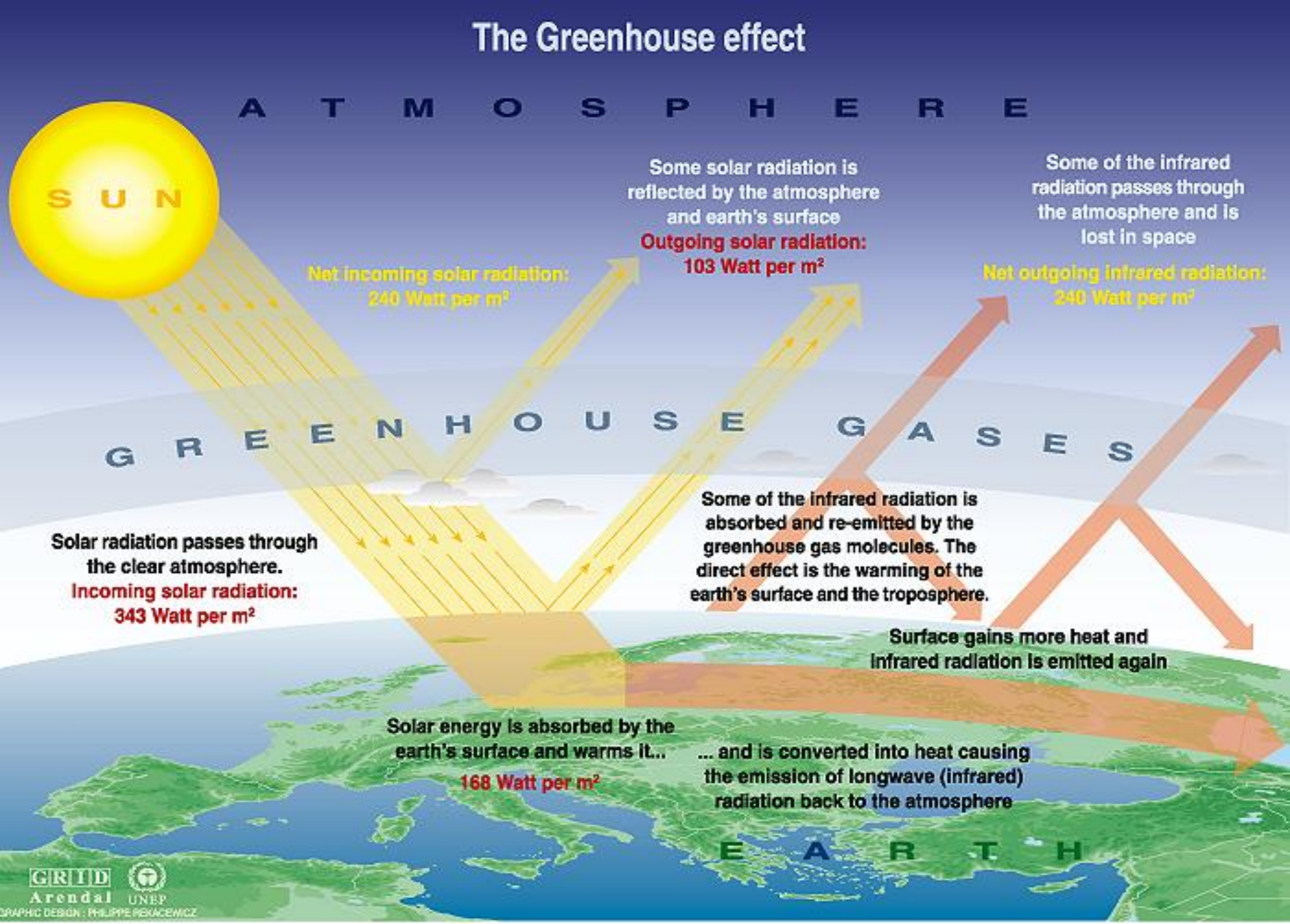
Venus
Thick atmosphere
containing 96% of CO_2
Average temperature : + 420°C

GRID Arendal UNEP

GRAPHIC DESIGN : PHILIPPE REKACEWICZ

Sources: Calvin J. Hamilton, Views of the solar system, www.planetscapes.com; Bill Arnett , The nine planets, a multimedia tour of the solar system, www.seds.org/billa/tnp/nineplanets.html

The Greenhouse effect



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Energy balance and carbon cycle

Complex earth system response to GHGs can be modelled as a black body energy-balance (+ biogeophysical feedbacks + ocean dynamics + ...)

Energy flux Climate feedback

$$\Delta N = F + \lambda \Delta T$$

Radiative forcing

Global mean surface temperature change

- Natural earth systems absorb emitted carbon
- 45% remains in the atmosphere
- 25% absorbed by trees, vegetation, etc.
- 30% absorbed by ocean

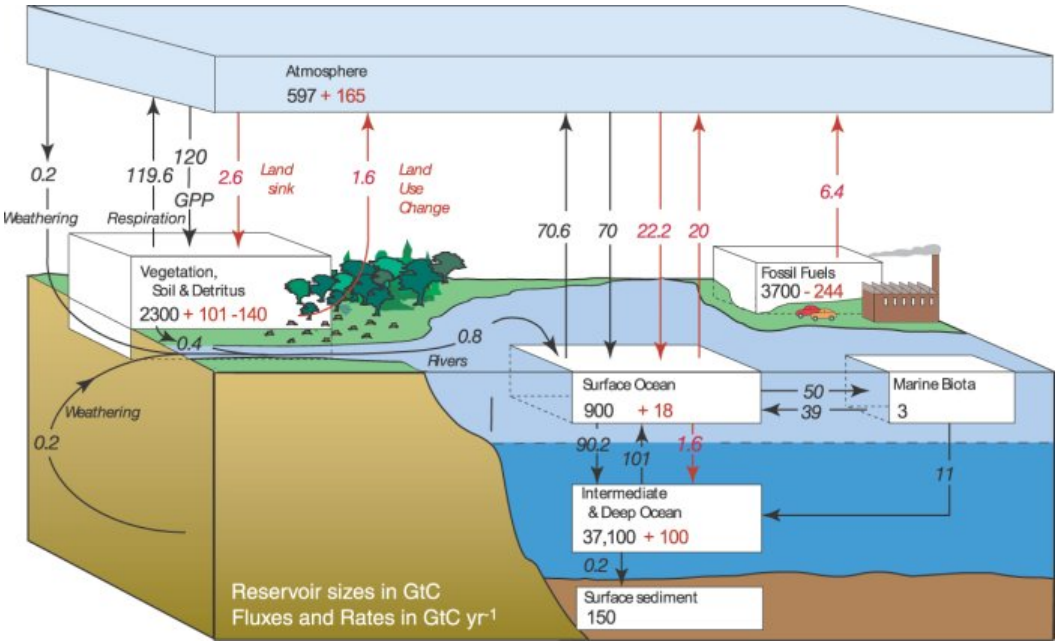
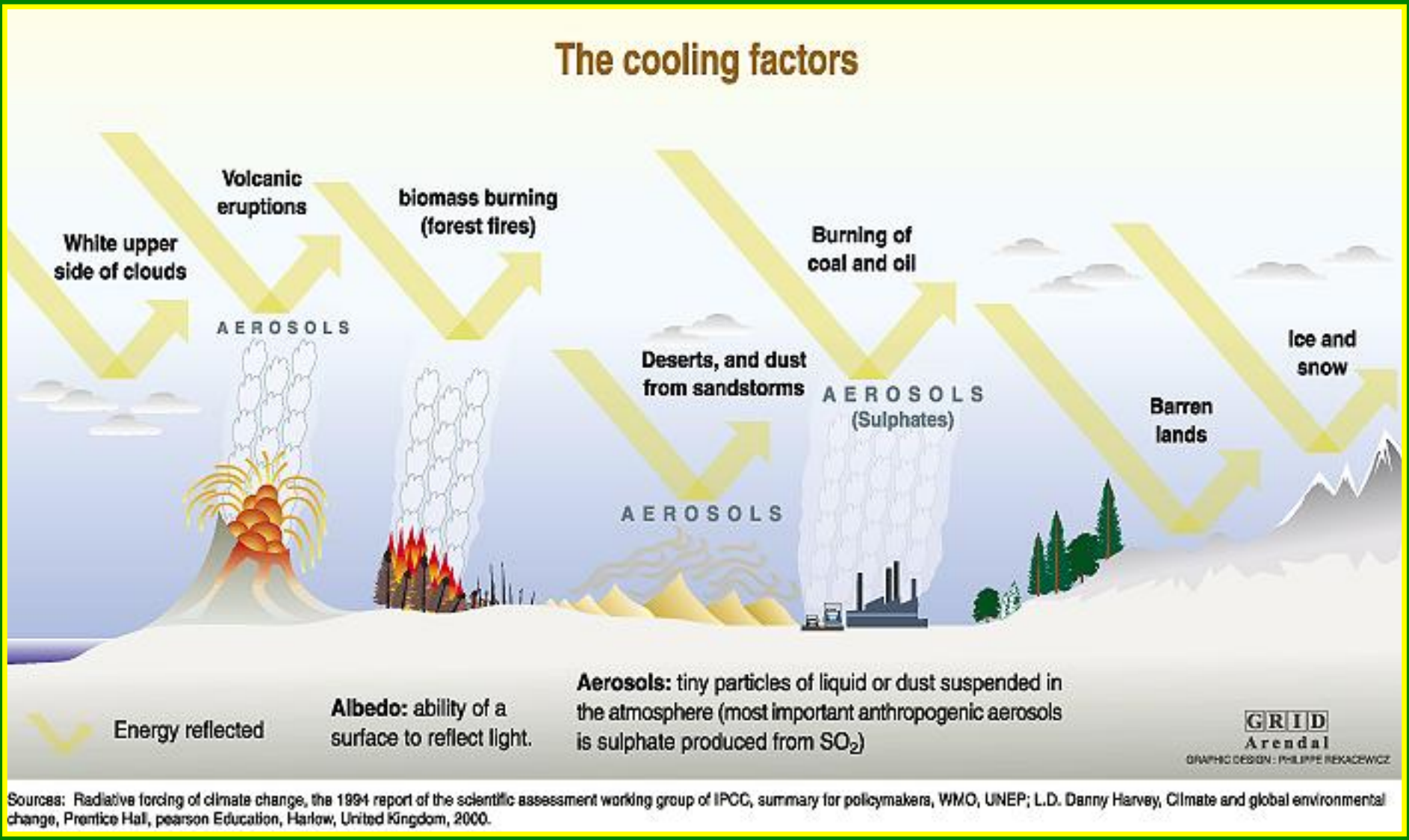


Image citation:https://gml.noaa.gov/outreach/behind_the_scenes/gases.html

Global Carbon Cycle
1990s

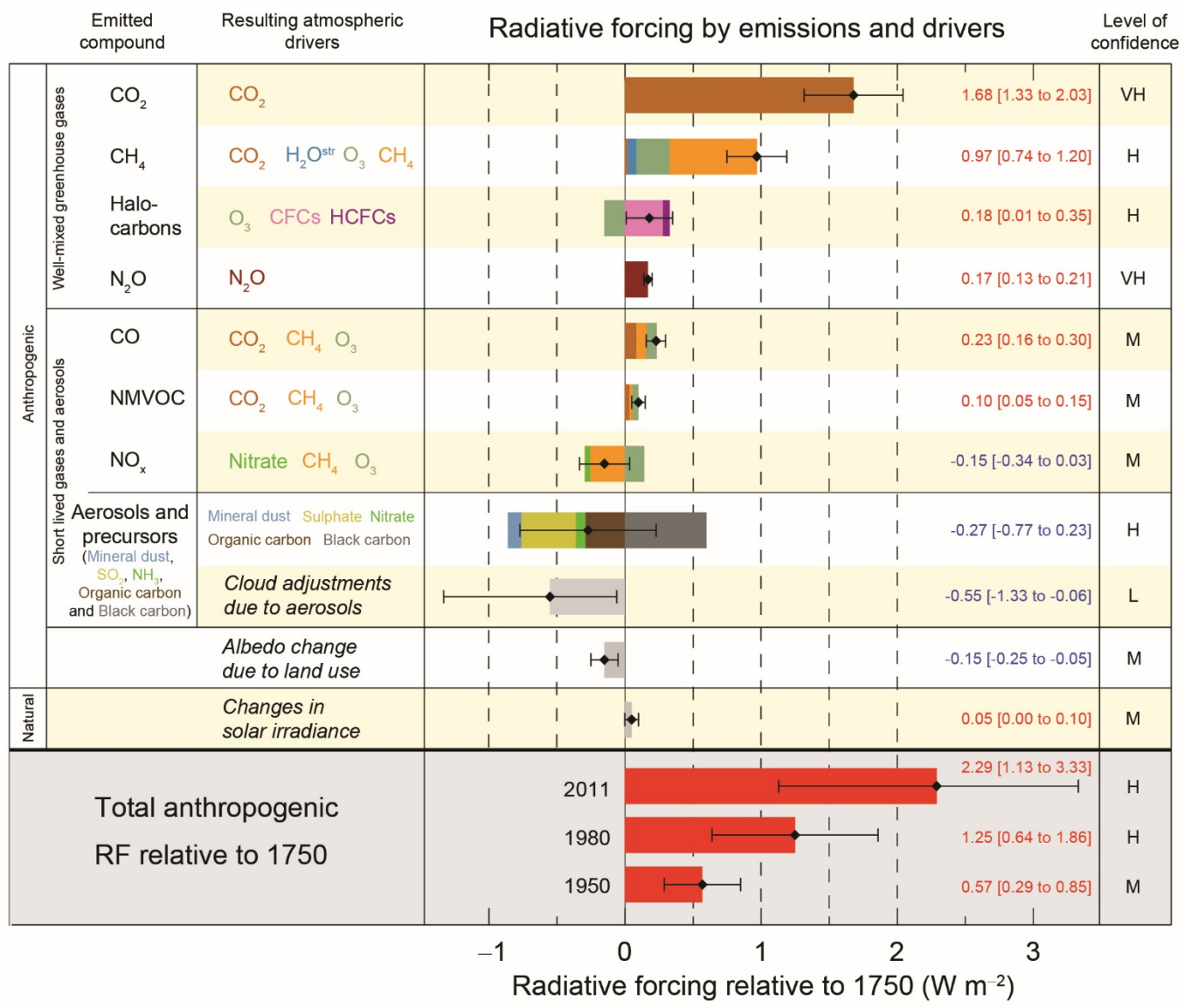
Atmospheric increase = industrial emissions
+ net land-use emissions
– ocean uptake – residual (missing sink)

3.3 (±0.2) = 5.5 (±0.5) + 1.1(0–2.8)
– 2.0(±0.8) – 1.3(0–3.3)



Sources: Radiative forcing of climate change, the 1994 report of the scientific assessment working group of IPCC, summary for policymakers, WMO, UNEP; L.D. Danny Harvey, Climate and global environmental change, Prentice Hall, pearson Education, Harlow, United Kingdom, 2000.

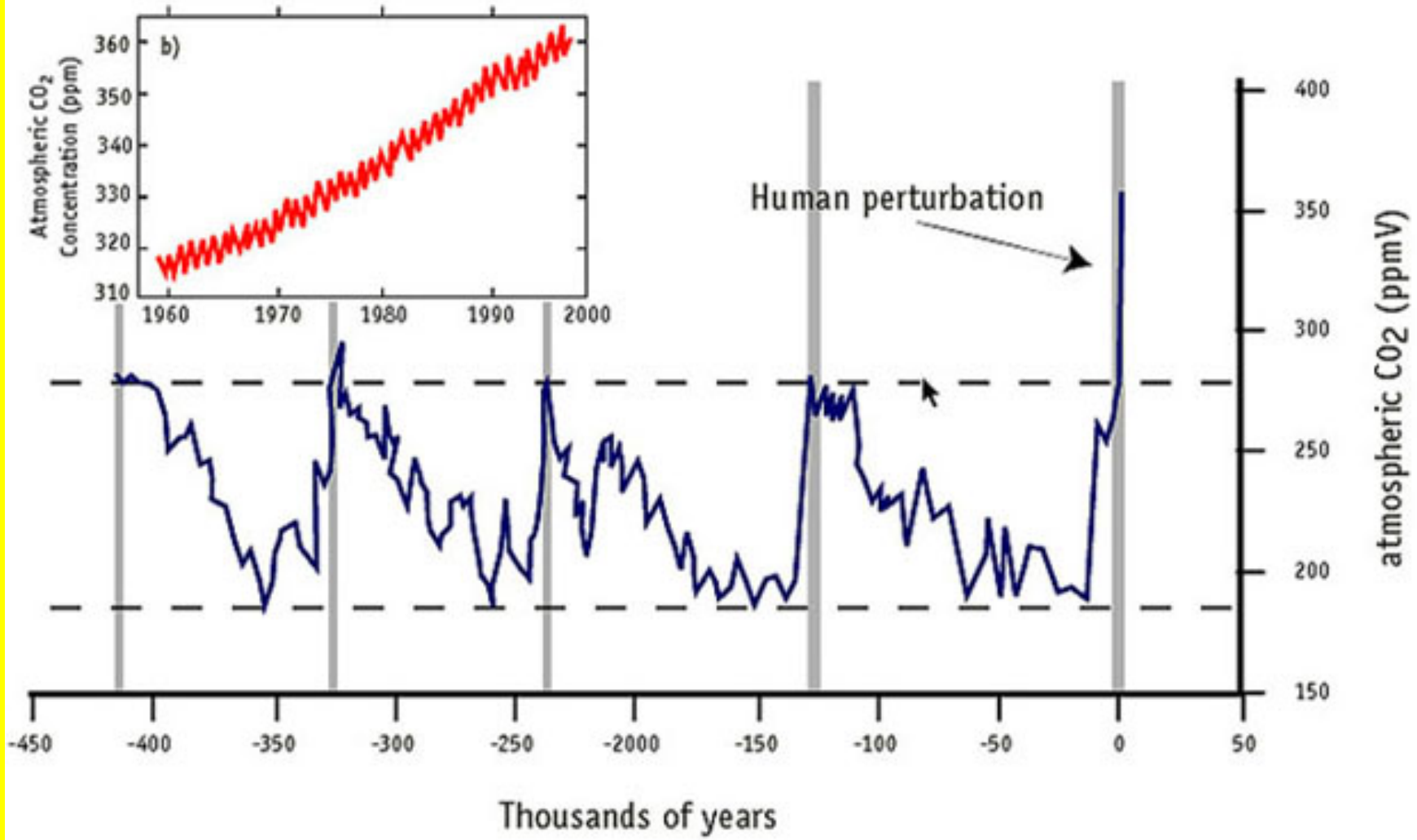
Change of Radiative Forcing



Energy Systems Analysis

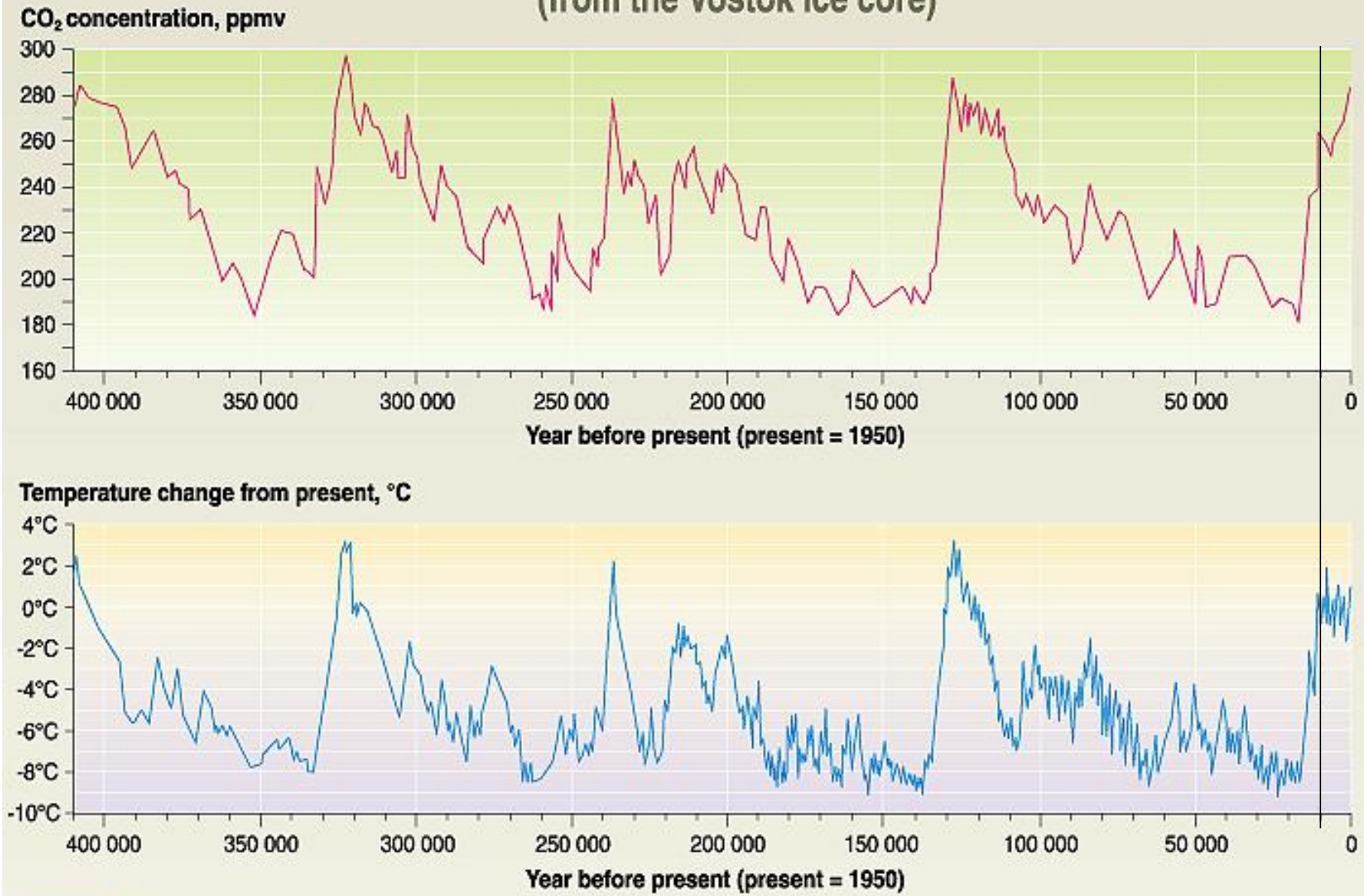
Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Atmospheric CO_2 Concentration



Source: Steffen, 2004

Temperature and CO_2 concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)

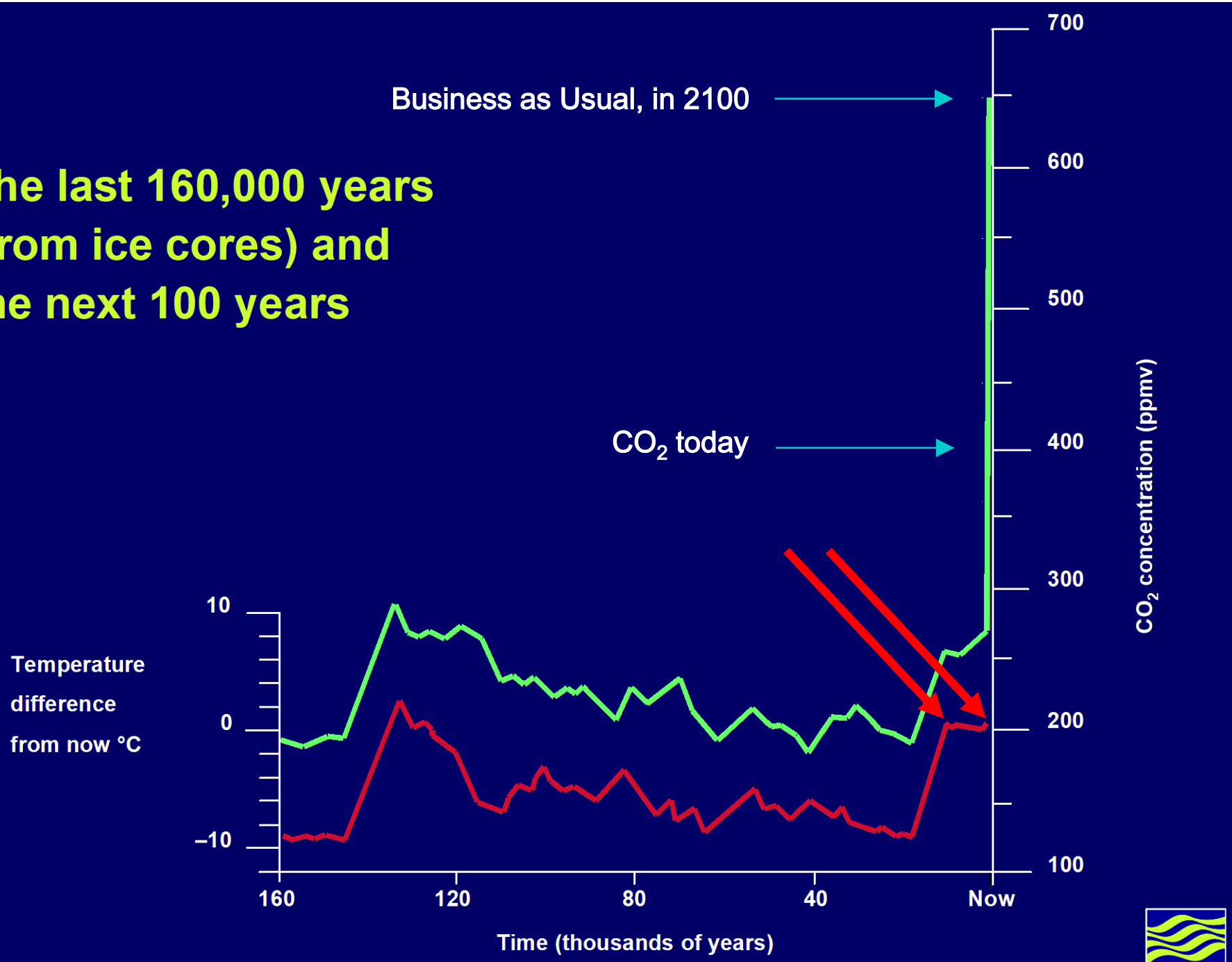


GRID Arendal UNEP

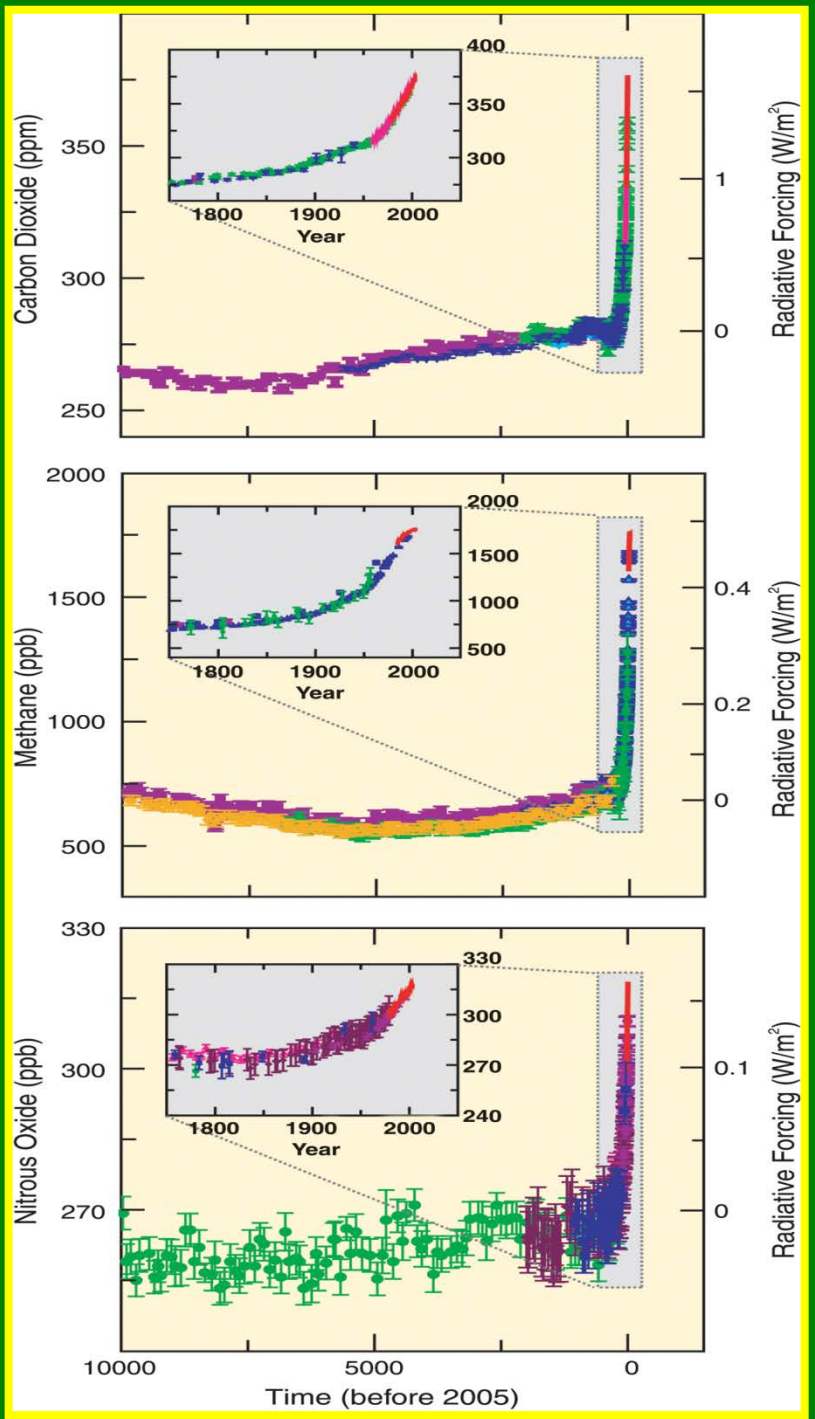
GRAPHIC DESIGN : PHILIPPE REKACEWICZ

Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

The last 160,000 years (from ice cores) and the next 100 years



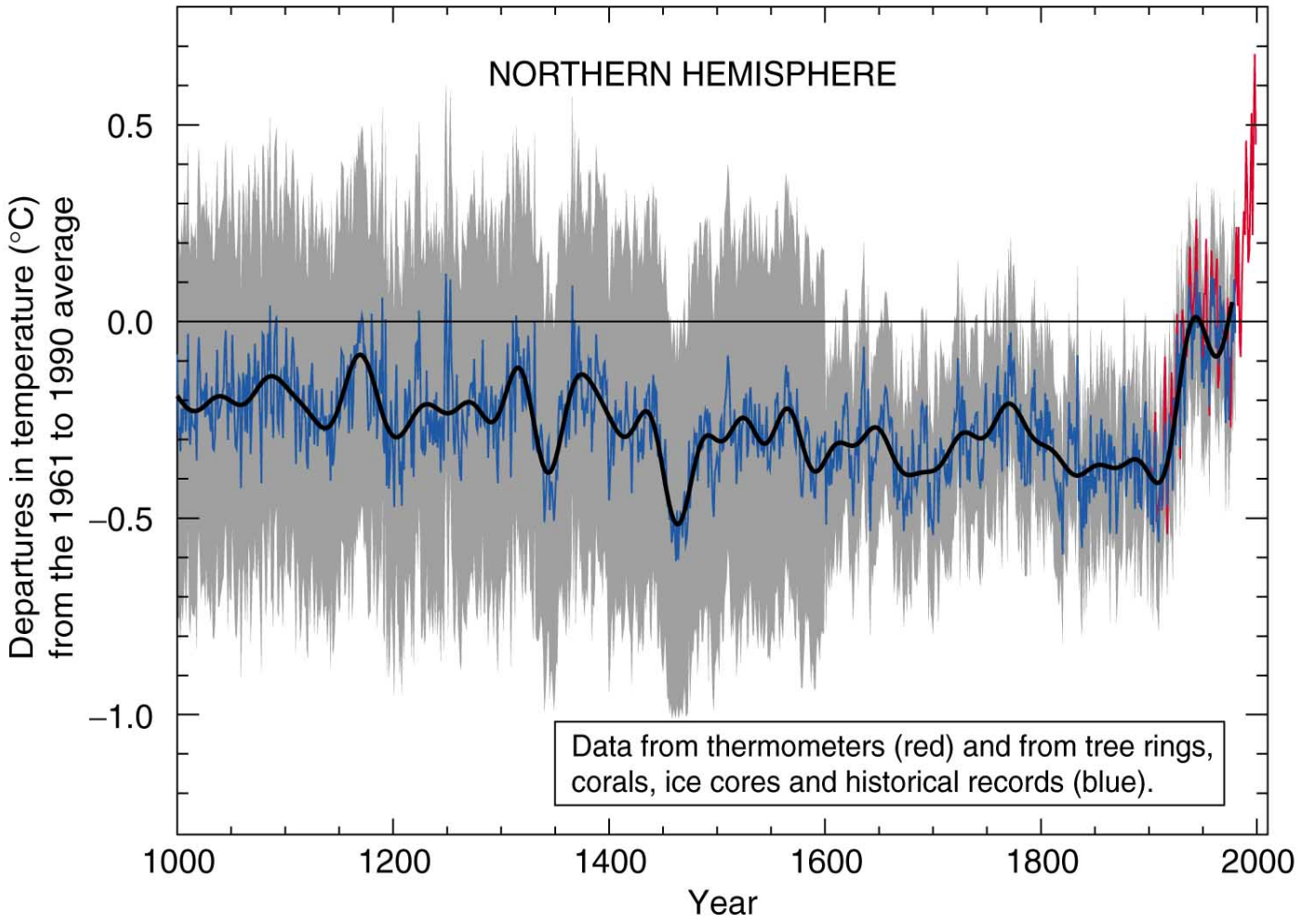
Met Office

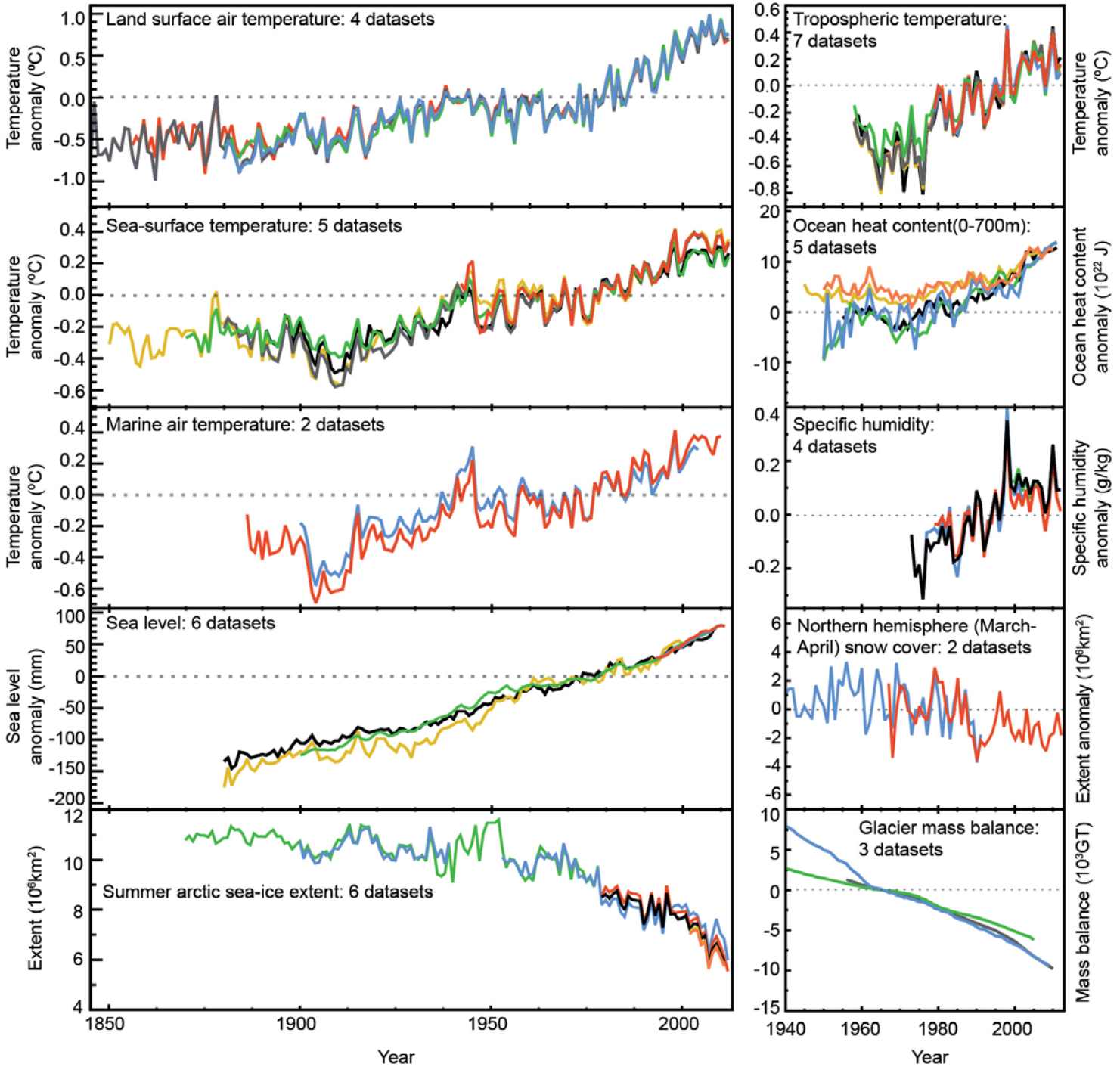


GHG Concentrations over the last 10000 years

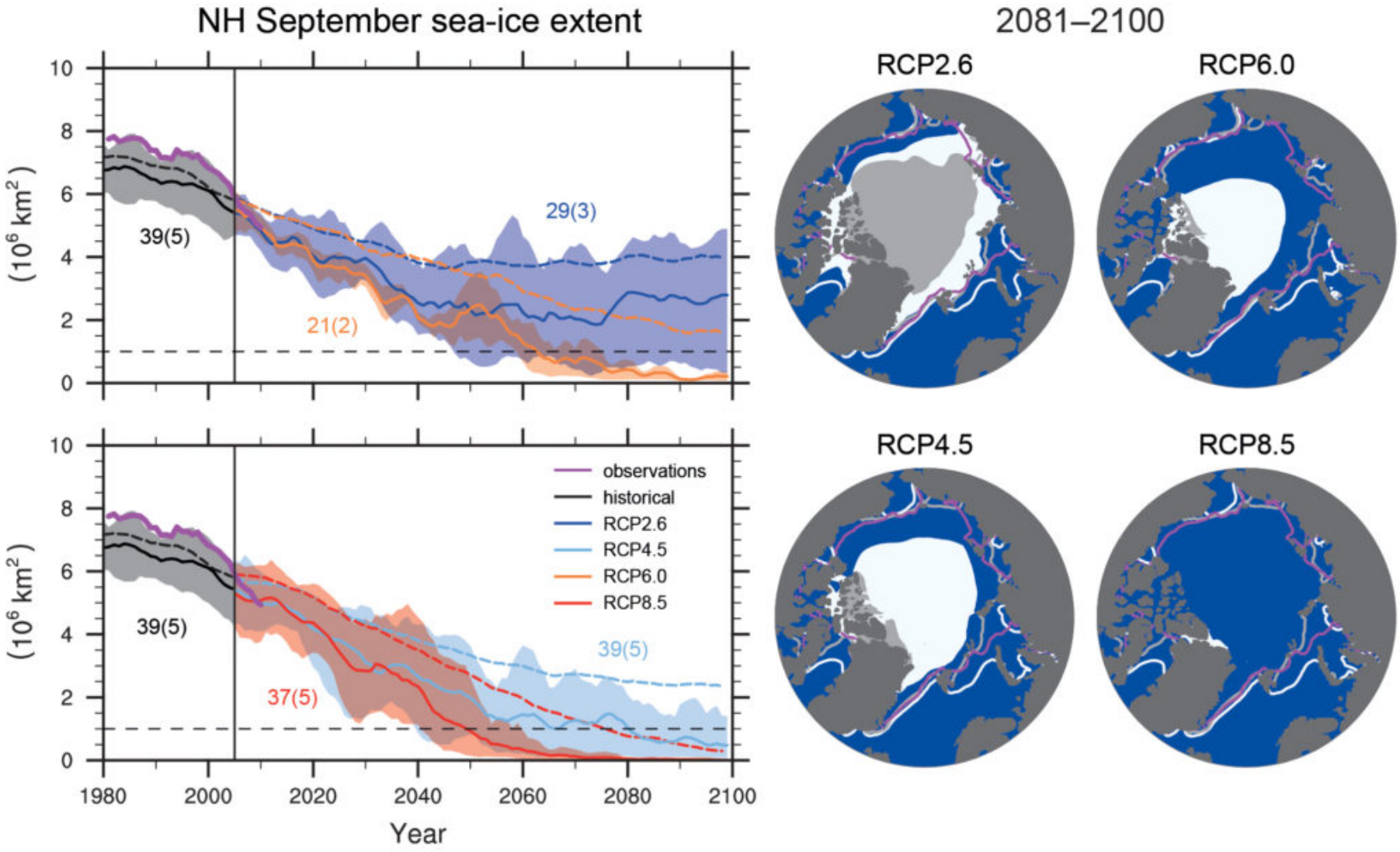
Source:
IPCC-AR4, 2007

Variations of the Earth's Surface Temperature

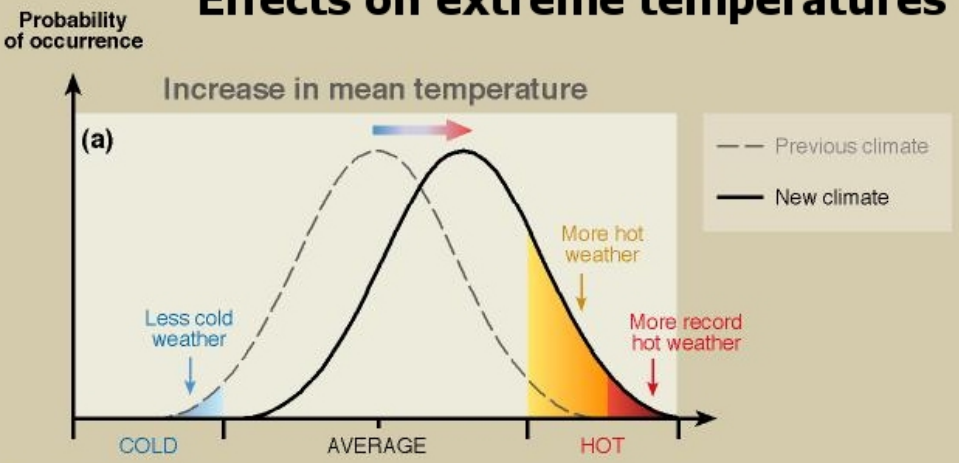


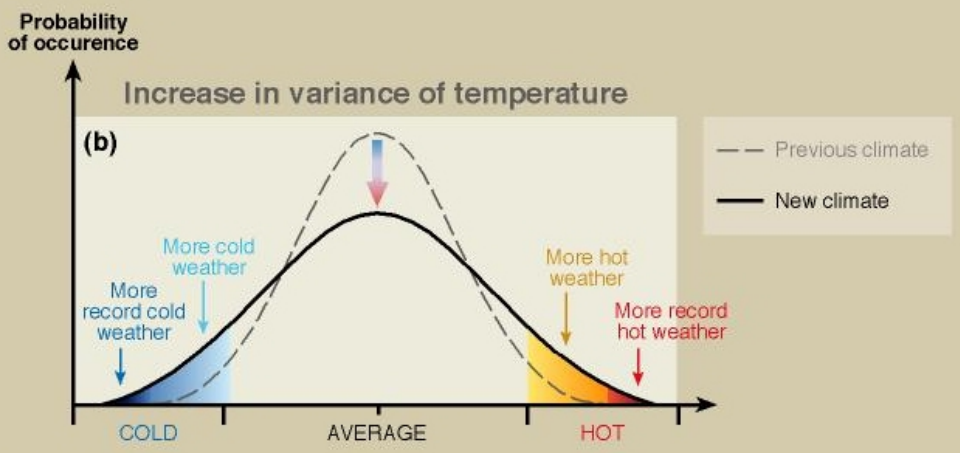

Land surface air temperature: 4 datasets
Temperature anomaly (ºC)
Sea-surface temperature: 5 datasets
Temperature anomaly (ºC)
Marine air temperature: 2 datasets
Temperature anomaly (ºC)
Sea level: 6 datasets
Sea level anomaly (mm)
Summer arctic sea-ice extent: 6 datasets
Extent (10⁶km²)
1850
1900
1950
2000
Year
Tropospheric temperature: 7 datasets
Temperature anomaly (ºC)
Ocean heat content(0-700m): 5 datasets
Ocean heat content anomaly (10²² J)
Specific humidity: 4 datasets
Specific humidity anomaly (g/kg)
Northern hemisphere (March-April) snow cover: 2 datasets
Extent anomaly (10⁶km²)
Glacier mass balance: 3 datasets
Mass balance (10³GT)
1940
1960
1980
2000
Year

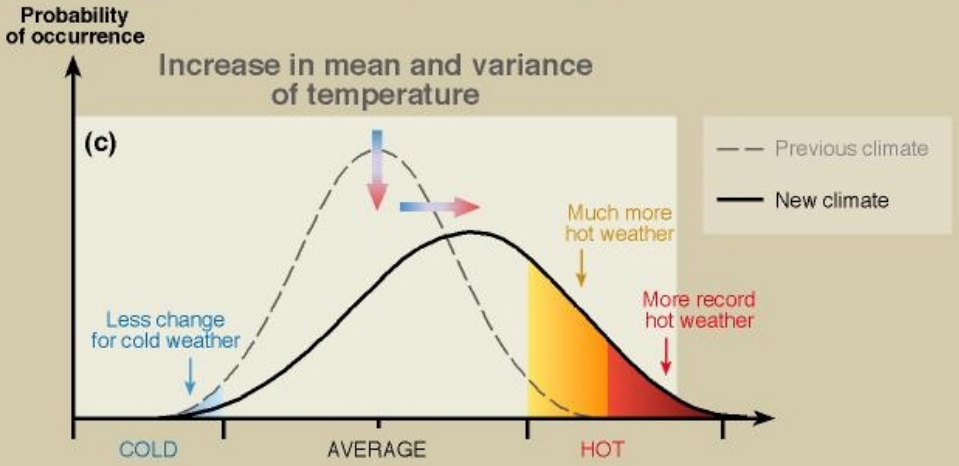
Sea Ice content



Effects on extreme temperatures

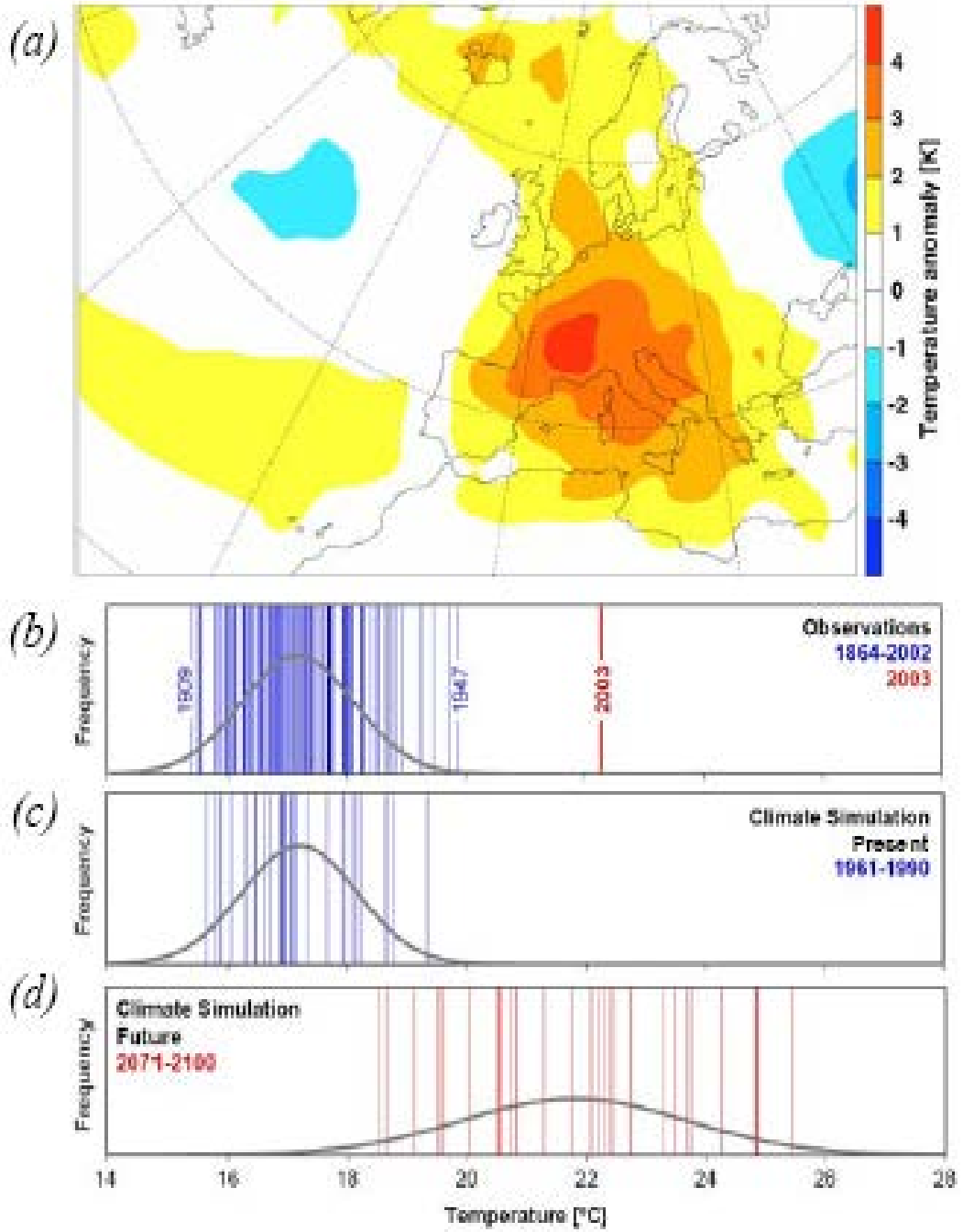






WMO

UNEP

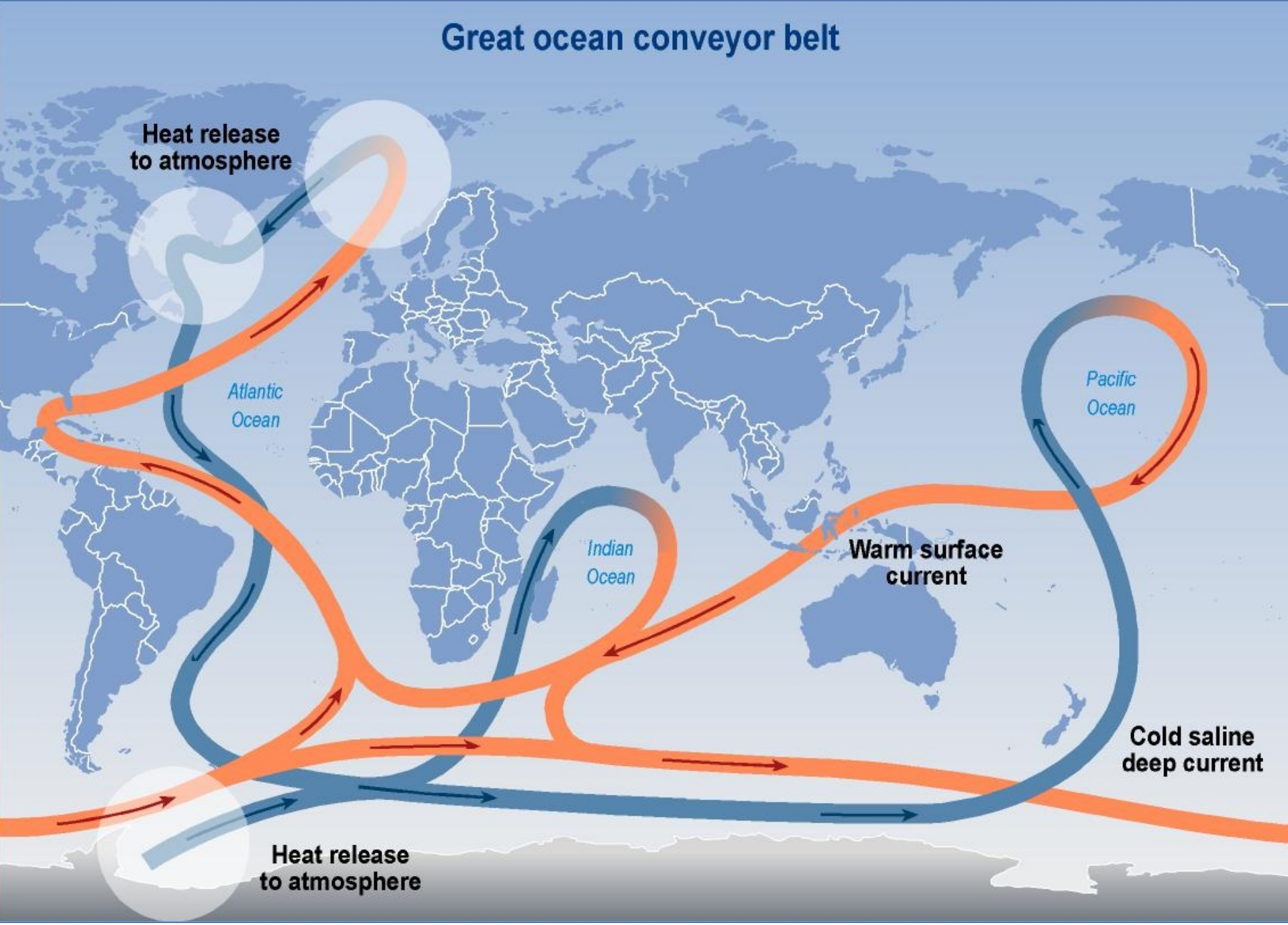


EU Regional Climate Variability: Observations (b) modeled for present (c) and future (d) conditions.

Note 2003 heat wave being far outside both observational and model range.

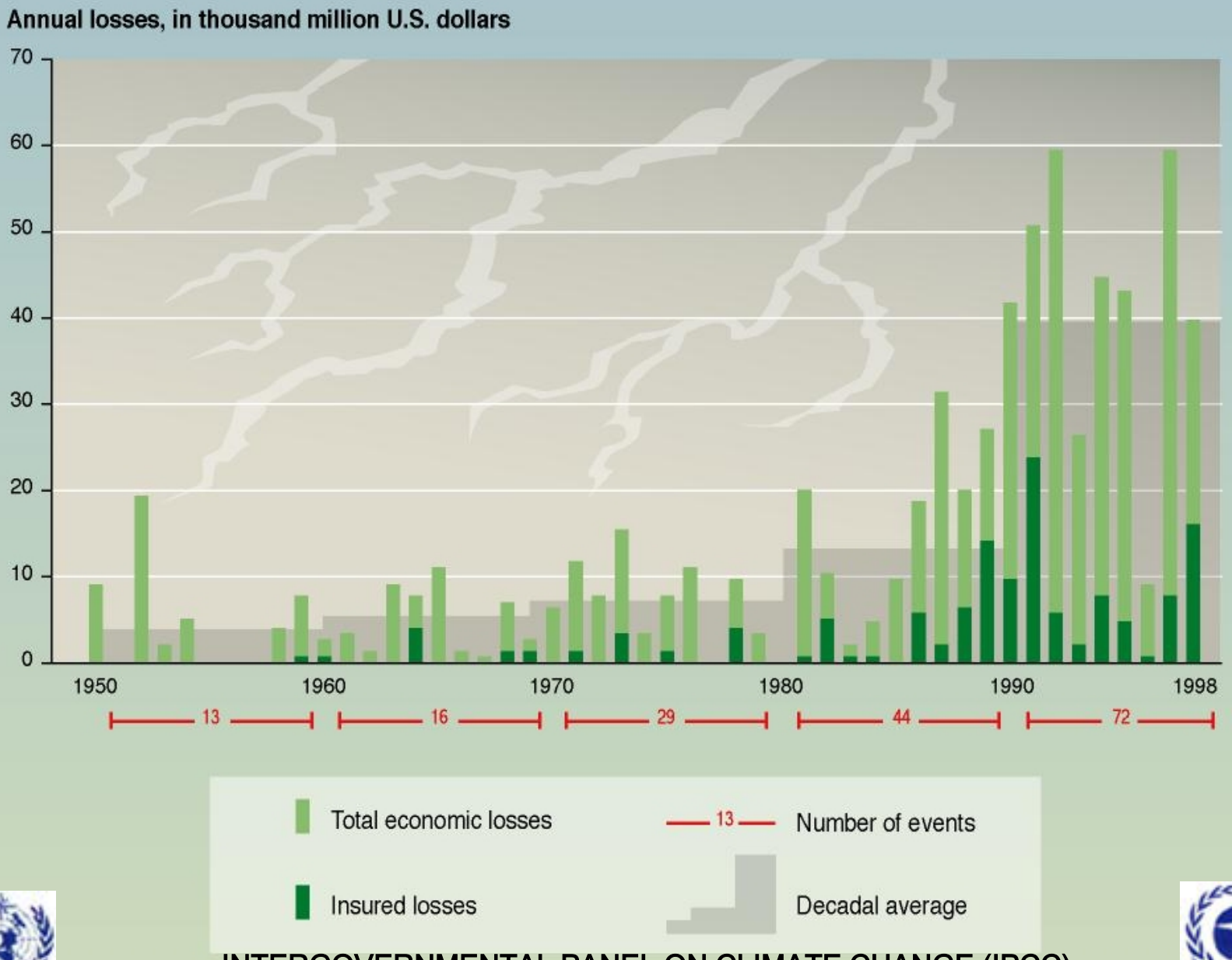
IPCC uncertainty terminology (adopted from Schneider and Moss) : <1% probability =“exceptionally unlikely” (but 2003 happened)

Source: IPCC-AR4



Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Global costs of extreme weather events (inflation-adjusted)

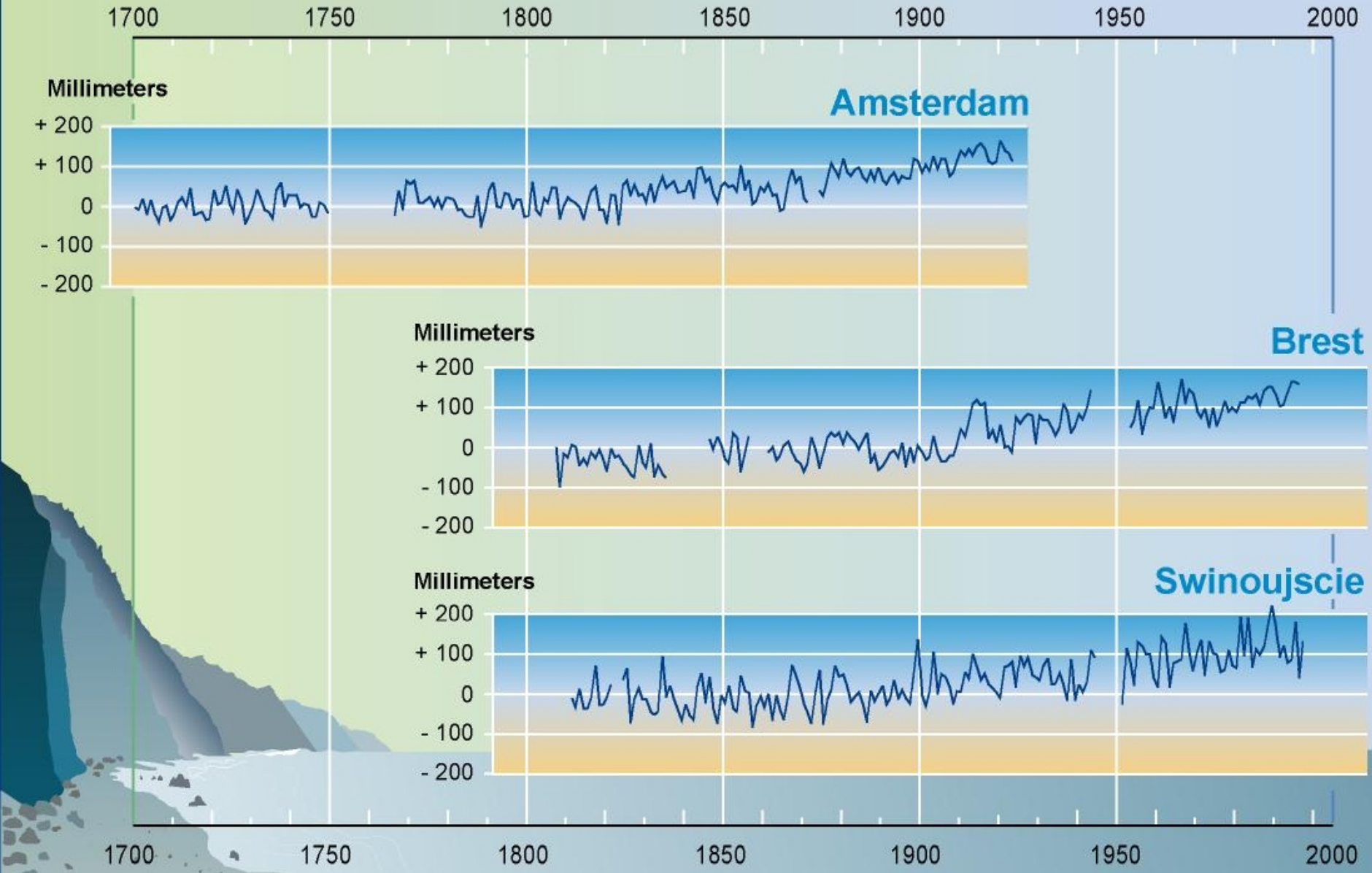


INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

WMO

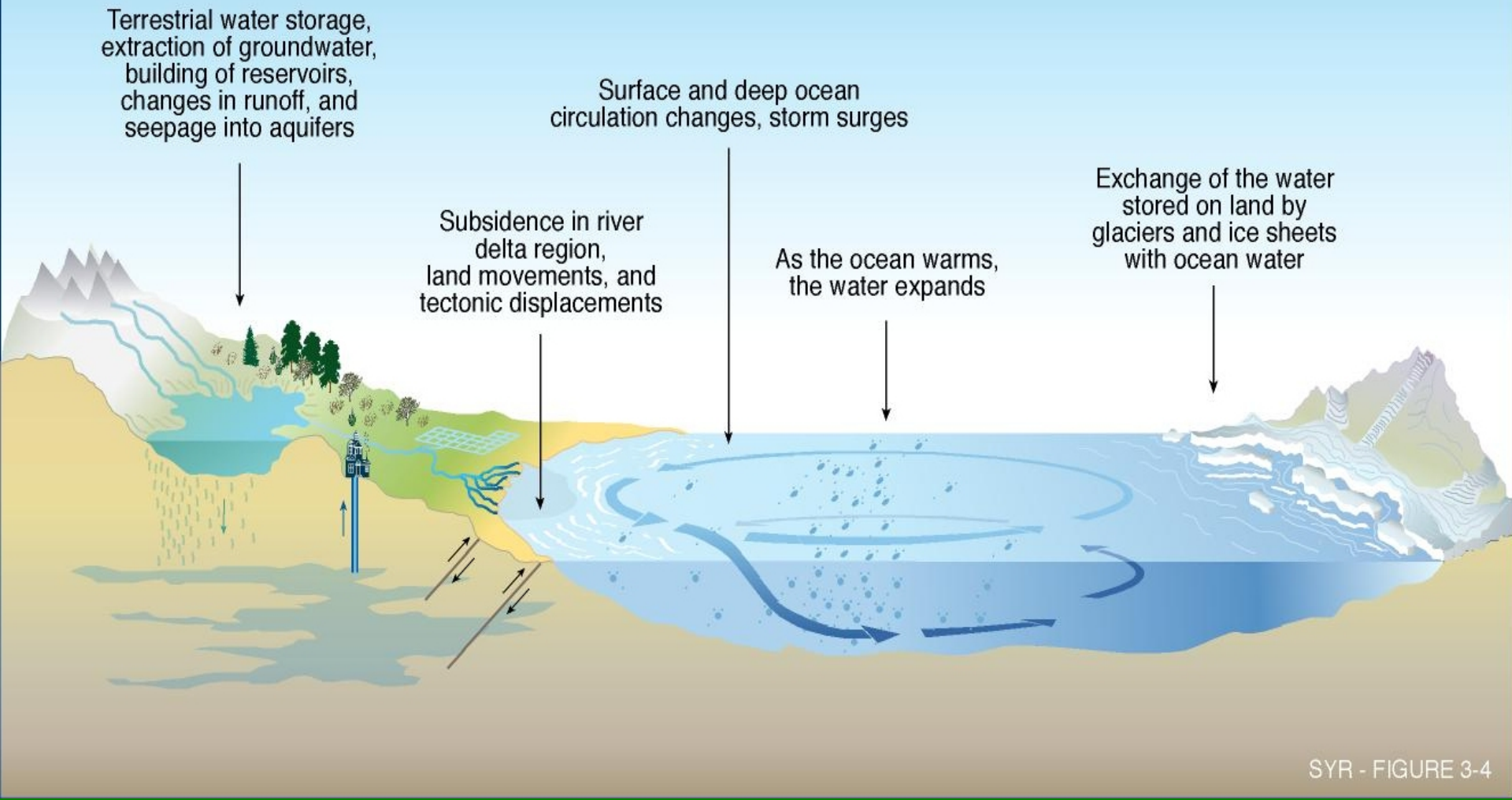
UNEP

Relative sea level over the last 300 years



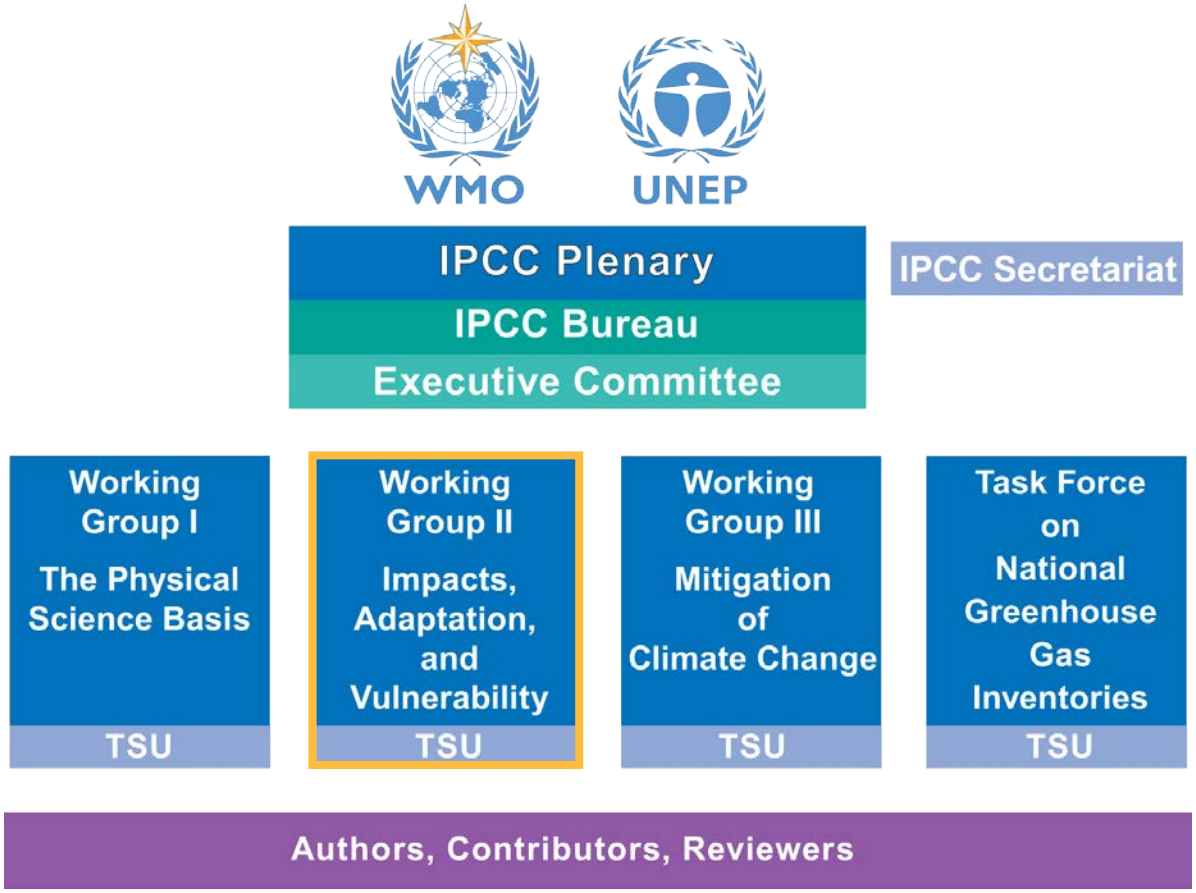
Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

What causes the sea level to change?

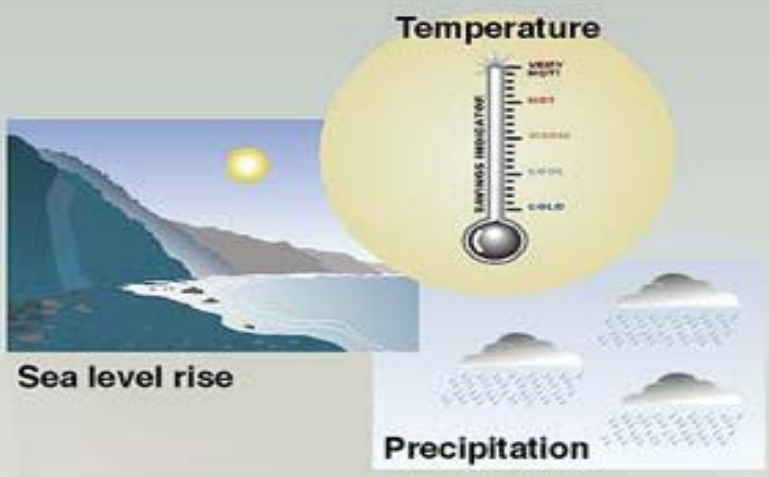


SYR - FIGURE 3-4

WGII: Impacts Adaptation and Vulnerability



Potential Impacts of Climate Change



Health impacts

Weather-related mortality
Infectious diseases
Air-quality respiratory illnesses

Agriculture impacts

Crop yields
Irrigation demands

Forest impacts

Forest composition
Geographic range of forest
Forest health and productivity

Water resources impacts

Water supply
Water quality
Competition for water

Impacts on coastal areas

Erosion of beaches
Inundation of coastal lands
additional costs to protect coastal communities

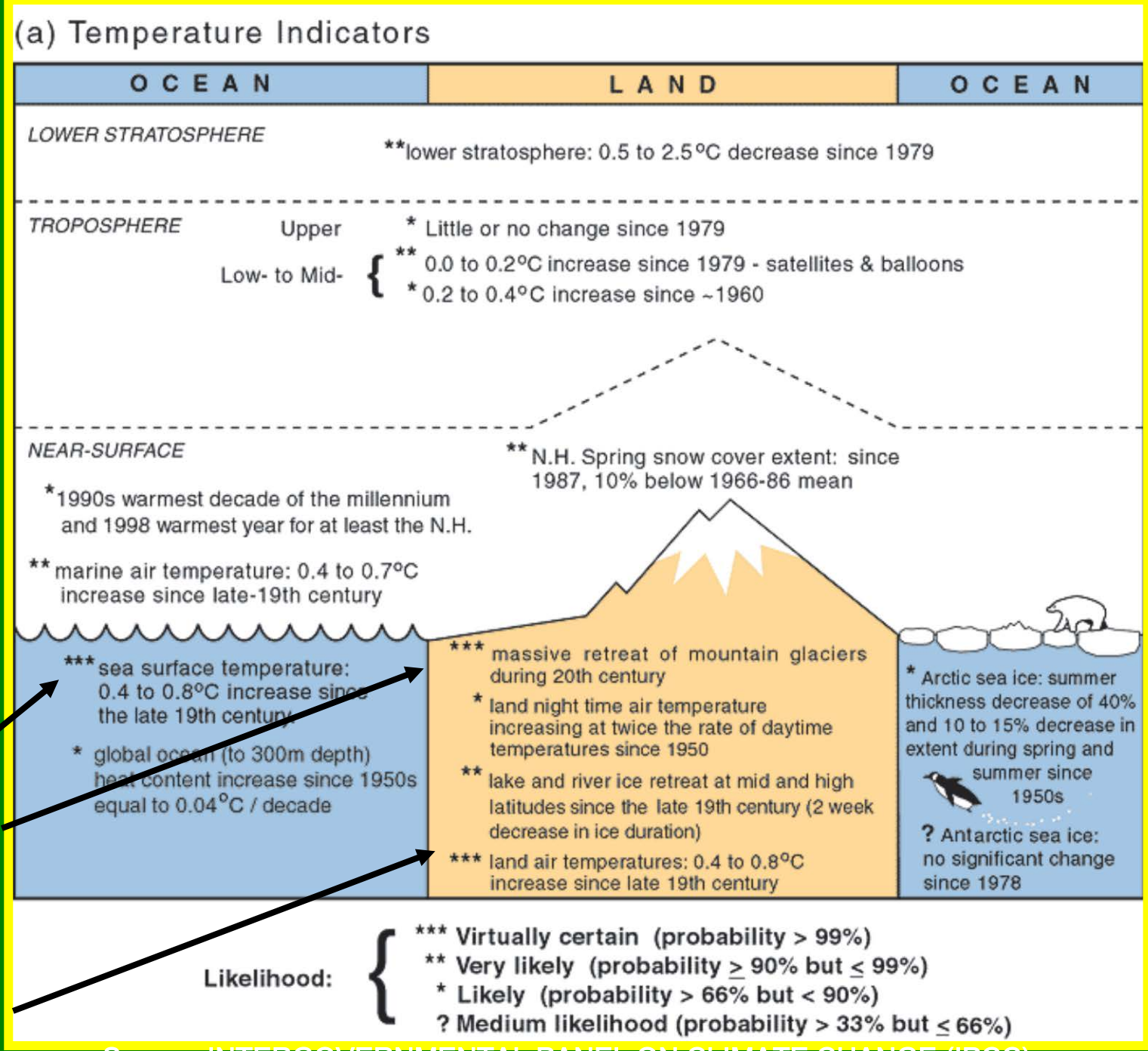
Species and natural areas

Loss of habitat and species

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

WMO

UNEP



Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

WGII: Impacts Adaptation and Vulnerability

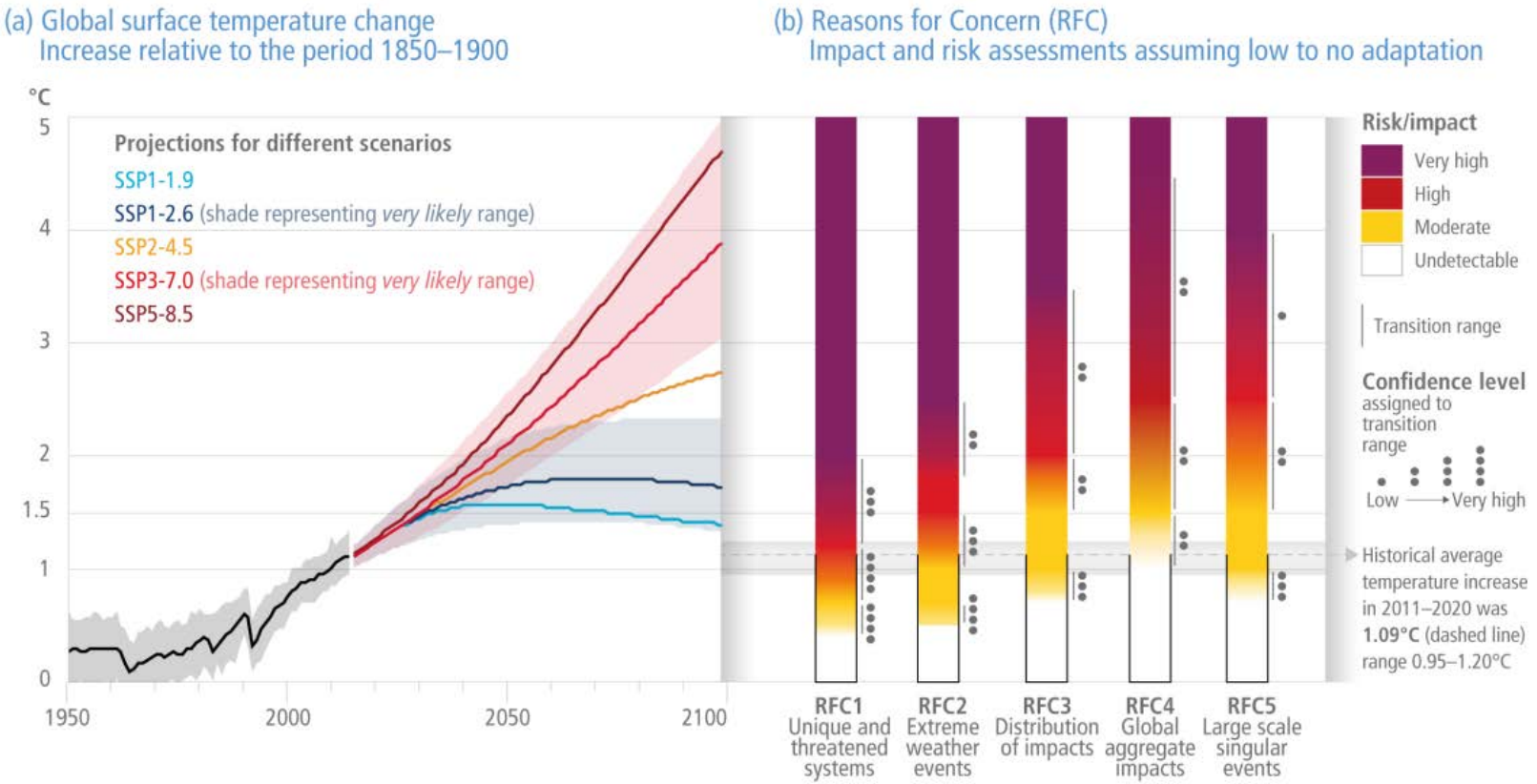
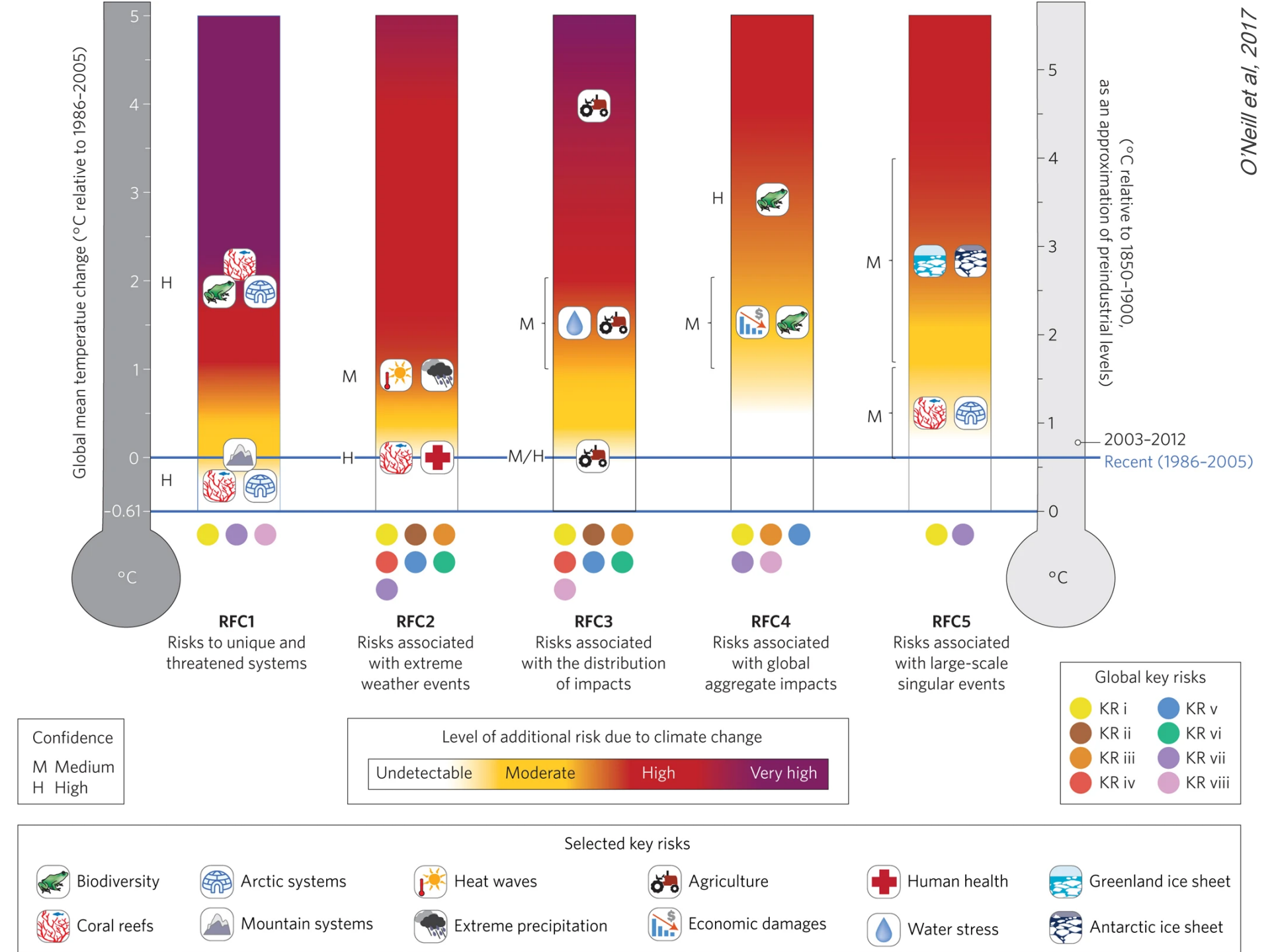


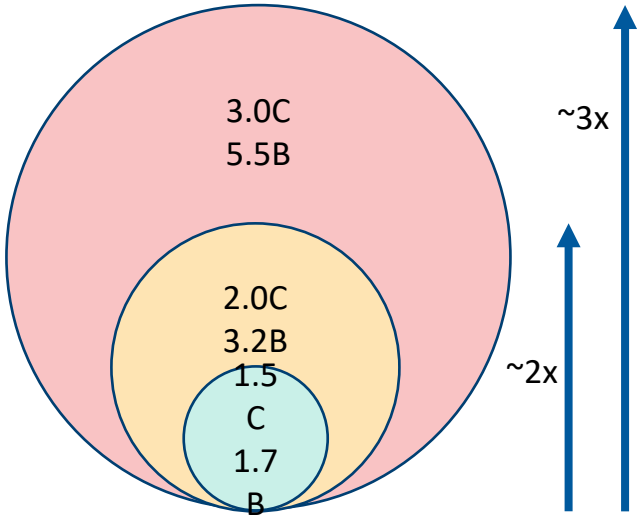
Image citation: IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contributions of WG1 to AR6. Figure SPM3.


Global mean temperatue change (°C relative to 1986–2005)
5
4
3
2
1
0
−0.61
°C
H
H
M
H
M/H
M
H
M
M
M
(°C relative to 1850–1900, as an approximation of preindustrial levels)
5
4
3
2
1
0
°C
2003–2012
Recent (1986–2005)
O'Neill et al, 2017
RFC1
Risks to unique and threatened systems
RFC2
Risks associated with extreme weather events
RFC3
Risks associated with the distribution of impacts
RFC4
Risks associated with global aggregate impacts
RFC5
Risks associated with large-scale singular events
Global key risks
KR i
KR ii
KR iii
KR iv
KR v
KR vi
KR vii
KR viii
Confidence
M Medium
H High
Level of additional risk due to climate change
Undetectable
Moderate
High
Very high
Selected key risks
Biodiversity
Coral reefs
Arctic systems
Mountain systems
Heat waves
Extreme precipitation
Agriculture
Economic damages
Human health
Water stress
Greenland ice sheet
Antarctic ice sheet

Impacts disproportionately affect world's poorest

Stresses magnify across multiple sectors by 2050

- Land use and agricultural production
- Energy production & consumption
- Water stress and drought



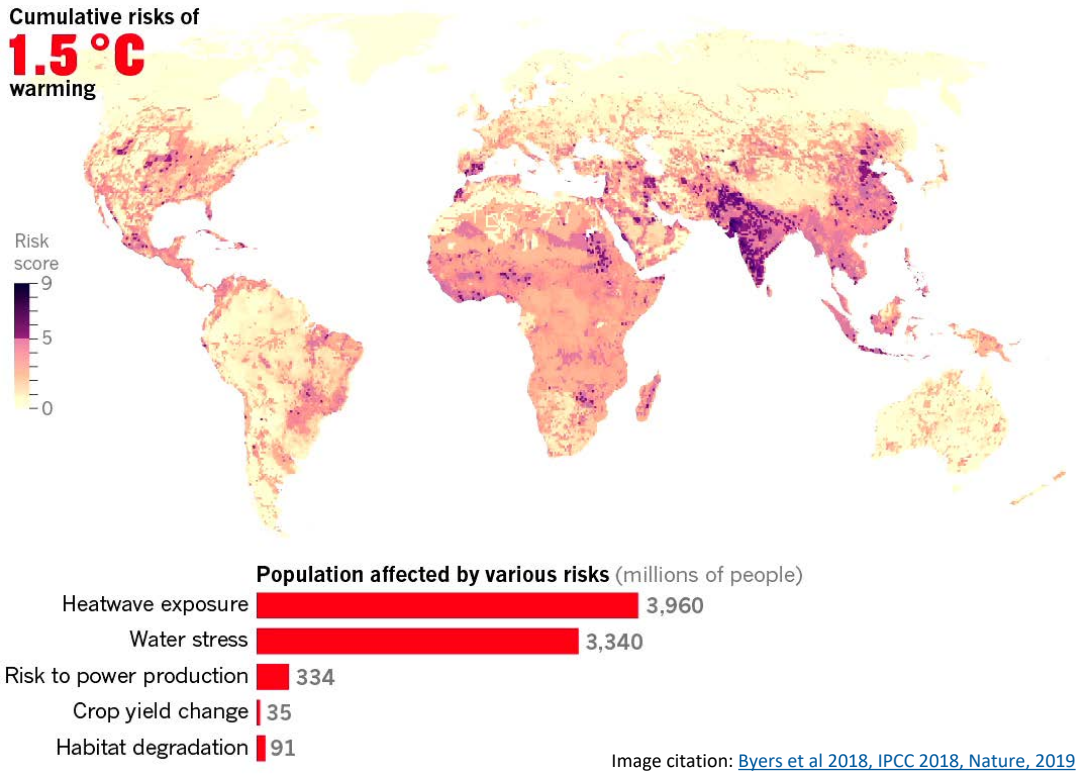


Image citation: Byers et al 2018, IPCC 2018, Nature, 2019

Some Impacts Appear Unavoidable (even under most stringent mitigation)

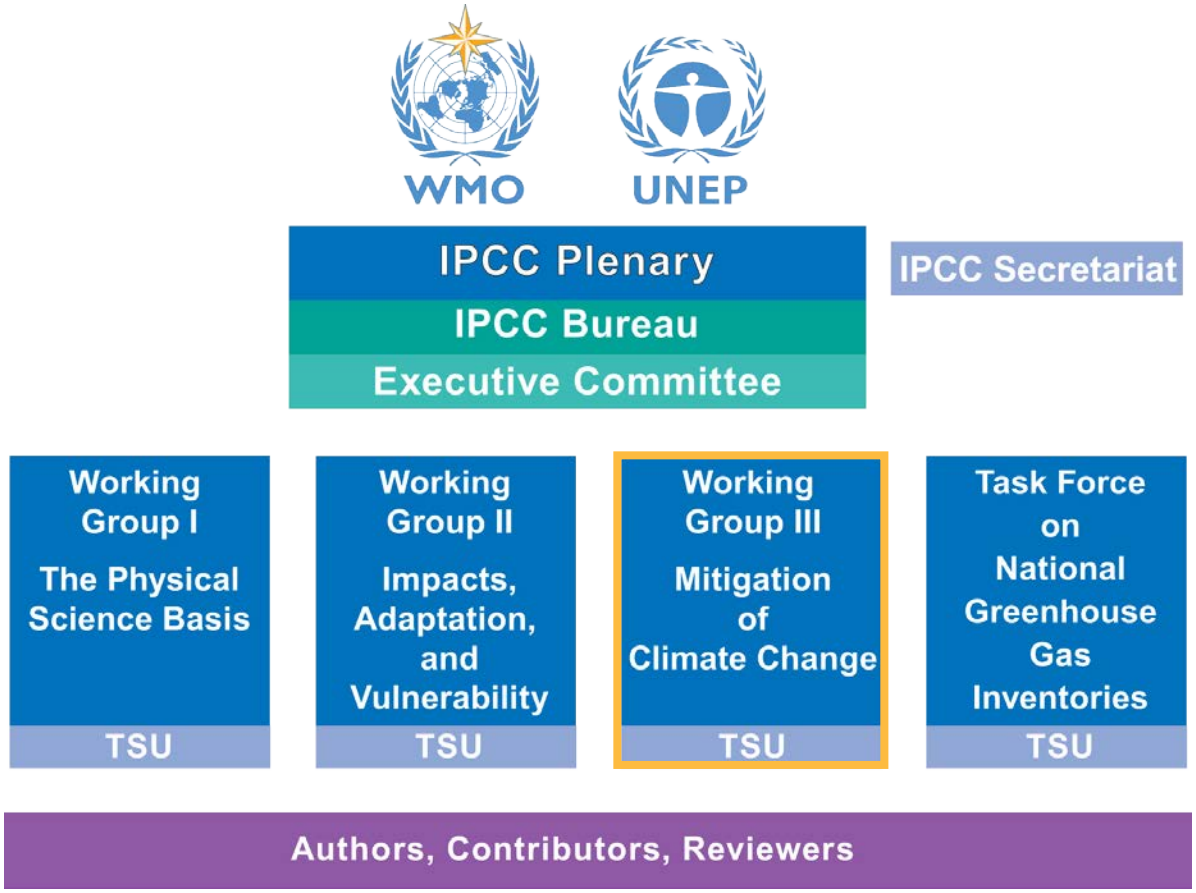
- Coral bleaching
- Species range shift
- Drought risk and water scarcity (Mediterranean, and particularly in the dry tropics and subtropics)
- Risk of wildfire
- Coastal damage from floods combined with sea level rise

Types of adaptation to climate change

	Anticipatory	Reactive
Natural Systems		• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
Human Systems — Private	• Purchase of insurance • Construction of houses on silts • Redesign of oil rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
Human Systems — Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment

Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

WGIII: Mitigation of Climate Change



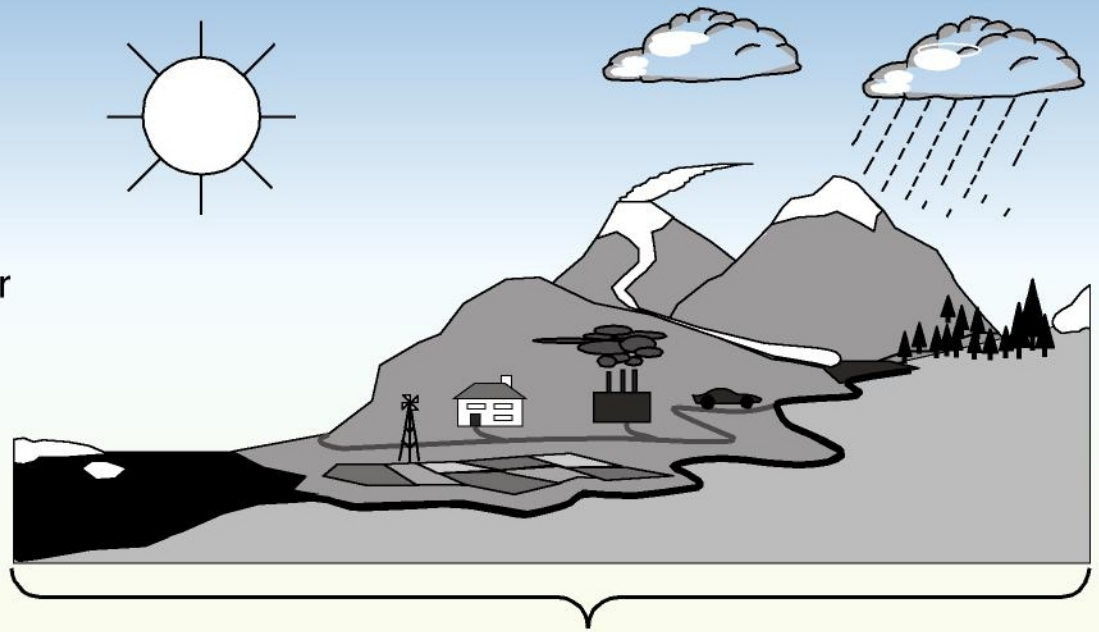
Key questions about the climate system and its relation to human kind

What changes have occurred?

Observations:

- temperatures
- precipitation
- snow / ice cover
- sea level
- circulation
- extremes

How well are the past and present climates understood?



What changes could lie ahead?

Simulations:

- natural variation
- forcing agents
- global climate
- regional climate
- high impact events
- stabilisation

Observations vis-à-vis Simulations

Timeline: Palaeo & Instrumental Periods → The Present → The Future

Source: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Energy balance and carbon cycle

A fundamental emergent outcome of climate science is the *linear relation between cumulative CO_2 and warming* – the Transient Climate Response to Emissions (TCRE)

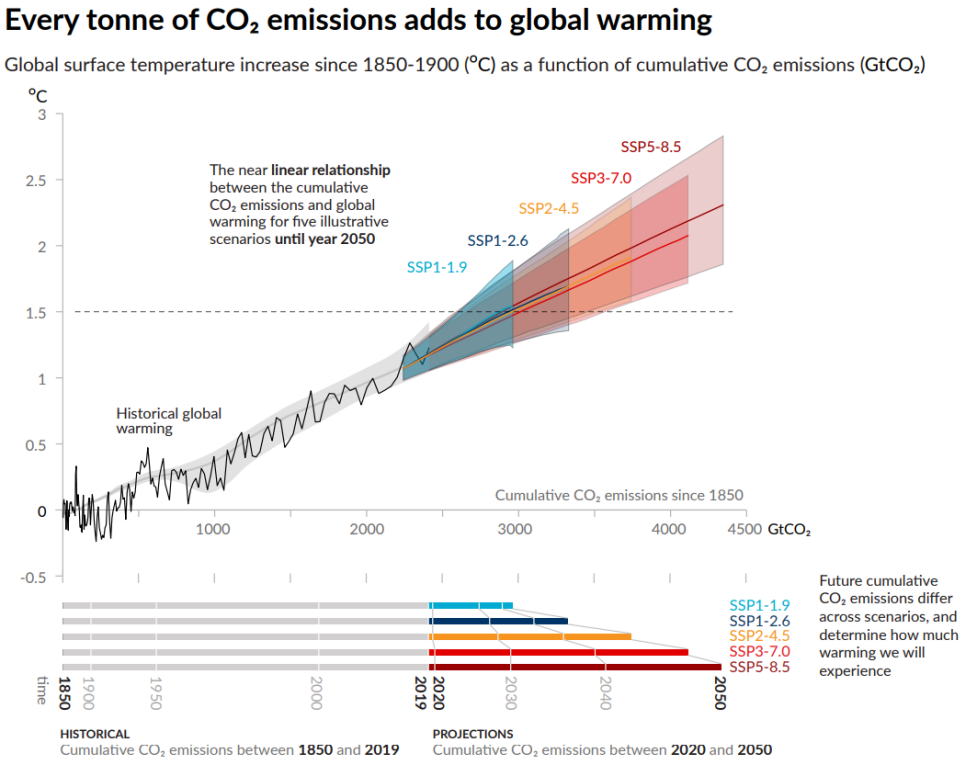
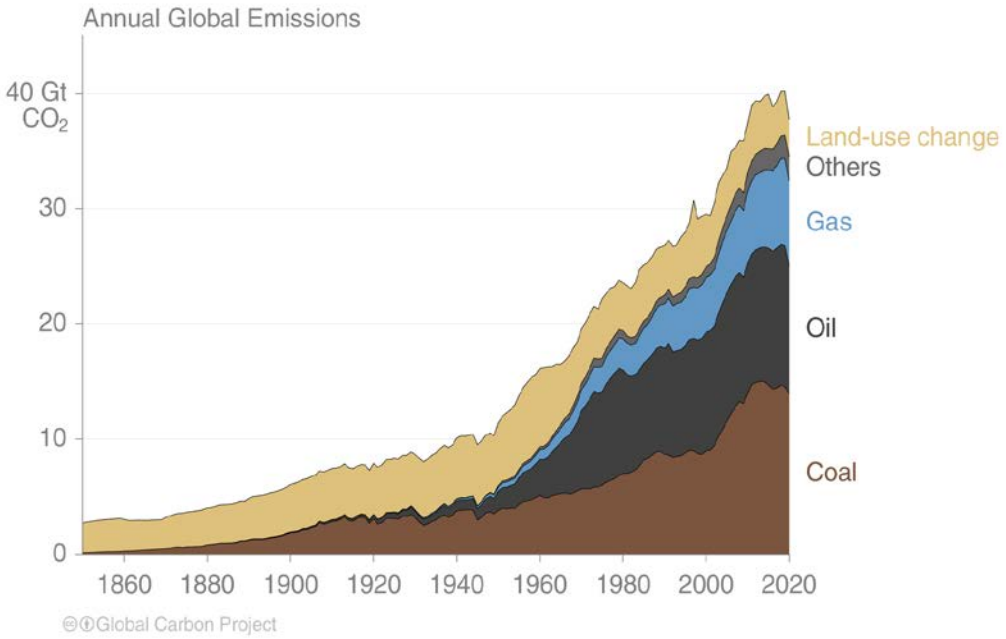


Image citation: IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contributions of WG1 to AR6.

A single, fundamental challenge: transitioning energy production and consumption away from fossil fuels



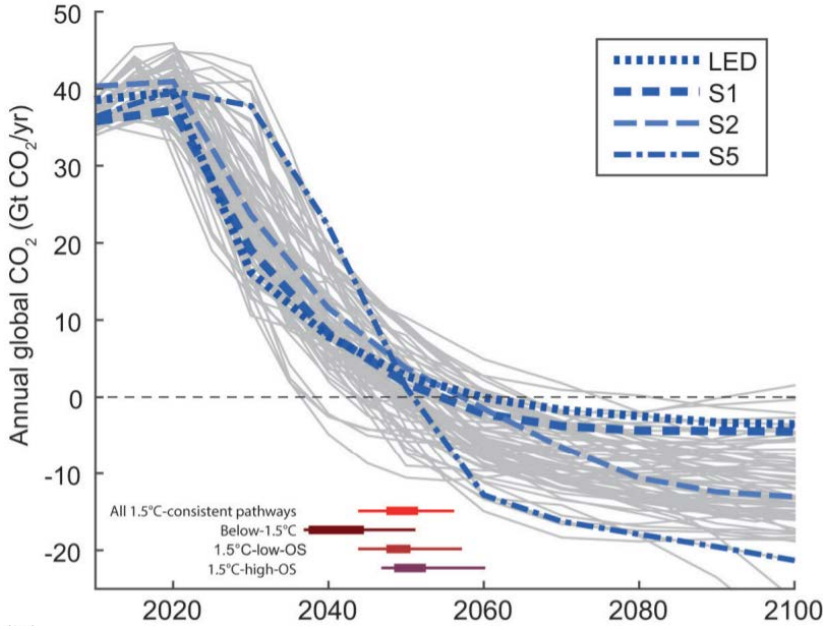
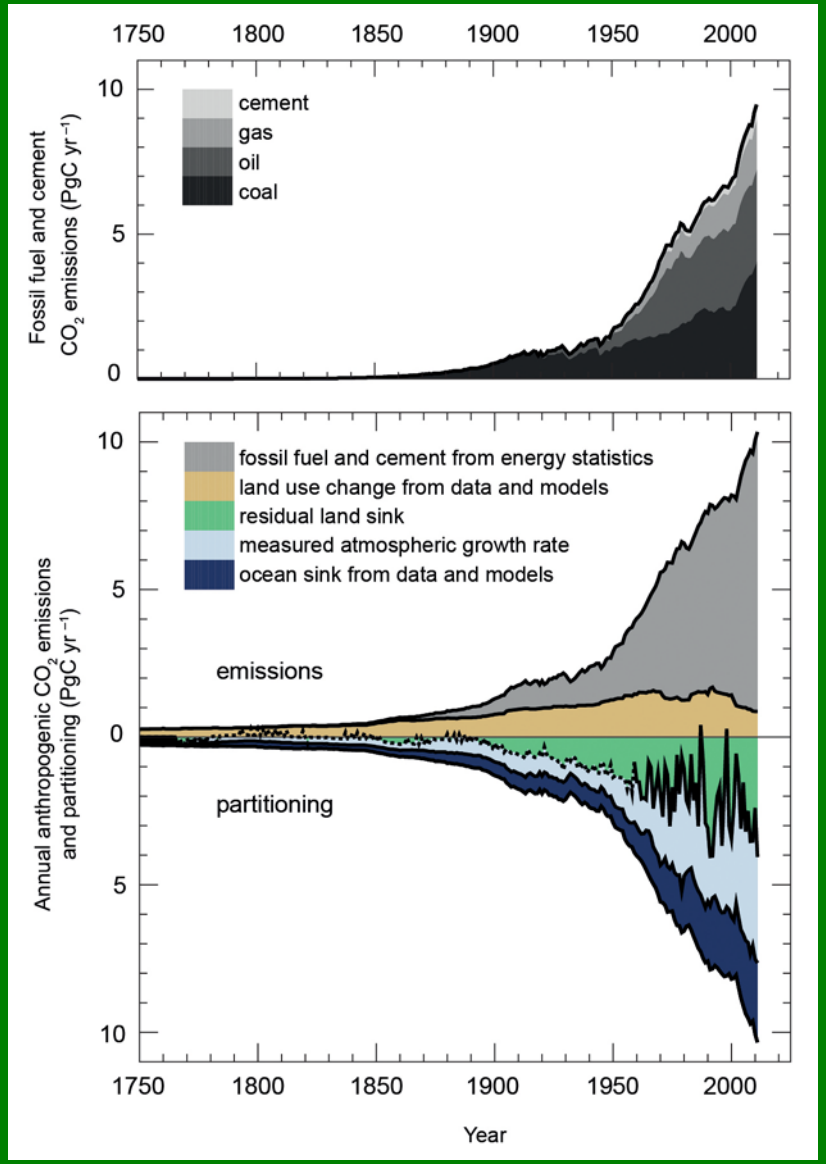


Image citation Friedlingstein et al 2021; Global Carbon Project 2021
Image citation: IPCC, 2018: Global warming of 1.5°C. Figure 2.5(a).

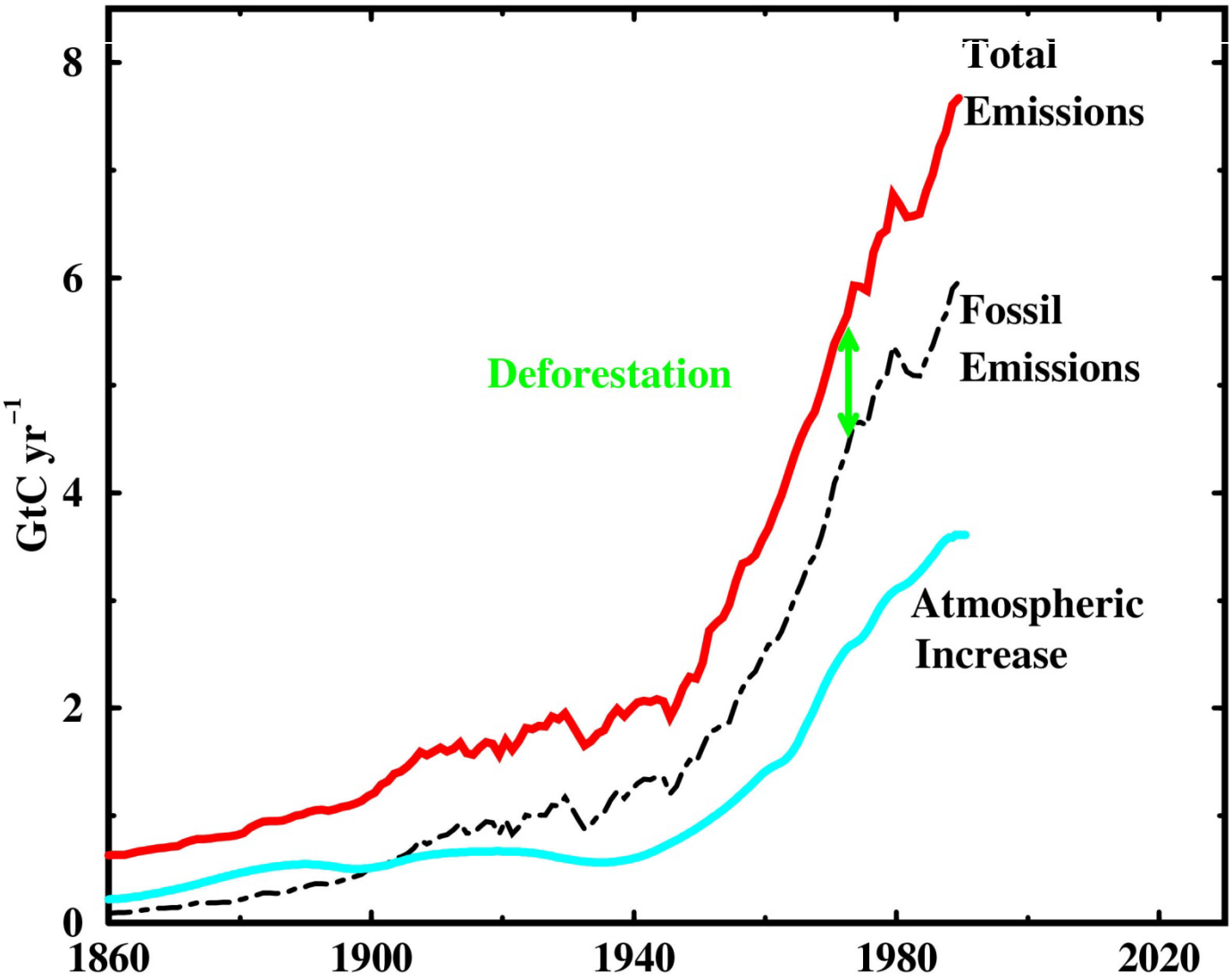
Global Carbon Budget



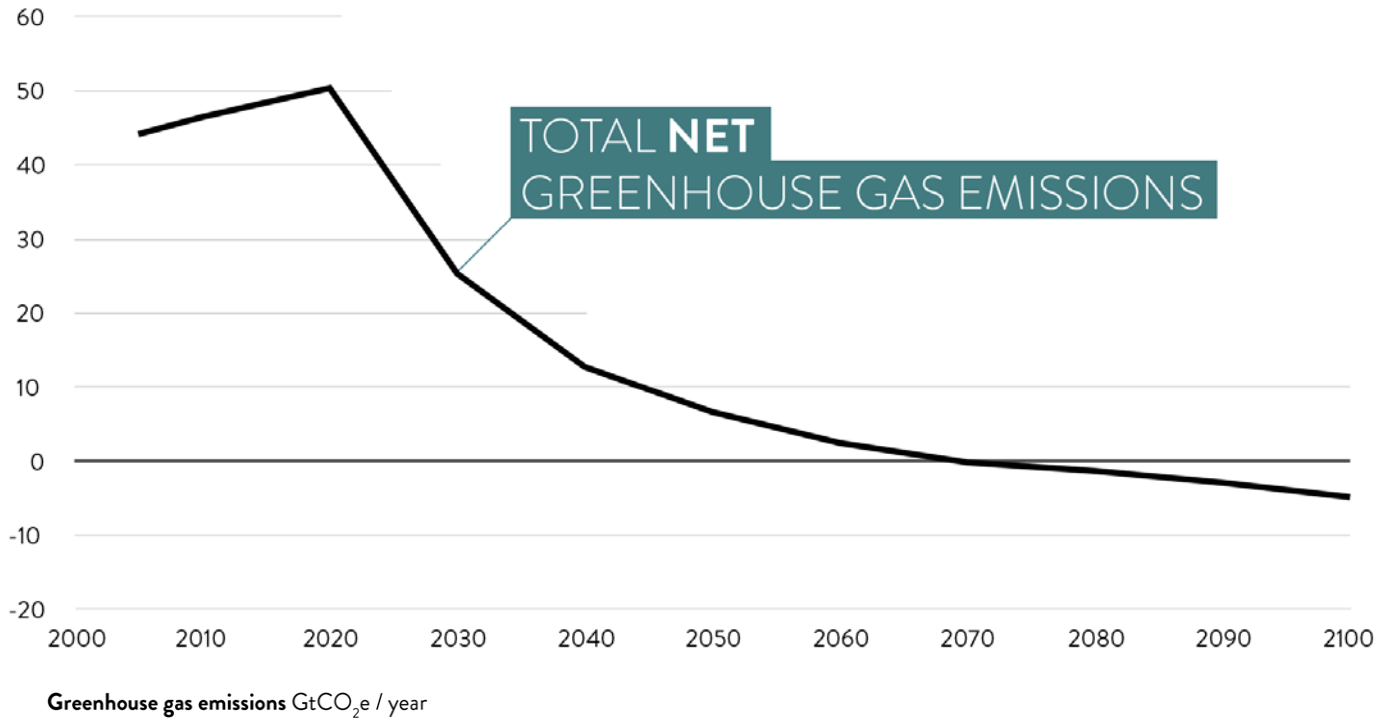
Energy Systems Analysis

Source: IPCC AR5

Carbon Emissions and Atmospheric Increase



Anatomy of a 1.5°C emission pathways



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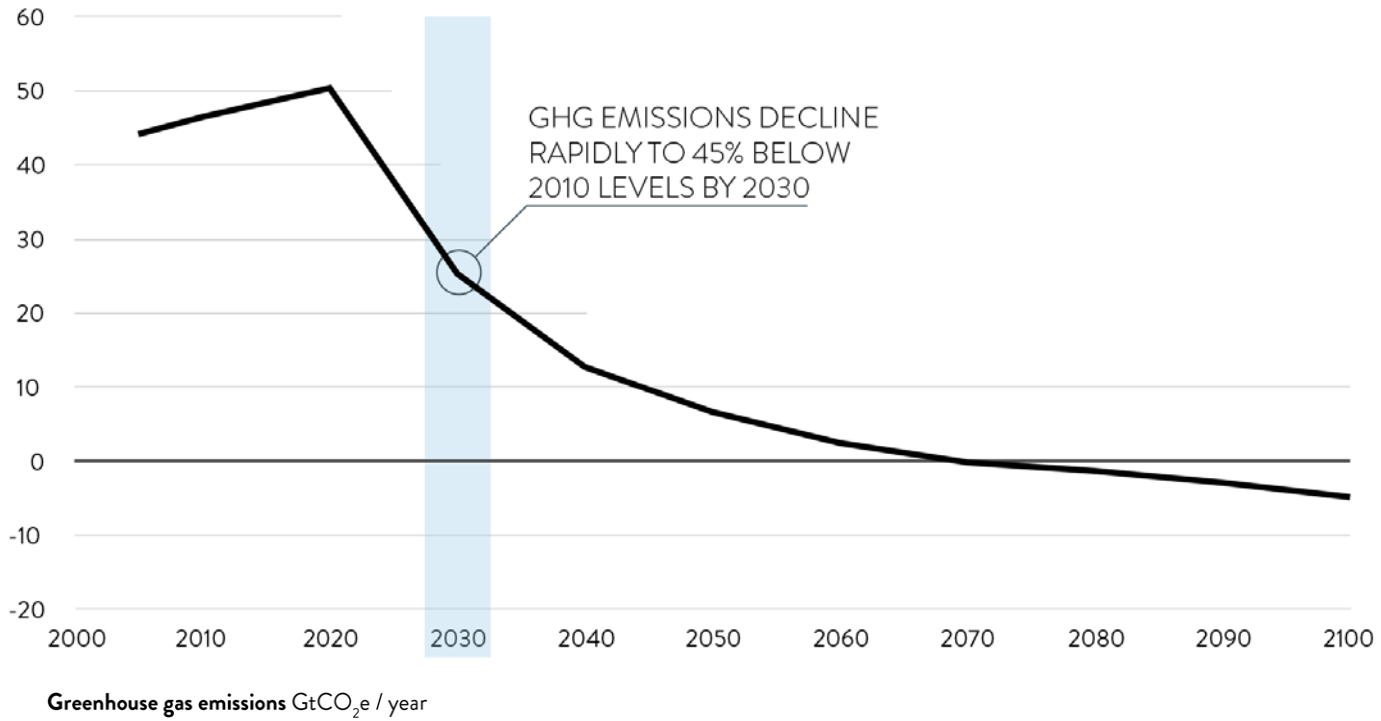
Anatomy of a 1.5°C emission pathways



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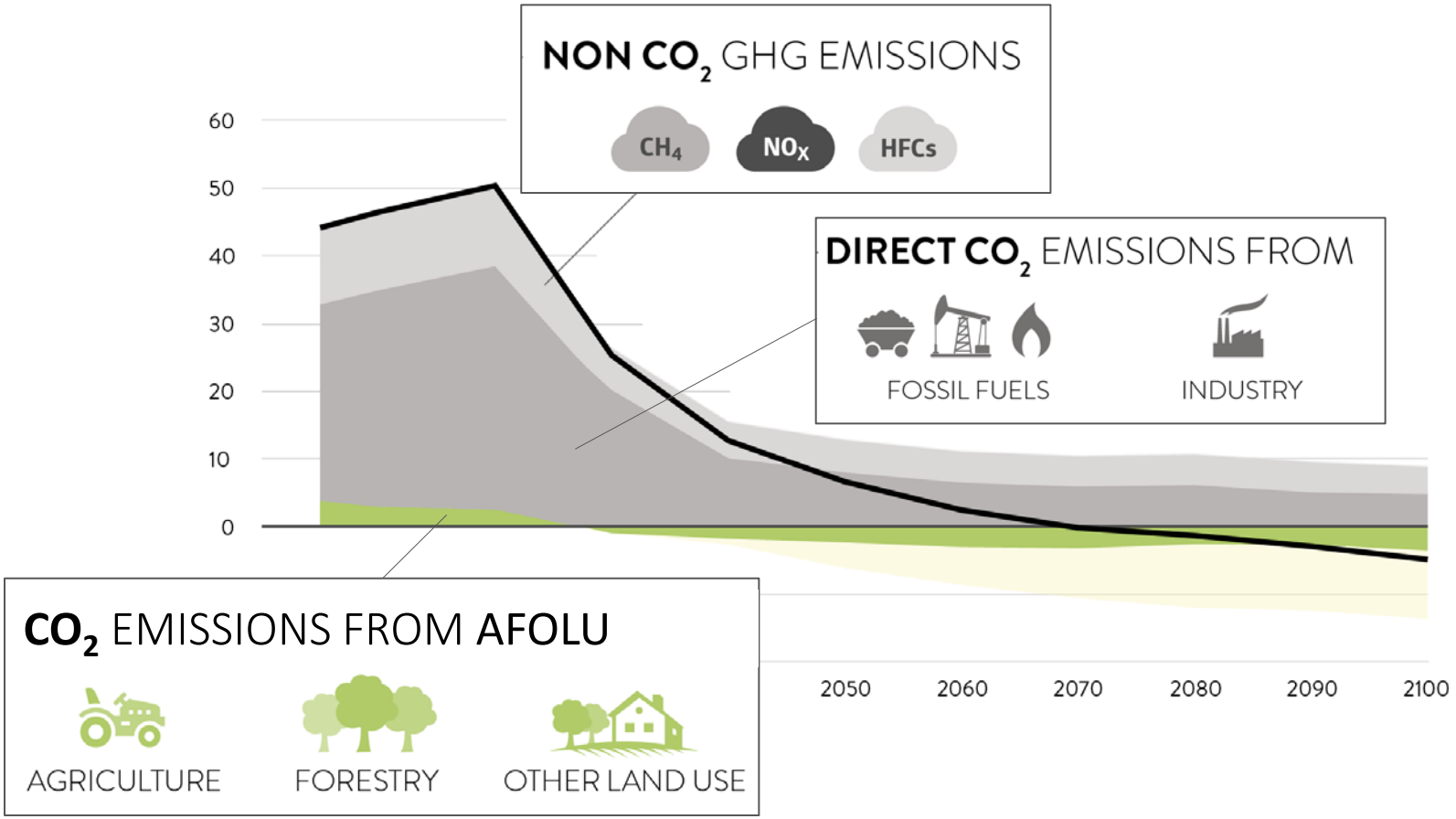
Anatomy of a 1.5°C emission pathways



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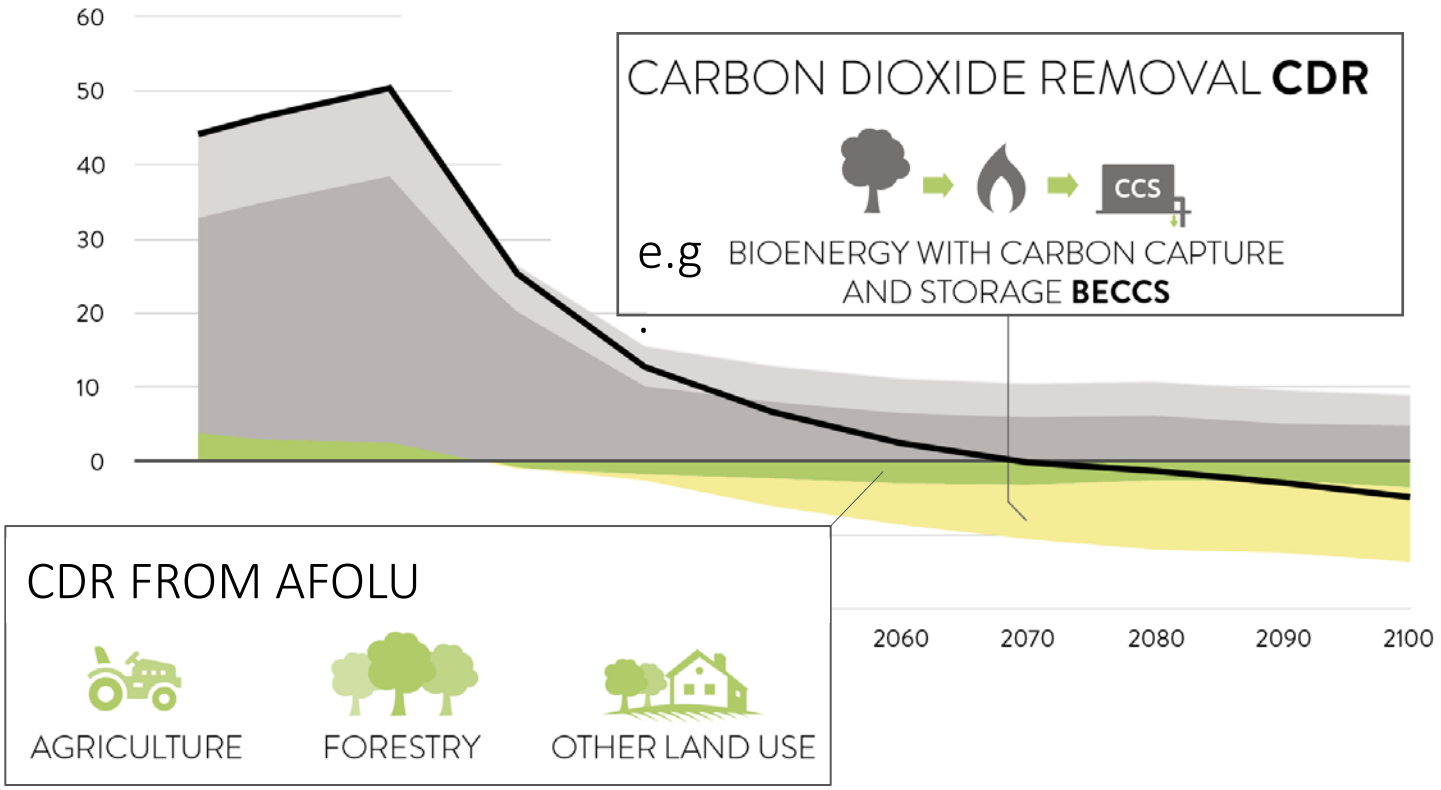
Anatomy of a 1.5°C emission pathways



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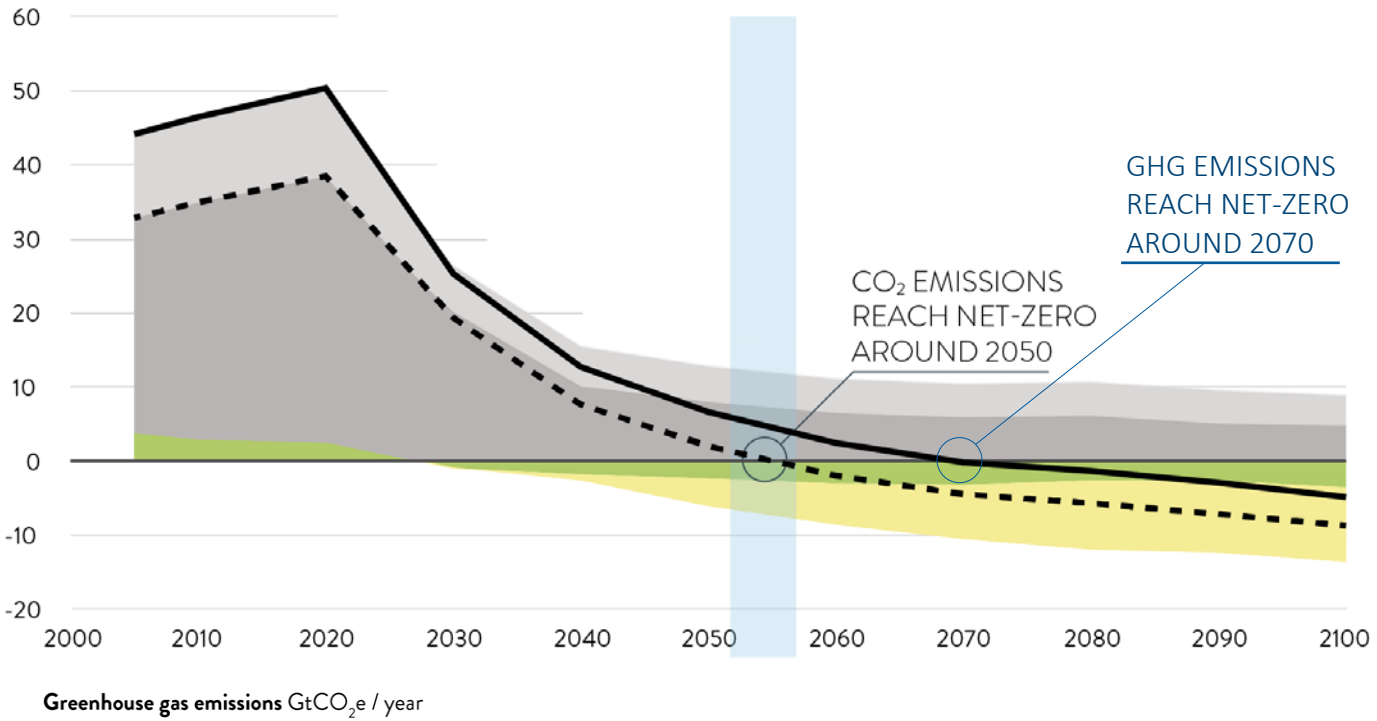
Anatomy of a 1.5°C emission pathways



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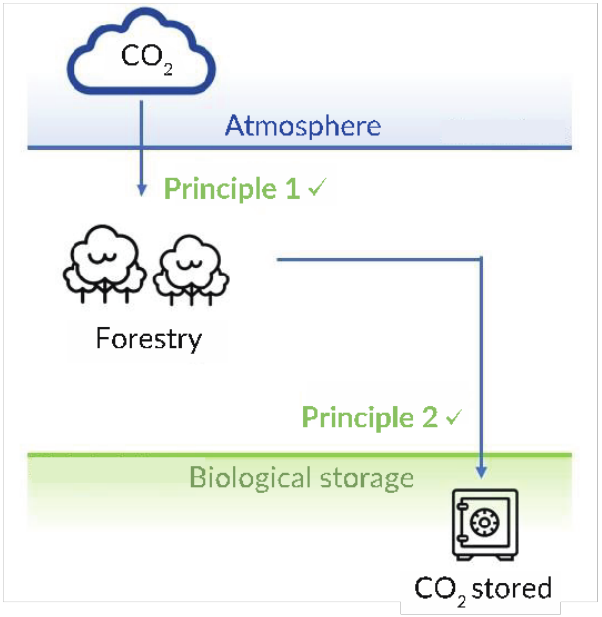
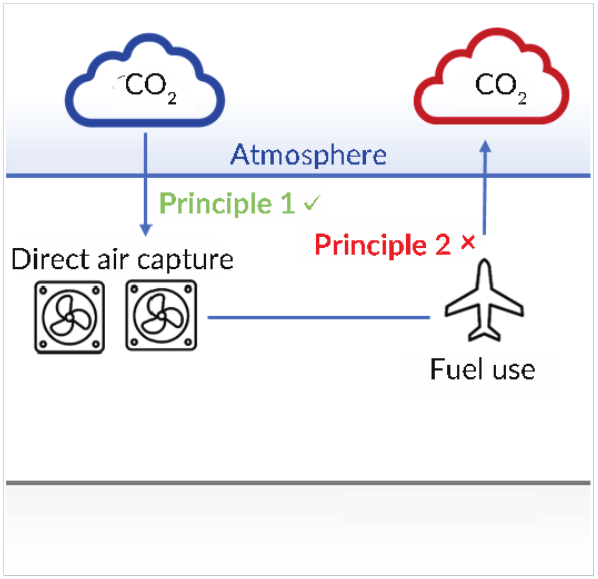
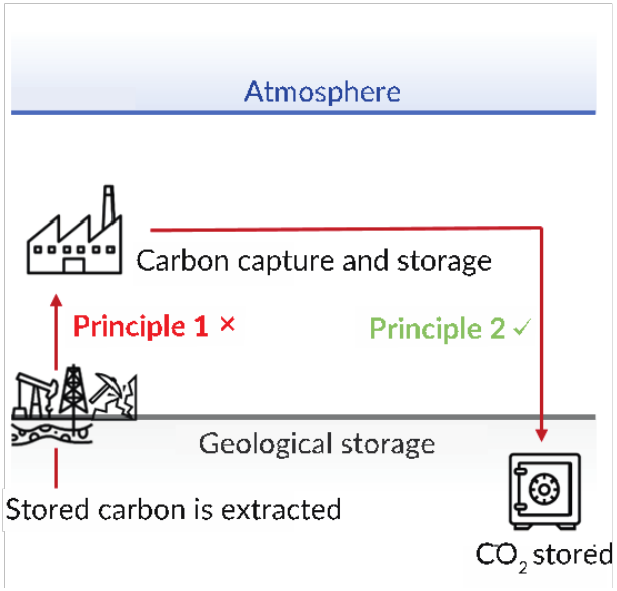
Carbon Dioxide Removal (CDR)

CDR methods capture **CO_2 from the atmosphere** (Principle 1) and **durably store it** (Principle 2). They must be **additional to natural** processes (Principle 3).





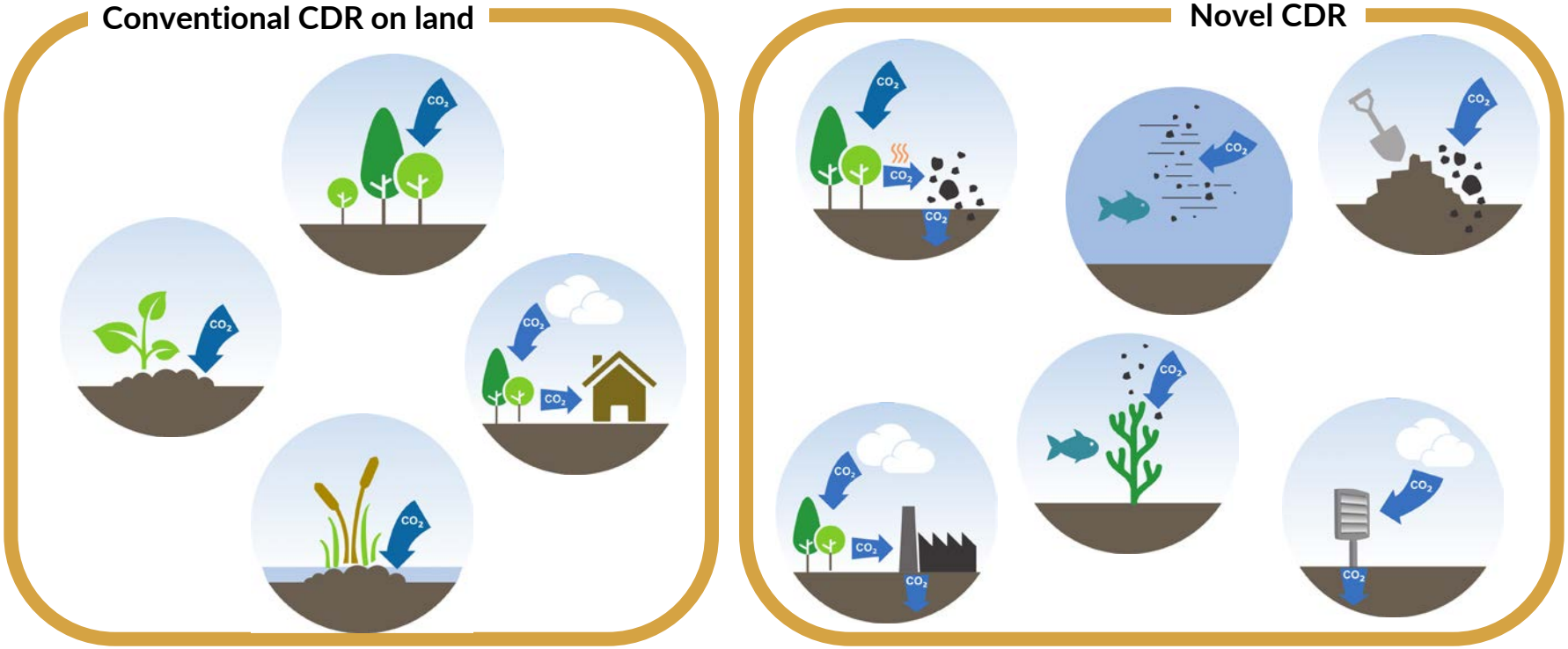


Source: Zero Emissions Platform (2020)

THE STATE OF Carbon Dioxide Removal https://www.stateofcdr.org/

gidden@iiasa.ac.at / @mattgidden

Many CDR methods



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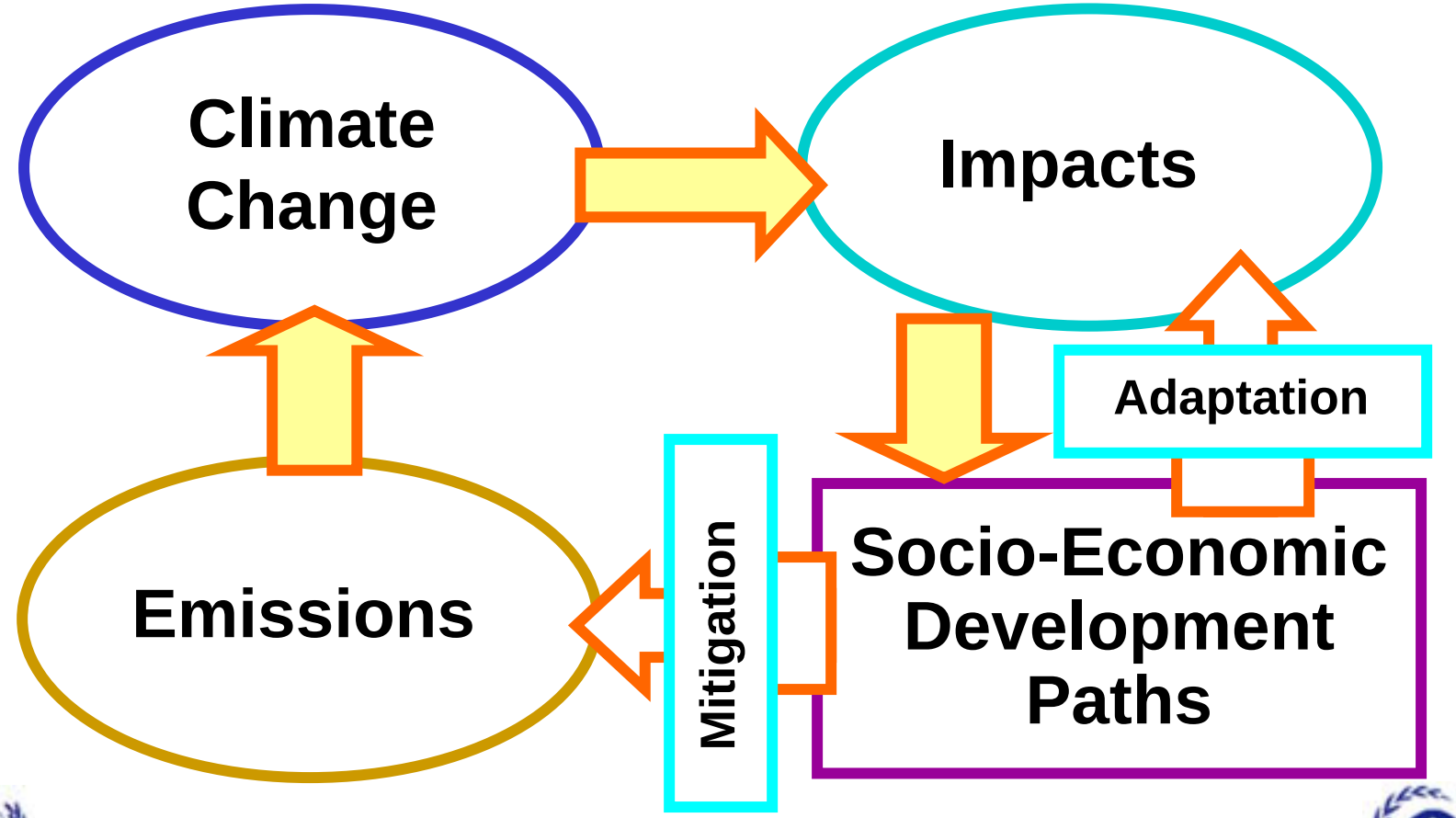
Integrated Assessment Framework

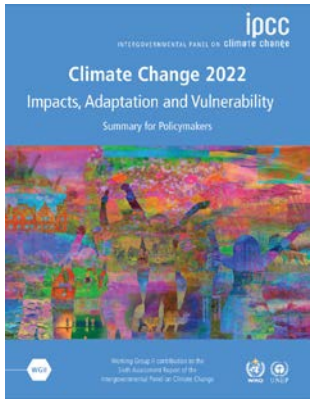
IPCC 2001



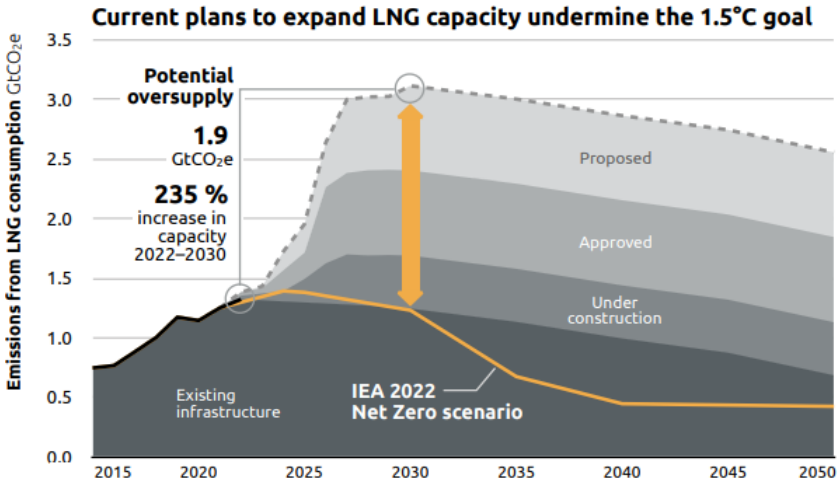
The Conference of Parties to the UNFCCC

- COP27 in Sharm El-Sheikh was billed as the ‘Implementation COP’
- Holds most Glasgow mitigation language, but adds ‘low-emission energy’ (gas?)
- Loss and Damage fund established
- Bridgetown Agenda for MDB reform strongly supported

Latest science and latest action



"**SPM B.1.2.** Climate change has caused **substantial damages**, and increasingly **irreversible losses**, in terrestrial, freshwater and coastal and open ocean marine ecosystems (high confidence). The extent and magnitude of climate change impacts are **larger than estimated in previous assessments** (high confidence). **Widespread deterioration of ecosystem structure and function**, resilience and natural adaptive capacity, as well as shifts in seasonal timing **have occurred due to climate change** (high confidence), with adverse socioeconomic consequences (high confidence). Approximately **half of the species assessed globally have shifted polewards** or, on land, also to higher elevations (very high confidence). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (high confidence), as well as **mass mortality events on land and in the ocean** (very high confidence) and loss of kelp forests (high confidence). Some losses are **already irreversible**, such as the first species extinctions driven by climate change (medium confidence). Other **impacts are approaching irreversibility** such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (medium confidence) and Arctic ecosystems driven by permafrost thaw (high confidence)."



COP26 final battle: "Phase ~~out~~ down coal"
COP27 battle: "Phase down ~~fossil fuel~~ coal"

Image citation: IPCC, March 2022, Climate Change 2022 *Impacts, Adaptation, and Vulnerability*
Image citation: Climate Action Tracker, November 2022