FRANKFURT UNIVERSITY OF APPLIED SCIENCES

# Environmental Assessment

**Fachbereich 2** Informatik und Ingenieurwissenschaften

# Organizational matters

- office hours: Tuesdays 2:30 - 4:30 pm, BCN 326
- email: sebastian.schaefer@fb2.fra-uas.de

- lecture (with integrated exercises): 15 sessions until February 7
- final exam: 90 minutes

FRANKFURT UNIVERSITY OF APPLIED SCIENCES

# Outline


1 Introduction

2 Counting emissions and voluntary emission market

3 The big market failure?

4 Pricing carbon

5 International cooperation for an international problem

6 From theory to practice – the EU ETS

7 Assessing the impact of the EU ETS

8 Subsidizing RES

9 Decoupling the EU ETS from demand-side effects

10 Building wind power plants in Germany

11 Preparation for exams – questions

# Related literature


- Pindcyck, R. S., Rubinfeld, D., L.: Microeconomics, Pearson, 9th ed., 2017.
- Stern, N.: The Economics of Climate Change – The Stern Review, Cambridge University Press, New York, 2007.
- Endres, A., Radke, V.: Economics for Environmental Studies, 2nd ed., Springer, Berlin Heidelberg, 2018.
- Sue Wing, I., Ellerman, A.D., Song, J., 2009. Absolute versus intensity limits for $CO_2$ emission control: performance under uncertainty. In: The design of climate policy. MIT Press, Cambridge (Massachusetts). In: CESIfo Working Paper No. 2749.
- Schäfer, S. Decoupling the EU ETS from subsidized renewables and other demand side effects: lessons from the impact of the EU ETS on $CO_2$ emissions in the German electricity sector. *Energy Policy* 2019, **133**, 110858.

# Environment and economics

**Figure:** Forest near Siegen; source: Frank Haubenschild `https://www.haubenschild.de/waldsterben/`

# The Greenhouse Effect

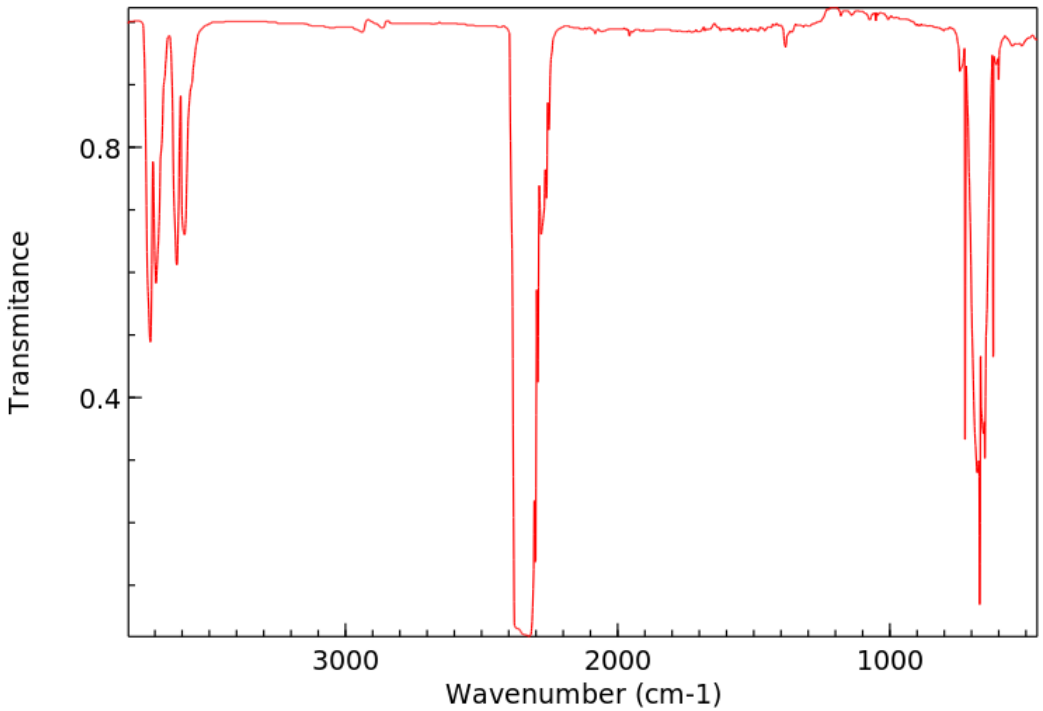


**Figure:** Infrared spectrum of $CO_2$; source: NIST Chemistry Webook `https://webbook.nist.gov/cgi/cbook.cgi?Spec=C124389&Index=1&Type=IR&Large=on`

- transmittance of radiation with low wave length
- interaction with matter leads to transformation into heat radiation (infrared)
- absorption of infrared radiation with longer wave lengths

# The Greenhouse Effect


**Figure:** Jean Baptiste Joseph Fourier (1768 – 1830); source: Wikipedia

- 1827 Jean Baptiste Fourier understood the atmosphere's asymmetry with respect to incoming light and outgoing infrared.
- 1859 John Tyndall presented a *"Note on the Transmission of Radiant Heat through Gaseous Bodies"*.
- 1896 Svante Arrhenius calculated that a doubling of $CO_2$ in the atmosphere would induce an average surface warming of 1°C.

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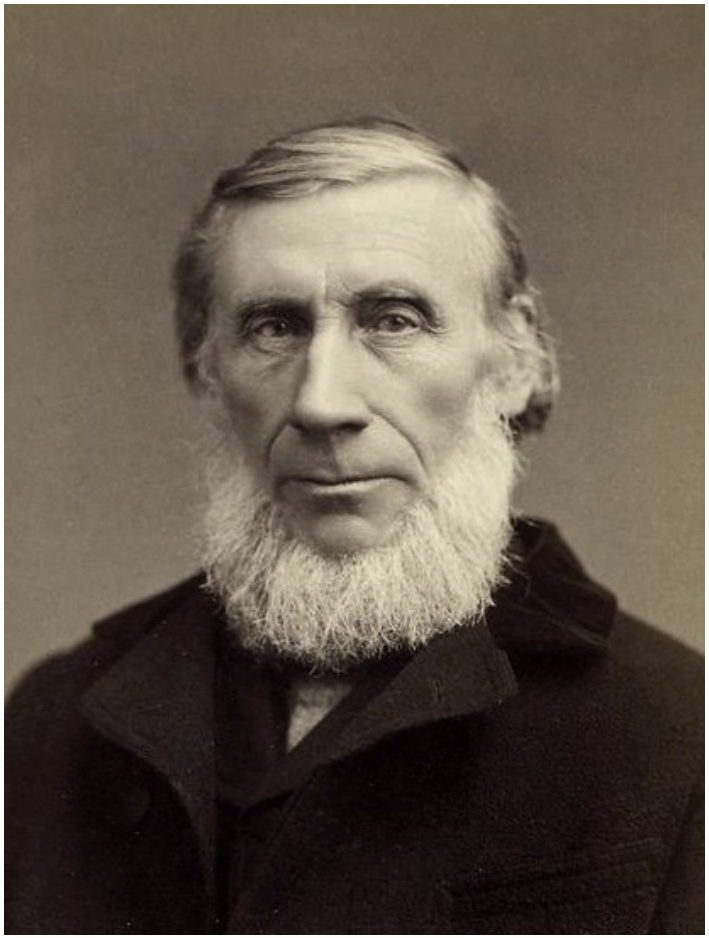

**Figure:** John Tyndall (1820 – 1893); source: Wikipedia

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**Figure:** Svante August Arrhenius (1859 – 1927); source: Wikipedia

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# Climate Change in the general public

- The Intergovernmental Panel on Climate Change (IPCC) was founded on December 6, 1988 to provide policy makers with regular scientific assessments
- Core of the IPCC are its assessment reports (AR) divided into several working groups (the IPCC does not do any own research)
- The first AR was published in 1990
- The latest AR is from 2022

IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

# IPCC – First Assessment Report

"*We are certain of the following: there is a **natural greenhouse effect** which already keeps the Earth warmer than it would otherwise be; **emissions resulting from human activities** are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide.*" (IPCC, 1990)

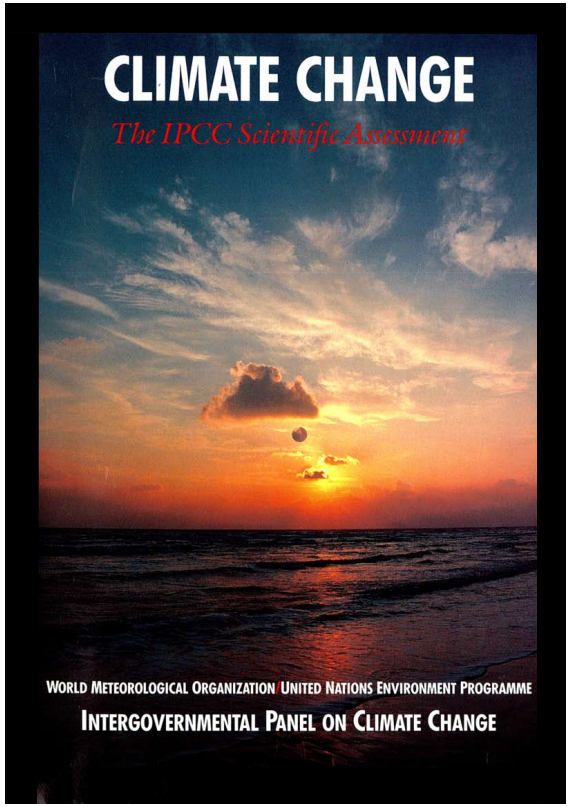


**Figure:** Cover of the First Assessment Report of the IPCC in 1990

# IPCC – Second Assessment Report

"*The balance of evidence* ***suggests a discernible human influence*** *on global climate [...] Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. [...] Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.*" (IPCC, 1995)

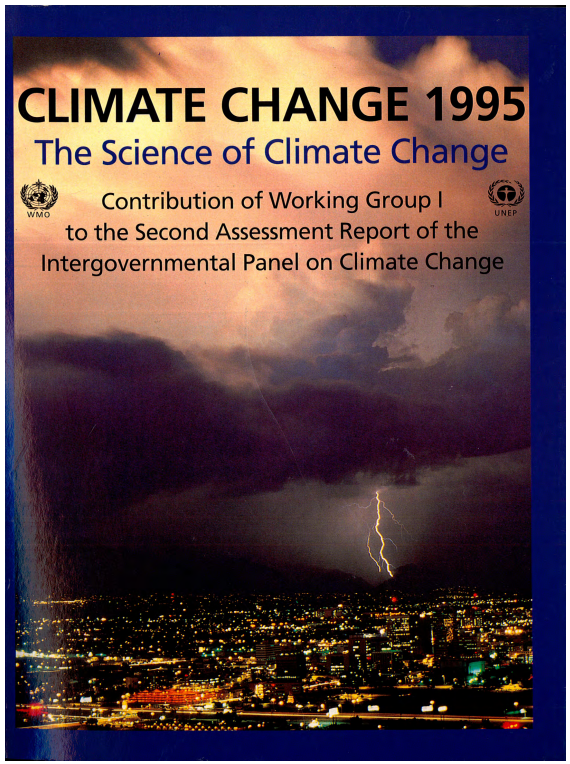


**Figure:** Cover of the Second Assessment Report of the IPCC in 1995

# IPCC – Third Assessment Report

"*There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. [...] In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is* ***likely*** *to have been due to the increase in greenhouse gas concentrations.*"
(IPCC, 2001)

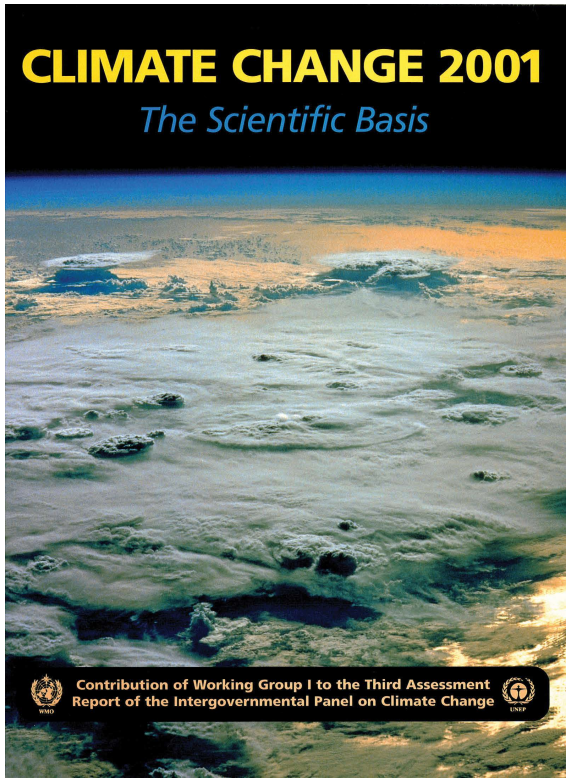


**Figure:** Cover of the Third Assessment Report of the IPCC in 2001

# IPCC – Fourth Assessment Report

"*Most of the observed increase in global average temperatures since the mid-20th century is* ***very likely*** *due to the observed increase in anthropogenic greenhouse gas concentrations.*" (IPCC, 2007)

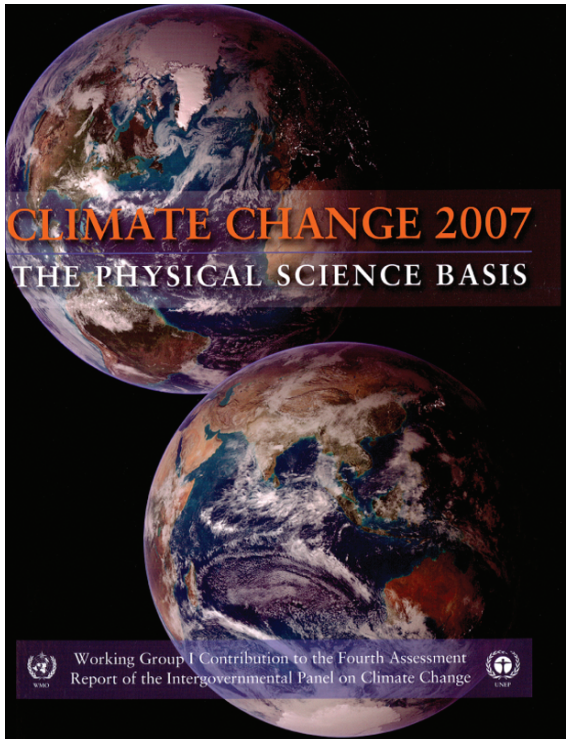


**Figure:** Cover of the Fourth Assessment Report of the IPCC in 2007

# IPCC – Fifth Assessment Report

"*Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. [...] It is* ***extremely likely*** *that human influence has been the* ***dominant cause*** *of the observed warming since the mid-20th century.*" (IPCC, 2013)

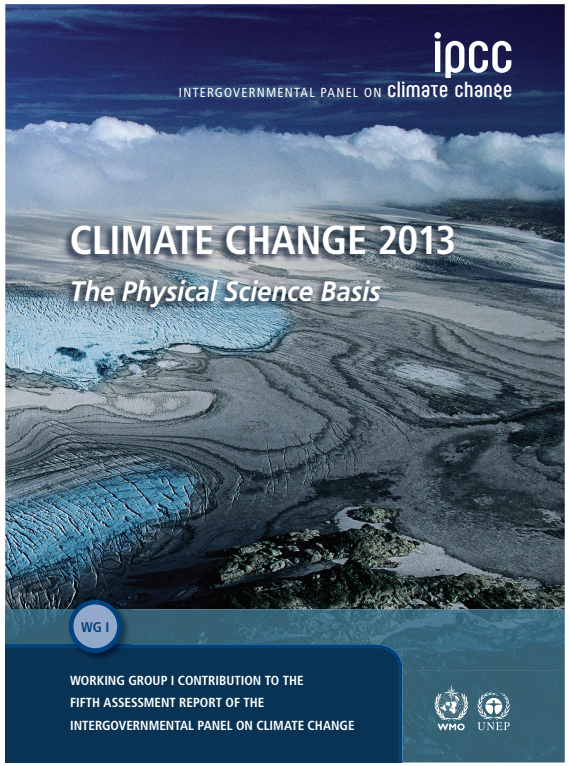


**Figure:** Cover of the Fifth Assessment Report of the IPCC in 2013

# IPCC – Sixth Assessment Report

"*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. [...] The likely range of total human-caused global surface temperature increase from 1850-1900 to 2010-2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C.*"
(IPCC, 2021)

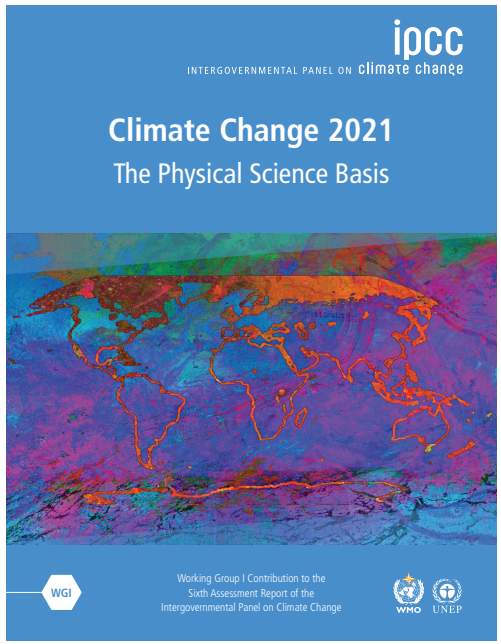


**Figure:** Cover of the Sixth Assessment Report of the IPCC

# Natural carbon sinks

- Contact of $CO_2$ and the ocean

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

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- Carbon weathering

$$2\,CO_2 + H_2O + CaSiO_3 \rightleftharpoons Ca^{2+} + 2\,HCO_3^- + SiO_2$$

# Life time of $CO_2$ in the atmosphere

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*"Carbon dioxide cycles between the atmosphere, oceans and land biosphere. Its removal from the atmosphere involves a range of processes with different time scales. About 50% of a $CO_2$ increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years"* (Denman *et al.*, 2007).

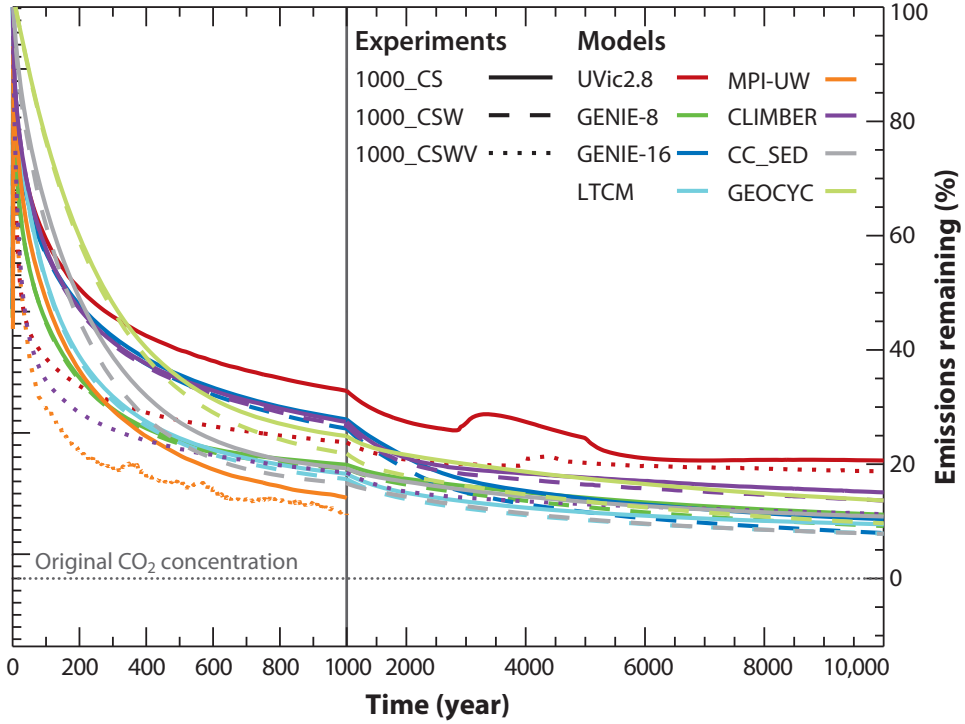



**Figure:** Atmospheric $CO_2$ trajectories for the 10,000-year duration of certain climate model simulations (Archer *et al.*, 2009)

# Changes in global surface temperature relative to 1850-1900

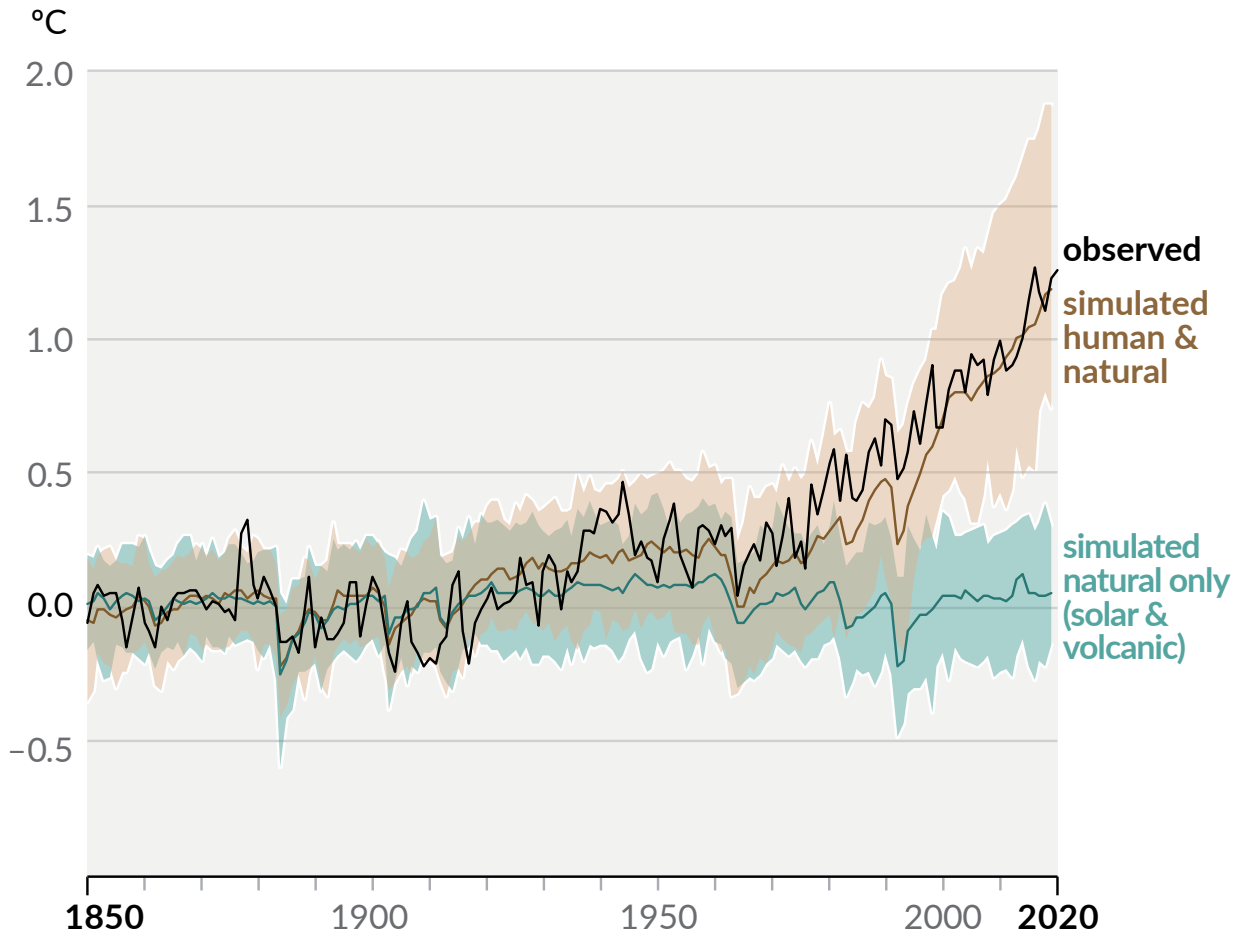



**Figure:** Change in global surface temperature (annual average) as observed and simulated using human and natural (brown) and only natural (mint) factors (both 1850-2020); source: IPCC (2021).

# Changes in global surface temperature relative to 1850-1900

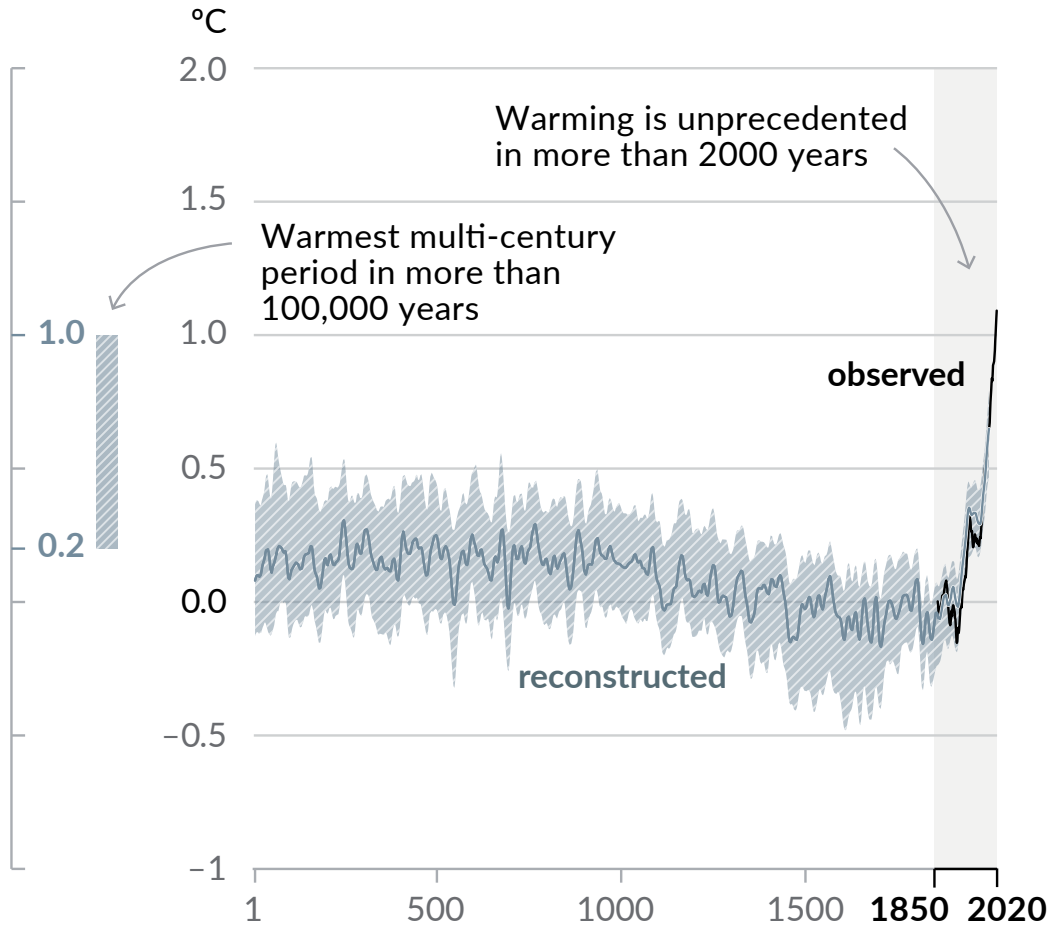
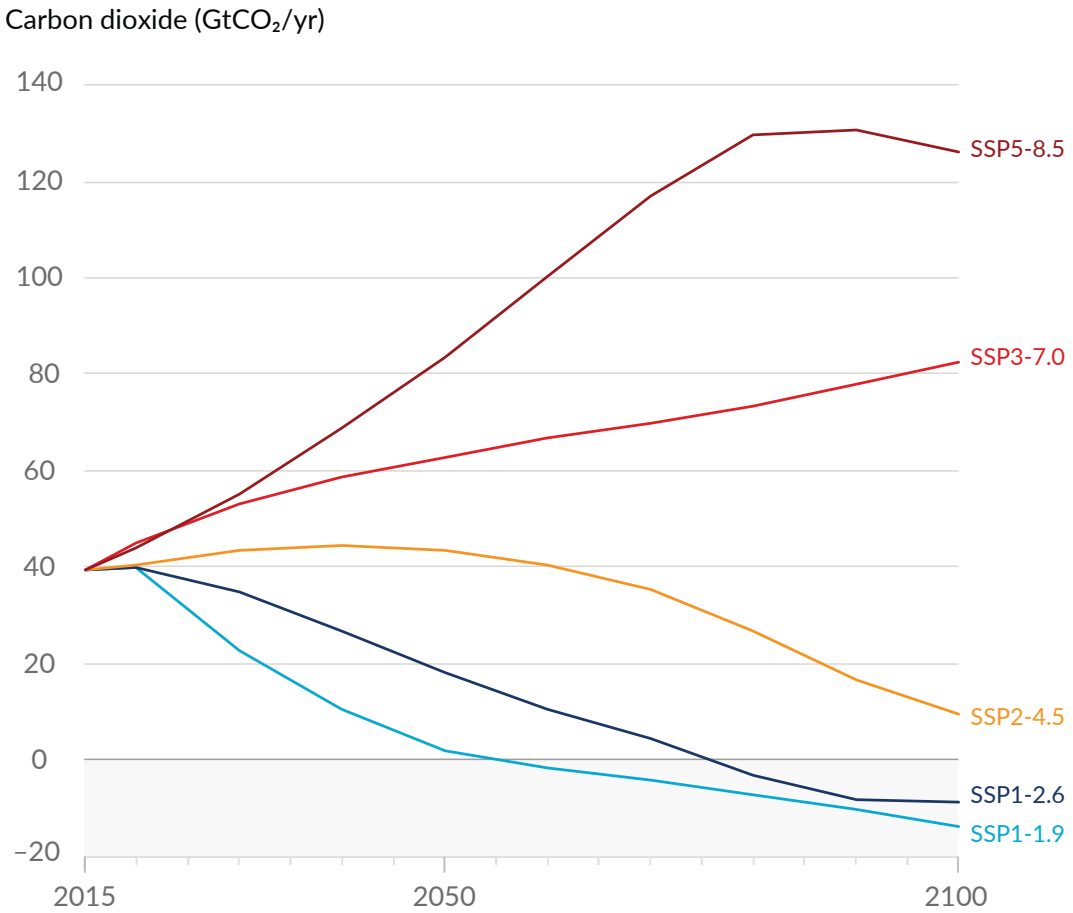



**Figure:** Change in global surface temperature (decadal average) as reconstructed (1-2000, grey) and observed (1850-2020, black); source: IPCC (2021).

# Emission change according to scenarios



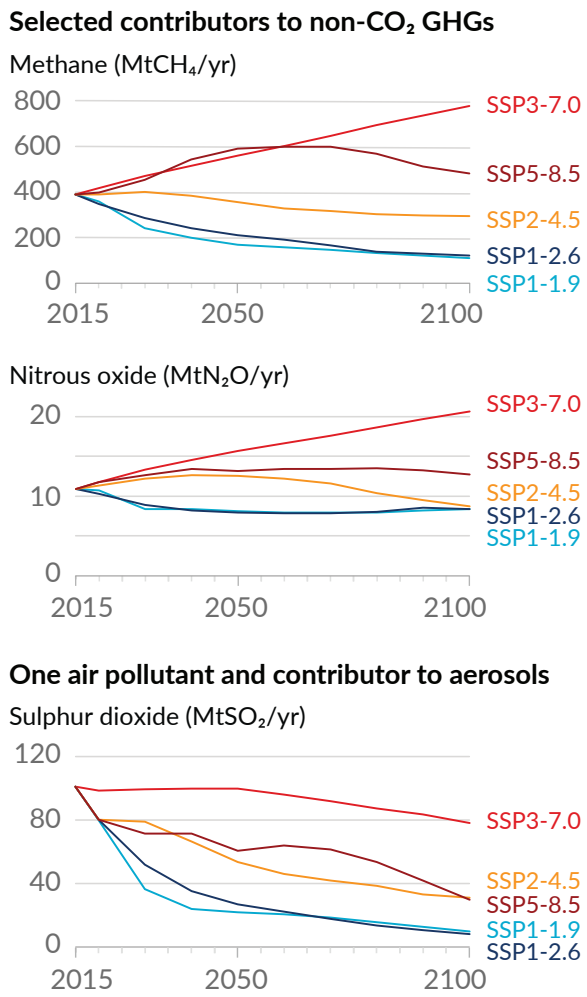




**Figure:** Future annual emissions of $CO_2$ (left) and of a subset of key non-$CO_2$ drivers (right), across five illustrative scenarios; source: IPCC (2021).

# Changes in global surface temperatures according to scenarios

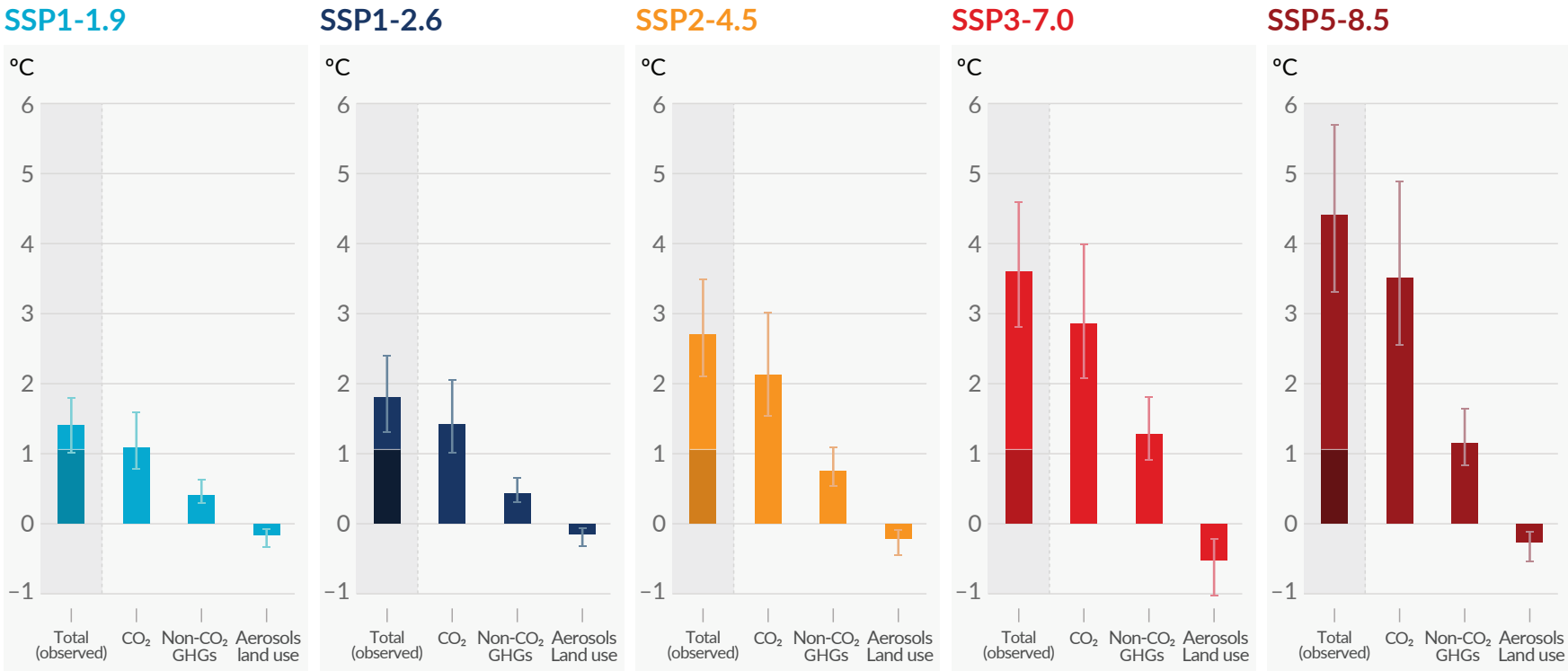



**Figure:** Contribution to global surface temperature increase from different emissions, with a dominant role of $CO_2$ emissions. Change in global surface temperature in 2081-2100 relative to 1850-1900 (°C). Total warming (observed warming to date in darker shade), warming from $CO_2$, warming from non-$CO_2$ GHGs and cooling from changes in aerosols and land use; source: IPCC (2021).

# Changes in global surface temperatures according to scenarios

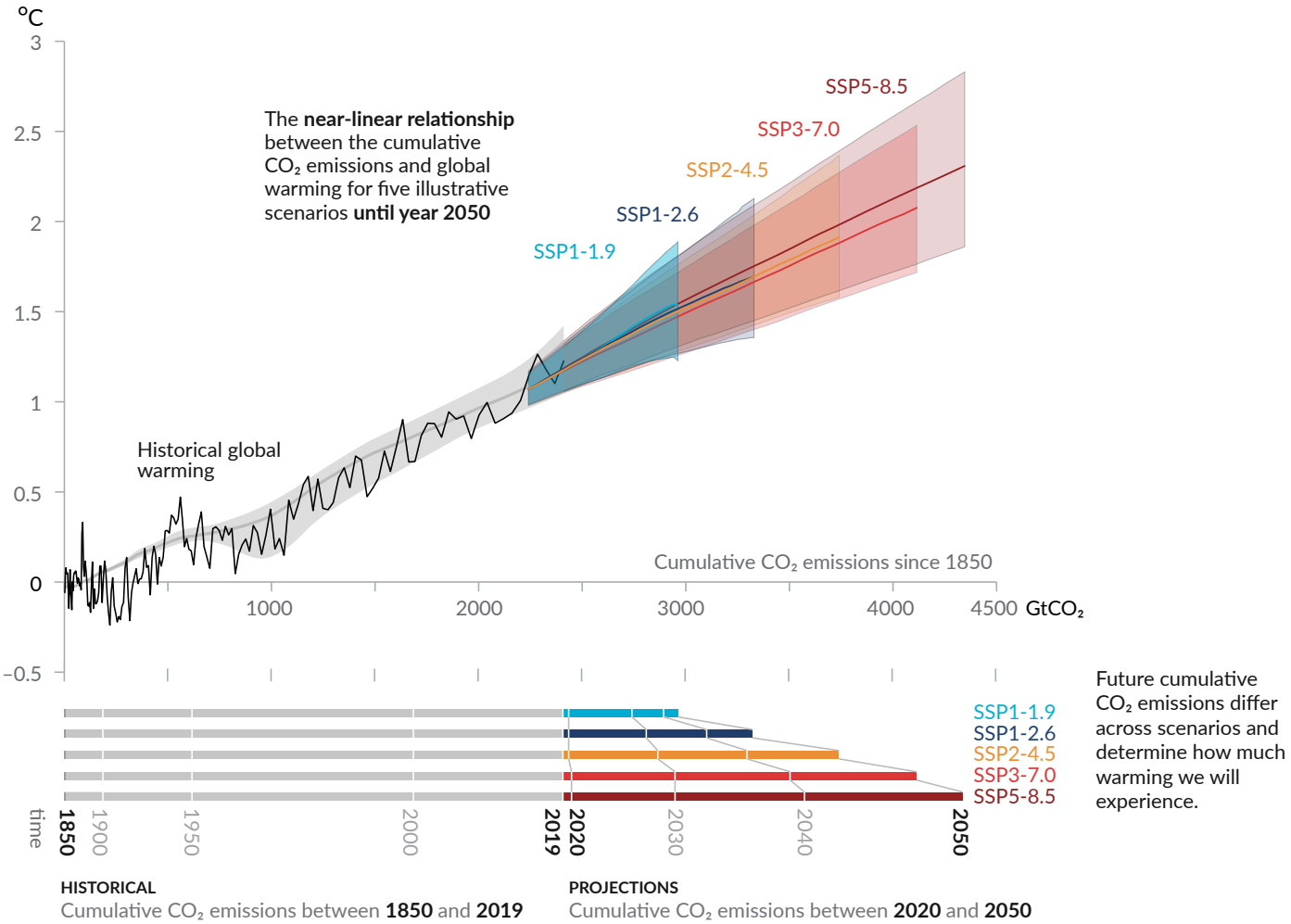



**Figure:** Global surface temperature increase since 1850-1900 (°C) as a function of cumulative $CO_2$ emissions ($GtCO_2$; source: IPCC (2021).

# Changes in global surface temperatures according to scenarios

| Global Warming Between 1850–1900 and 2010–2019 (°C) | | Historical Cumulative $CO_2$ Emissions from 1850 to 2019 ($GtCO_2$) | | | | | |
|---|---|---|---|---|---|---|---|
| 1.07 (0.8–1.3; likely range) | | 2390 (± 240; likely range) | | | | | |
| Approximate global warming relative to 1850–1900 until temperature limit (°C)[a] | Additional global warming relative to 2010–2019 until temperature limit (°C) | Estimated remaining carbon budgets from the beginning of 2020 ($GtCO_2$)<br><br>*Likelihood of limiting global warming to temperature limit*[b] | | | | | Variations in reductions in non-$CO_2$ emissions[c] |
| | | *17%* | *33%* | *50%* | *67%* | *83%* | |
| 1.5 | 0.43 | 900 | 650 | 500 | 400 | 300 | Higher or lower reductions in accompanying non-$CO_2$ emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more |
| 1.7 | 0.63 | 1450 | 1050 | 850 | 700 | 550 | |
| 2.0 | 0.93 | 2300 | 1700 | 1350 | 1150 | 900 | |

**Figure:** Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850-1900 are reported in °C; source: IPCC (2021).

# Carbon sinks

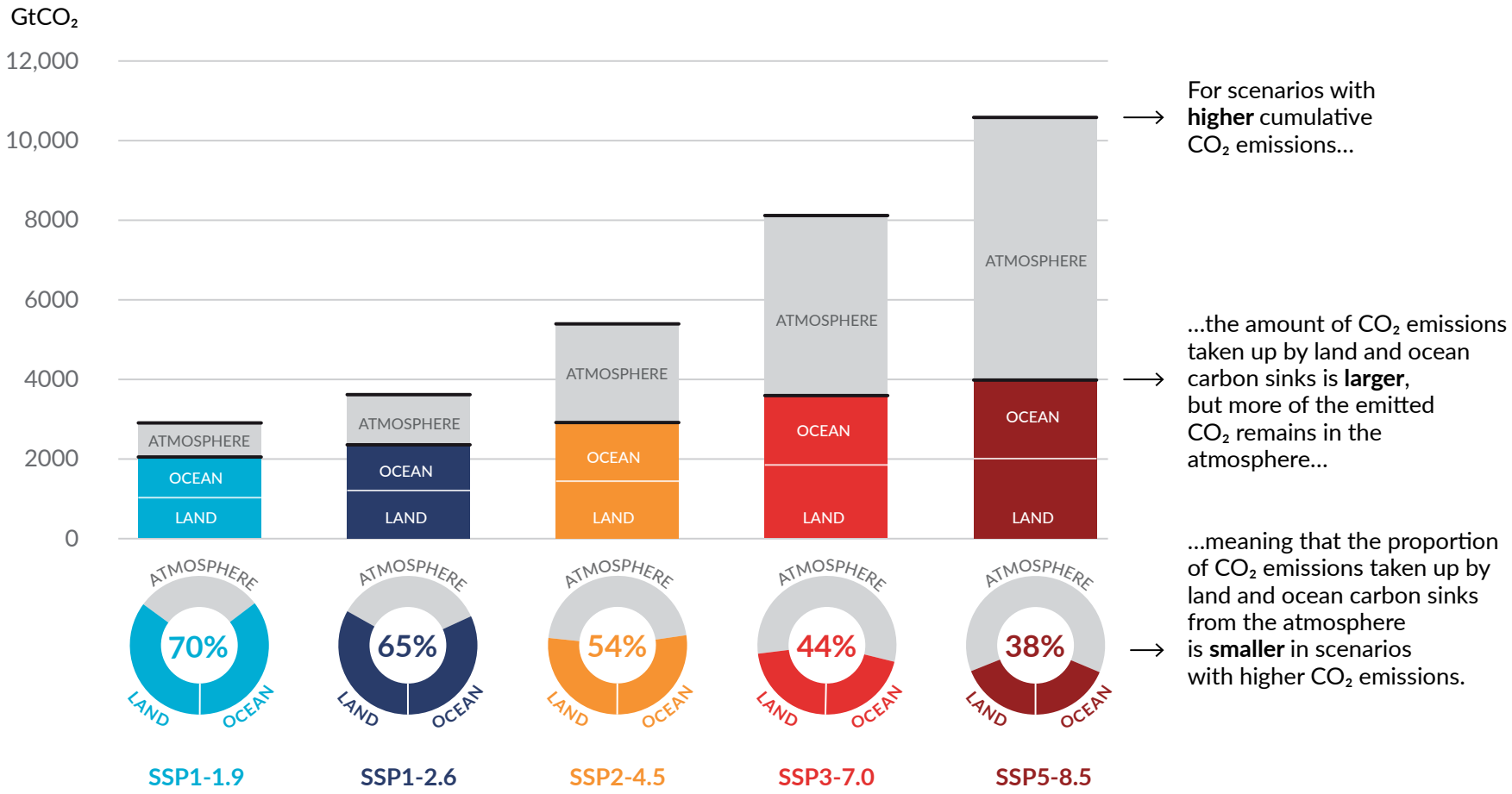



**Figure:** Total cumulative $CO_2$ emissions taken up by land and ocean (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100; source: IPCC (2021).

# Scenarios for the global surface temperature

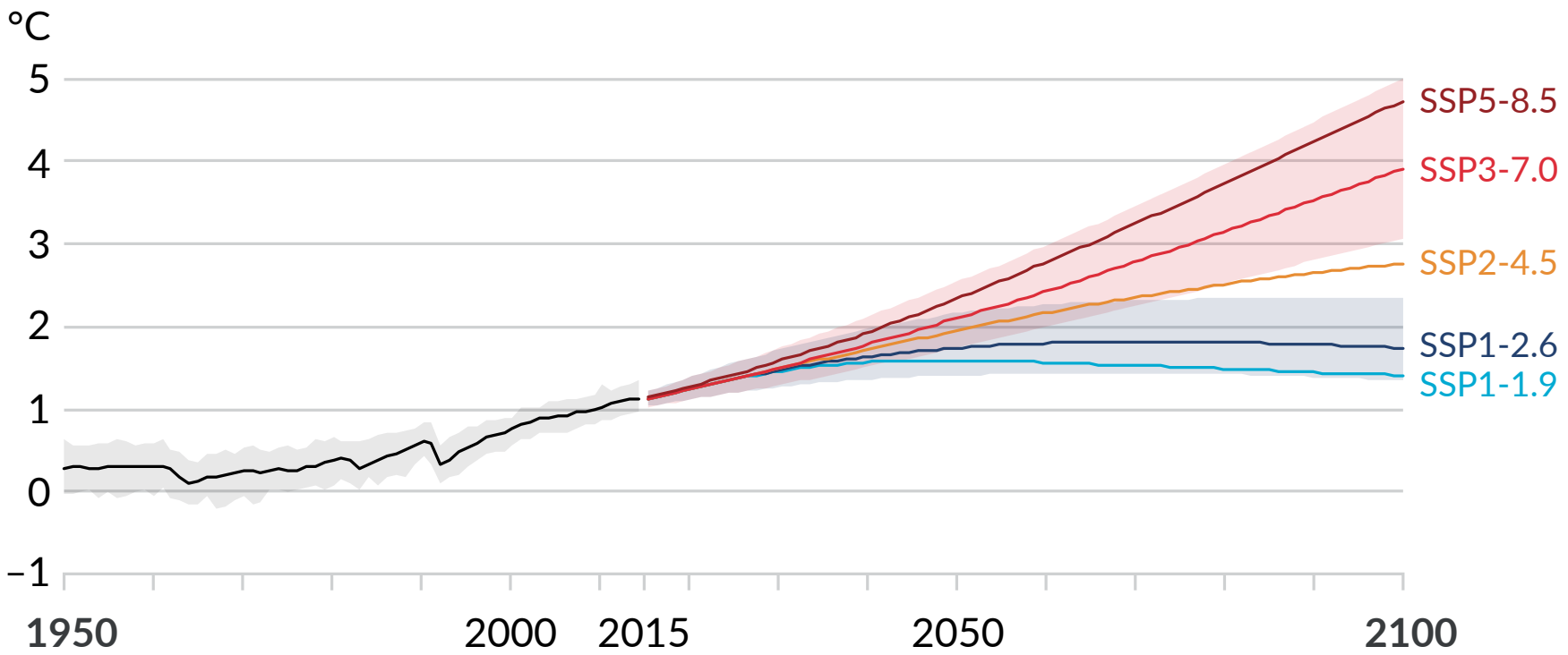



**Figure:** Global surface temperature change relative to 1850-1900; source: IPCC (2021).

# Reconstructed historic temperature development

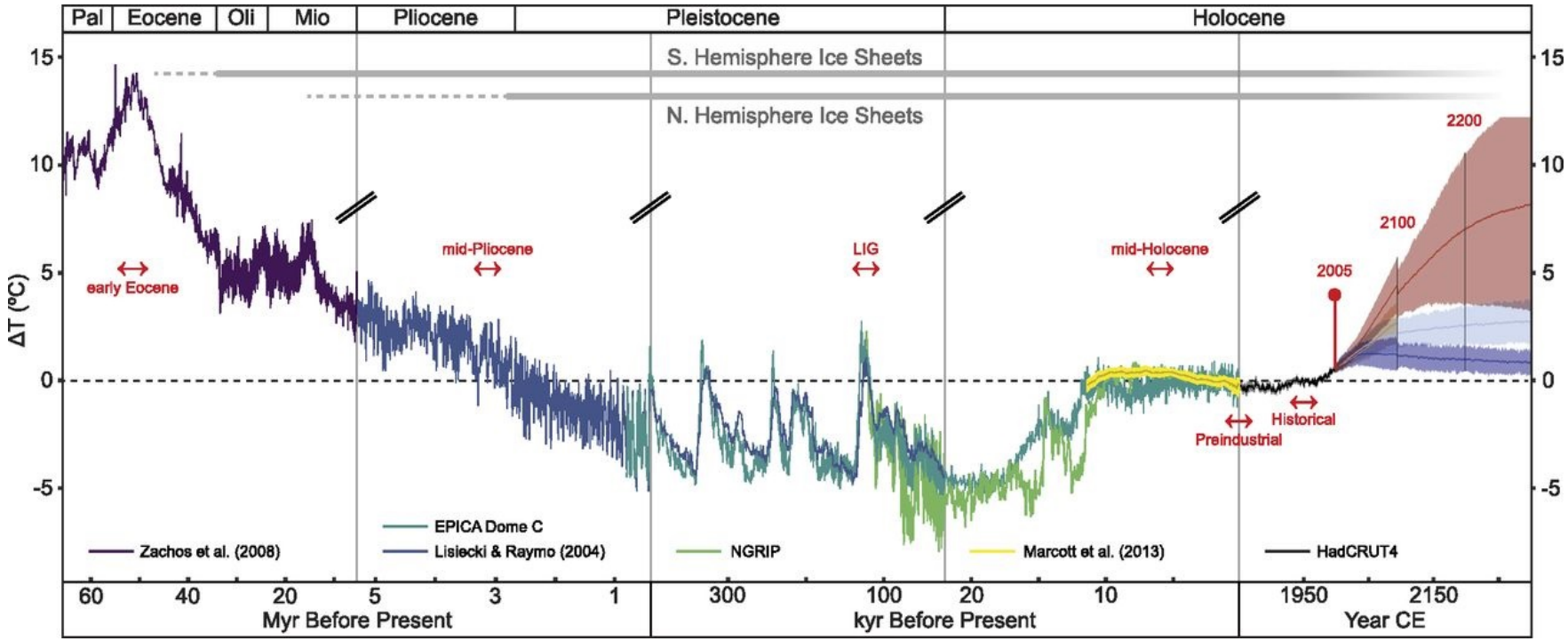



**Figure:** Temperature trends for the past 65 million years together with scenarios for future temperature development; source: Burke *et al.* (2018).

# Projected changes in extremes

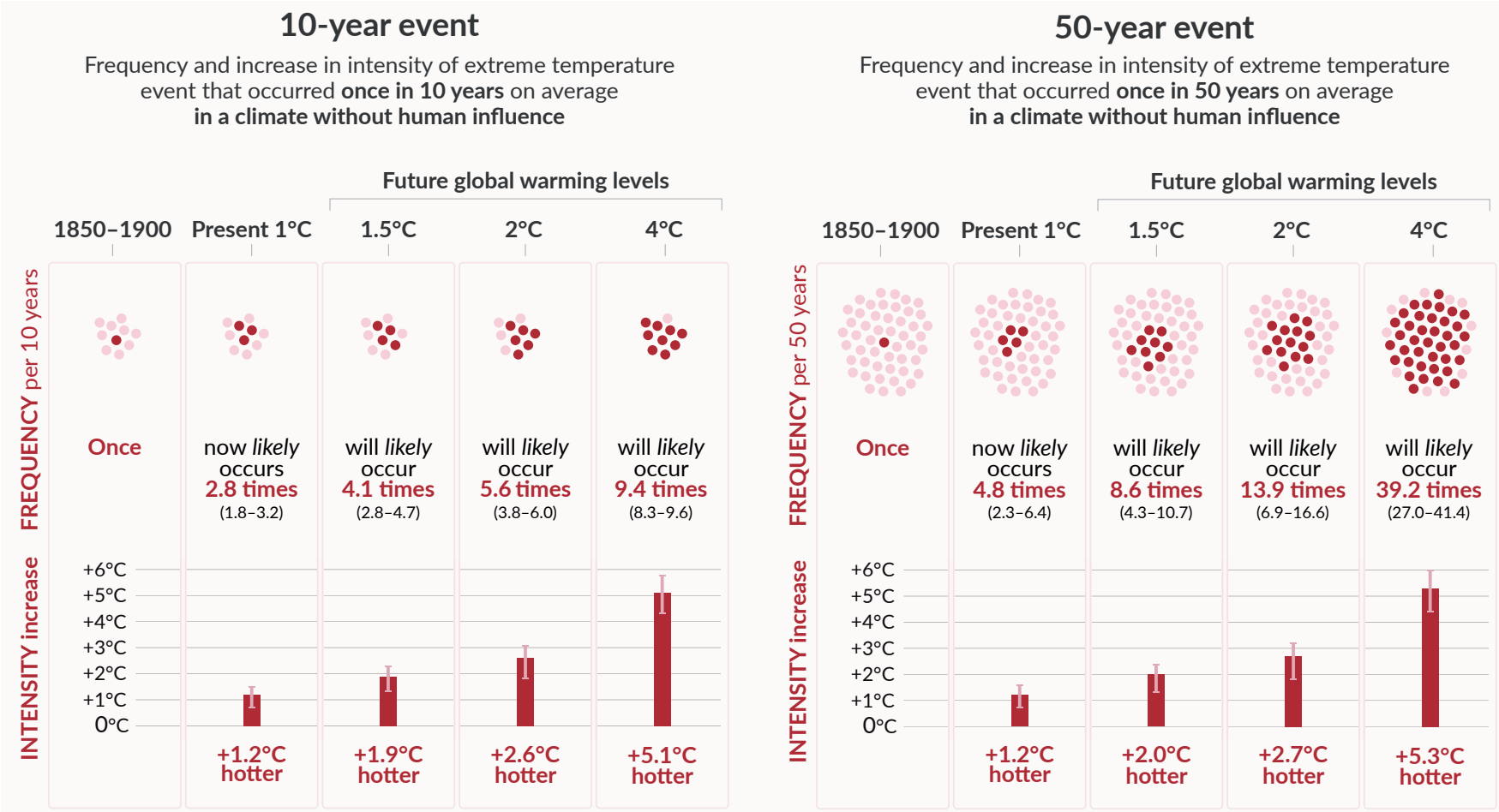



**Figure:** Hot temperature extremes over land; source: IPCC (2021).

# Projected changes in extremes

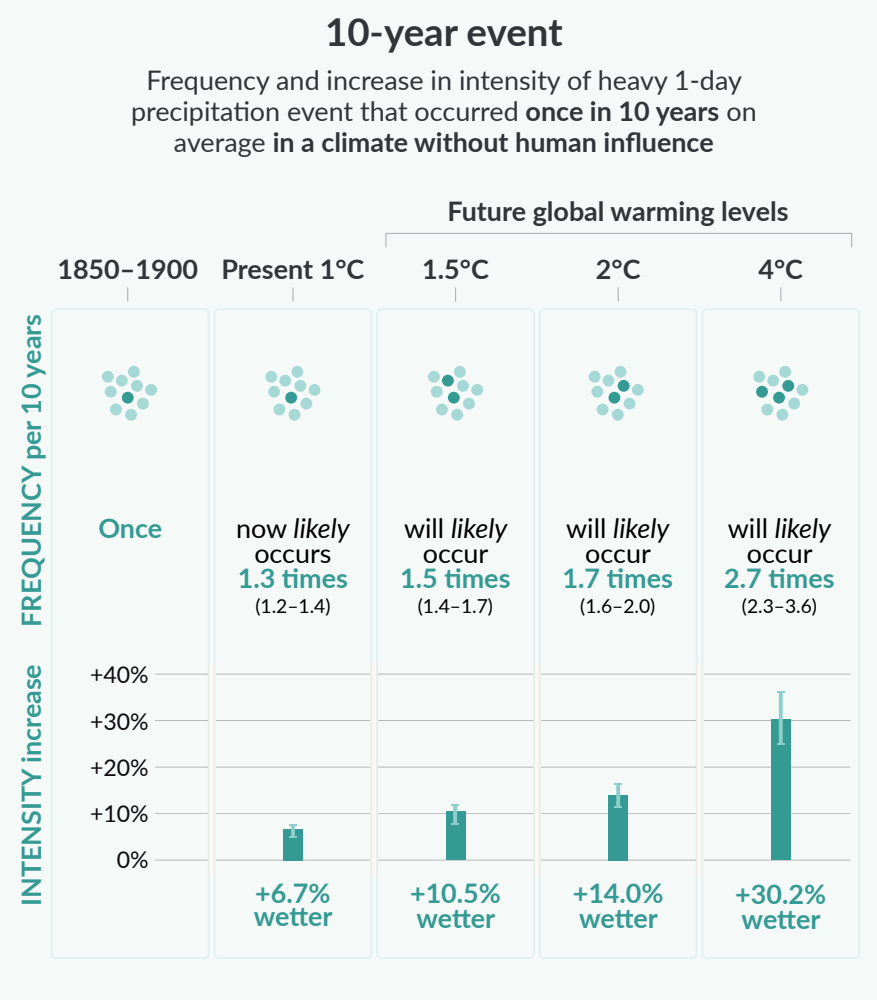



**Figure:** Heavy precipitation over land; source: IPCC (2021).

# Projected changes in extremes

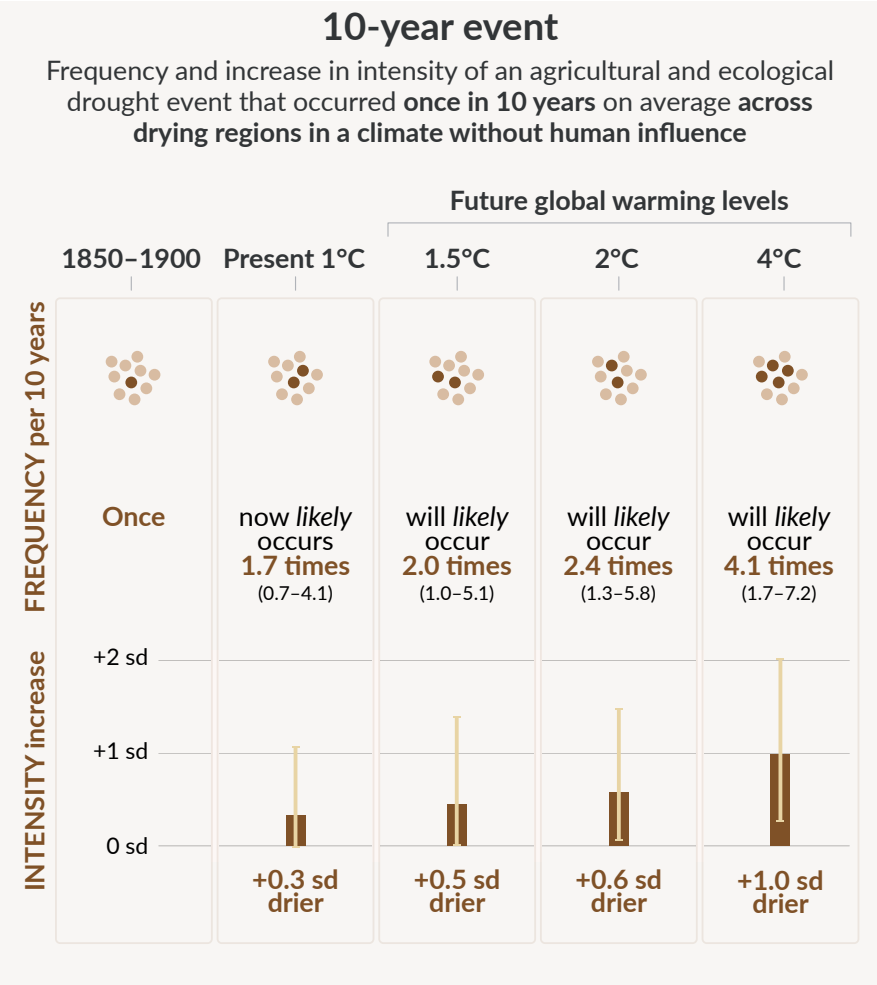
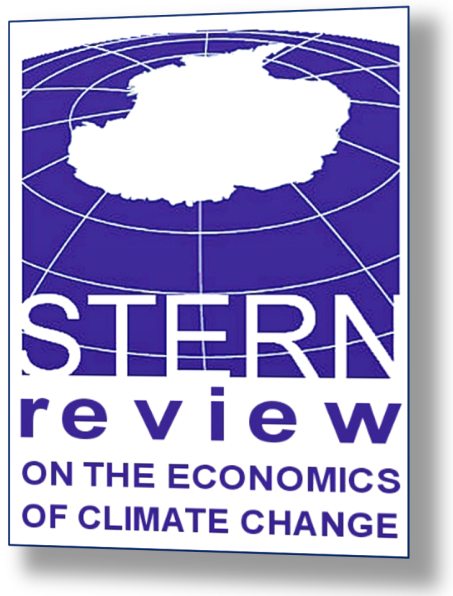



**Figure:** Agricultural and ecological droughts in drying regions; source: IPCC (2021).

# The Stern Review

- "*The benefits of strong and early action far outweigh the economic costs of not acting [...] So prompt and strong action is clearly warranted.*" (Stern, 2007)
- "*Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections [...] A range of options exists to cut emissions; strong, deliberate policy action is required to motivate their take-up.*" (Stern, 2007)
- broad discussion of the discount factor...



# Development of $CO_2$ emissions

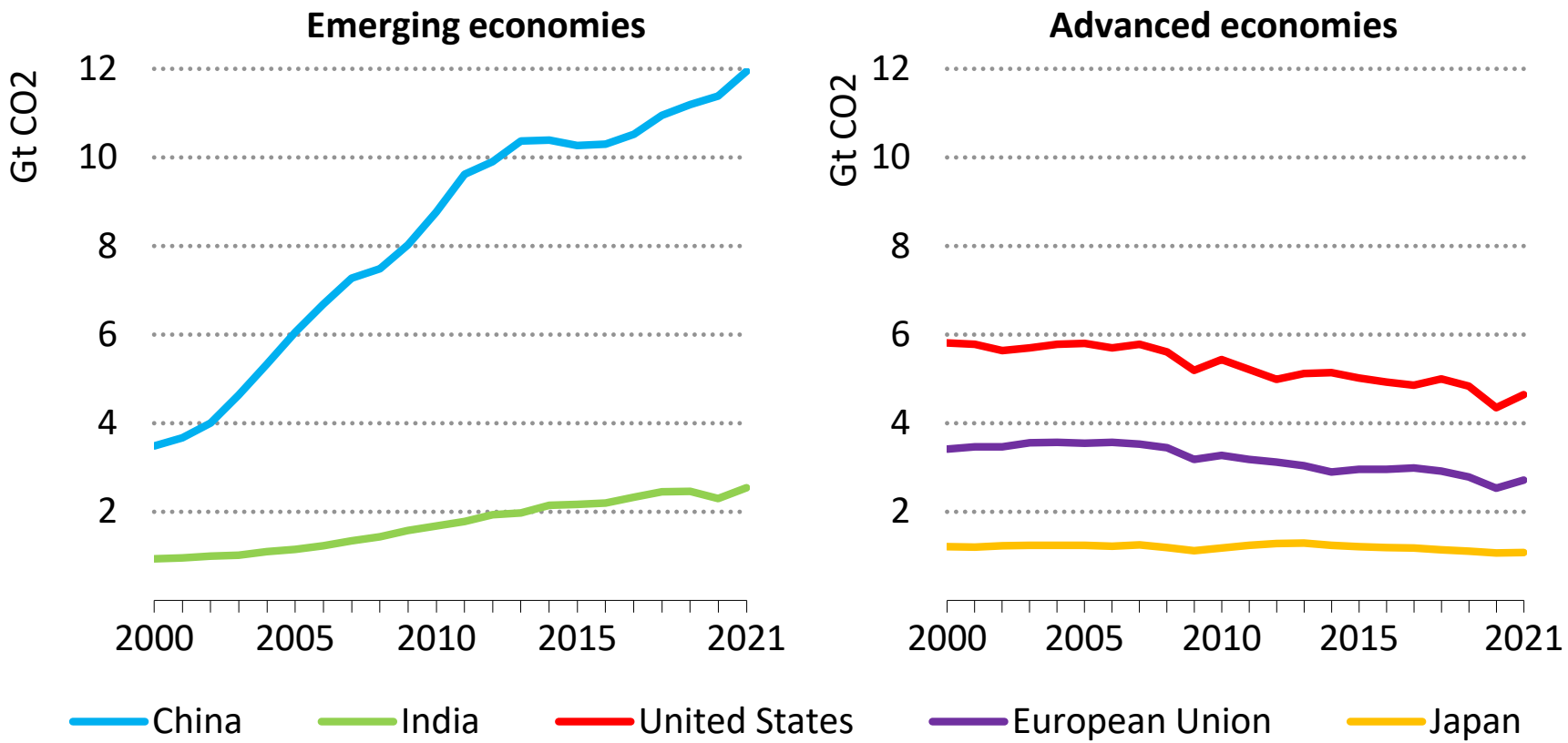



**Figure:** $CO_2$ emissions in selected emerging and advanced economies, 2000-2021; source: IEA (2022).

# Cumulative $CO_2$ emissions worldwide

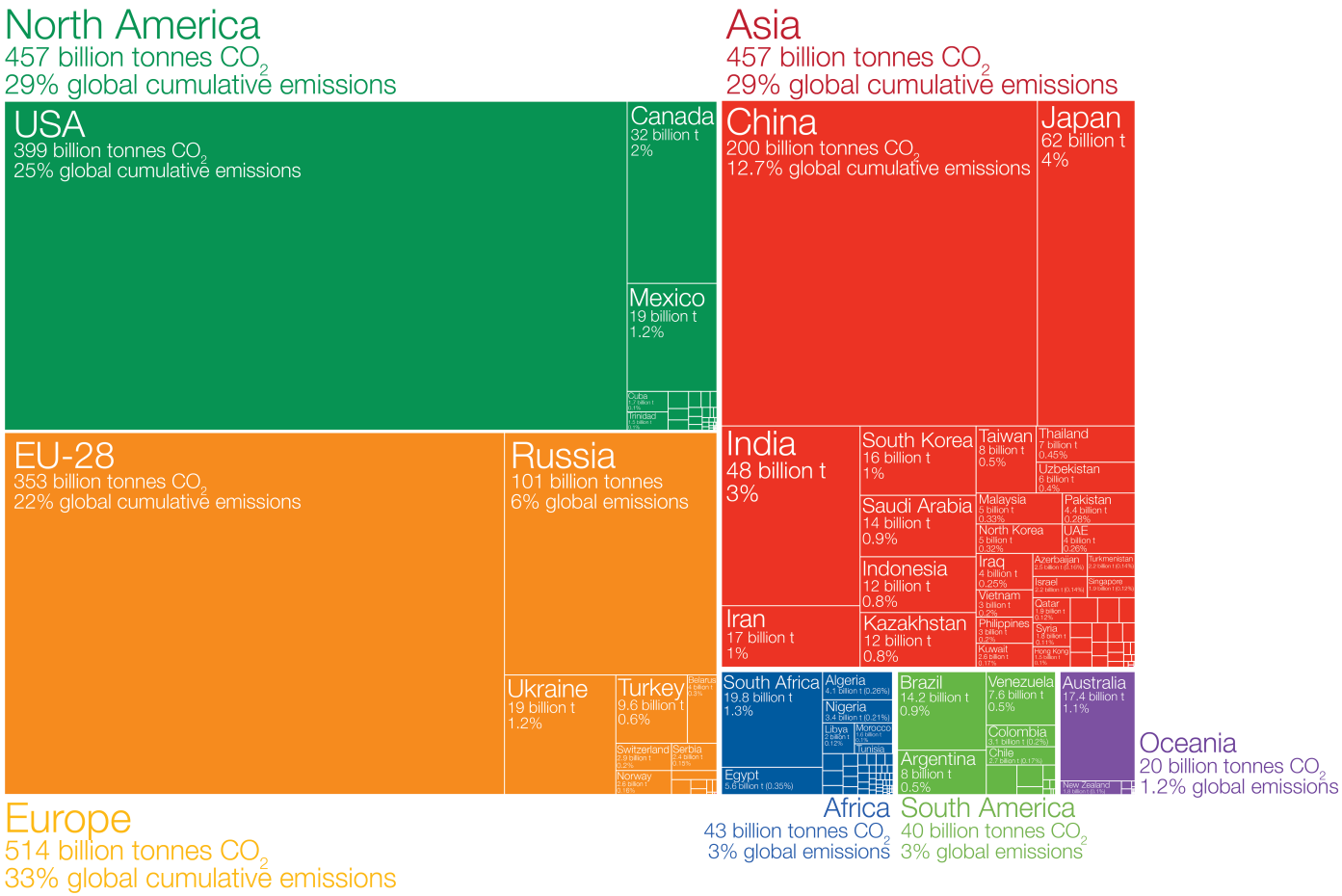



**Figure:** Cumulative $CO_2$ emissions over the period from 1751 to 2017. Figures are based on production-based emissions which measure $CO_2$ produced domestically from fossil fuel combustion and cement and do not correct for embedded in trade (i.e. consumption-based). Emissions from international travel are not included; source: OurWorldinData.org `https://ourworldindata.org/contributed-most-global-co2`.

# Development of per capita $CO_2$ emissions

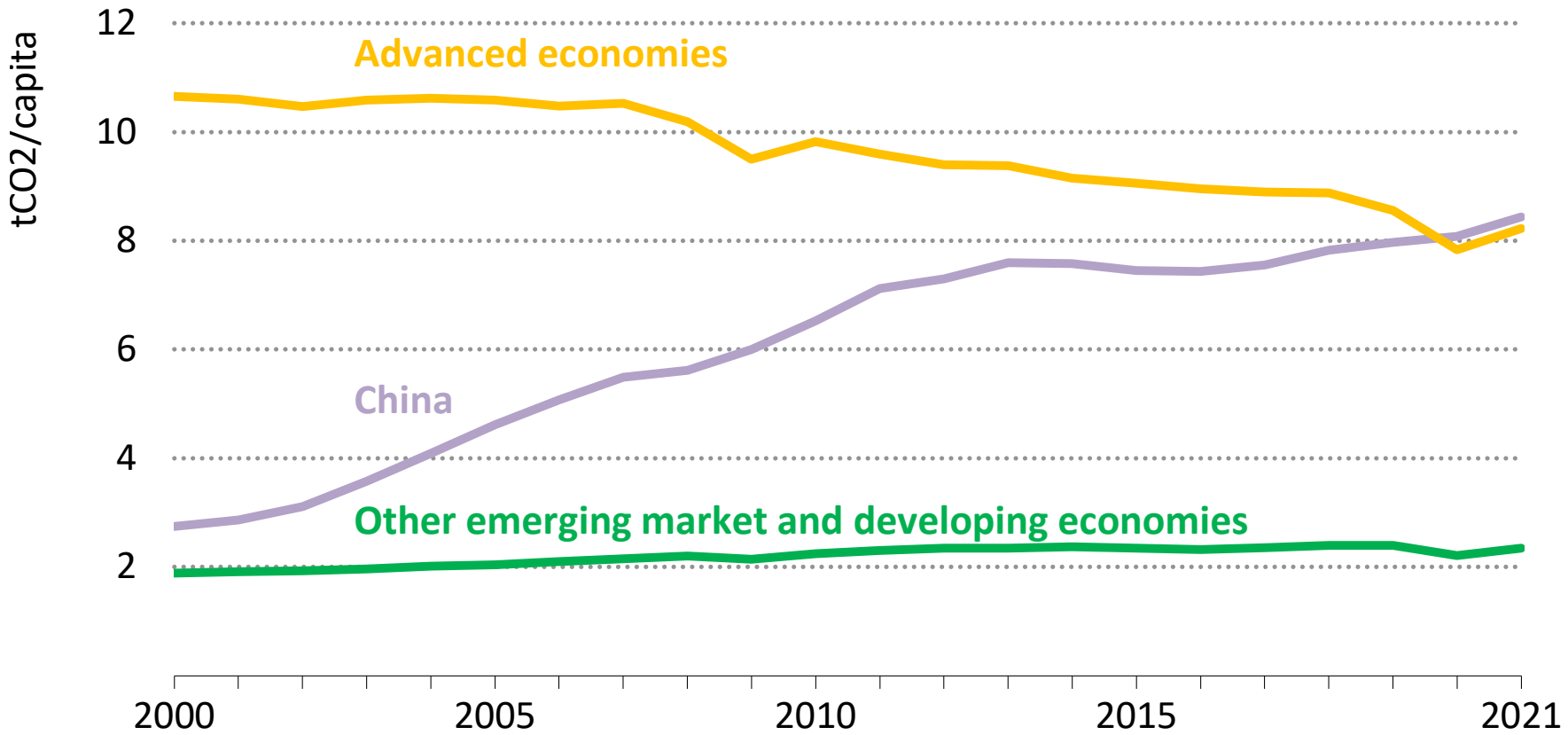



**Figure:** $CO_2$ emissions per capita by region, 2000-2021; source: IEA (2022).

# Development of $CO_2$ emissions per output

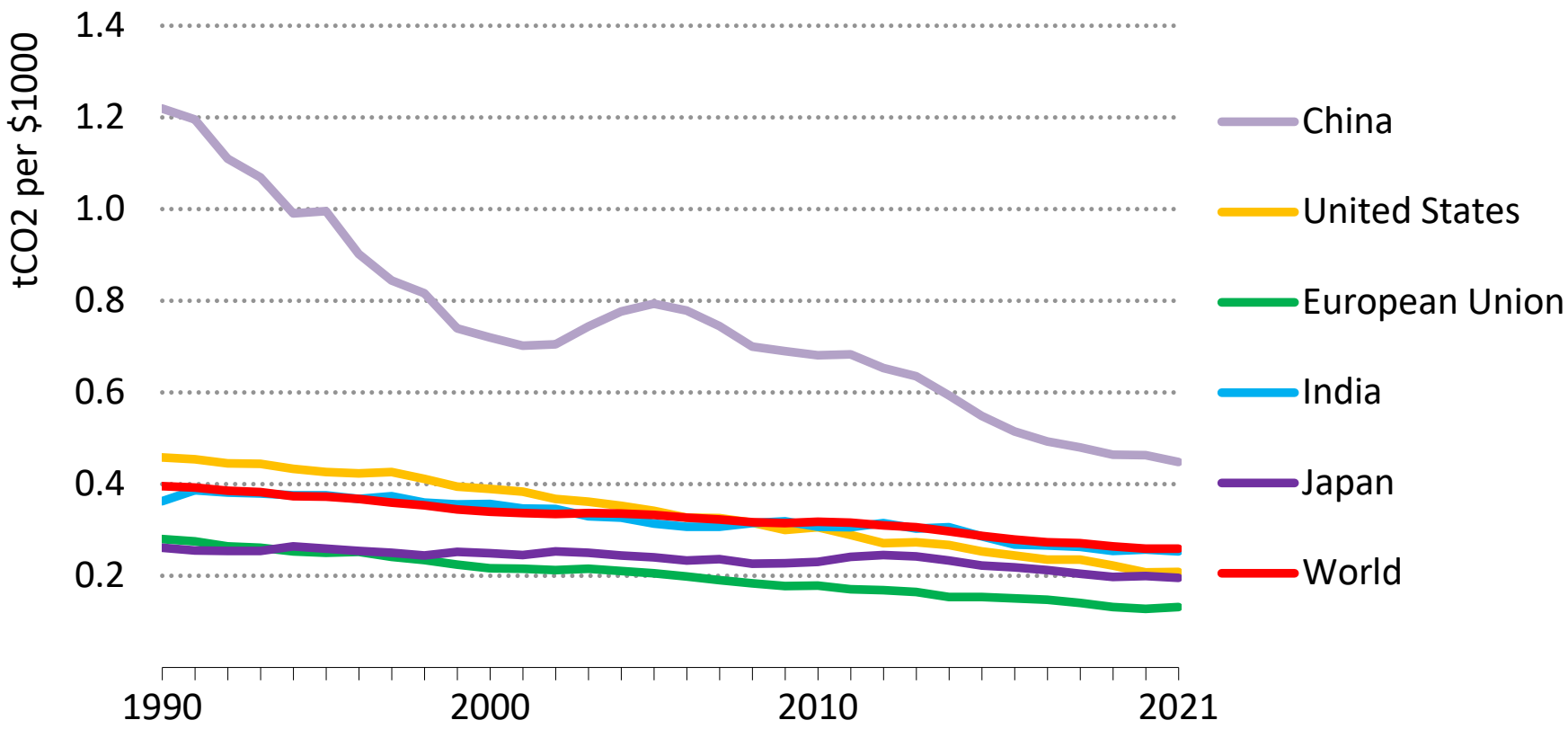



**Figure:** $CO_2$ emissions intensity of GDP, 1990-2021; source: IEA (2022).

# References I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Burke, K. D., Williams, J. W., Chandler, M. A., Haywood, A. M., Lunt, D. J. and Otto-Bliesner, B. L. (2018). Pliocene and eocene provide best analogs for near-future climates. *Proceedings of the National Academy of Sciences*, **115** (52), 13288–13293.

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