INTRODUCTION TO CLIMATE CHANGE



Benjamin I Cook

GUIDELINES FOR TODAY

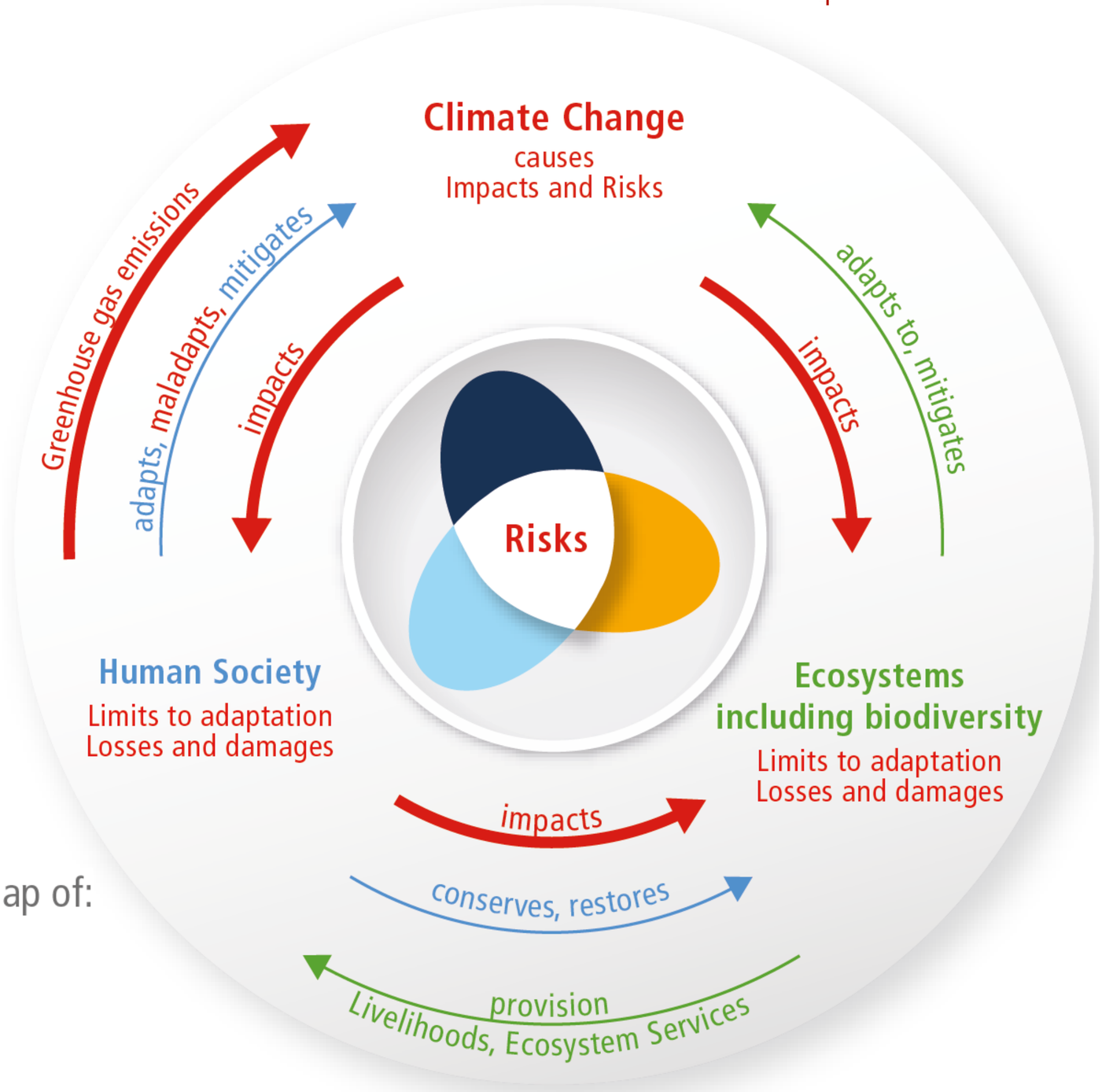
GOAL: To provide fundamental physical understanding of climate change, related uncertainties, and how the science can inform ***adaptation*** and ***mitigation***

Please **ASK QUESTIONS** as they occur by dropping them into the Zoom chat

WARM UP QUESTION

WHAT PERCENT OF GLOBAL WARMING CAN BE ATTRIBUTED (BLAMED) ON HUMAN ACTIVITIES?

Climate Change is one key component of future risks



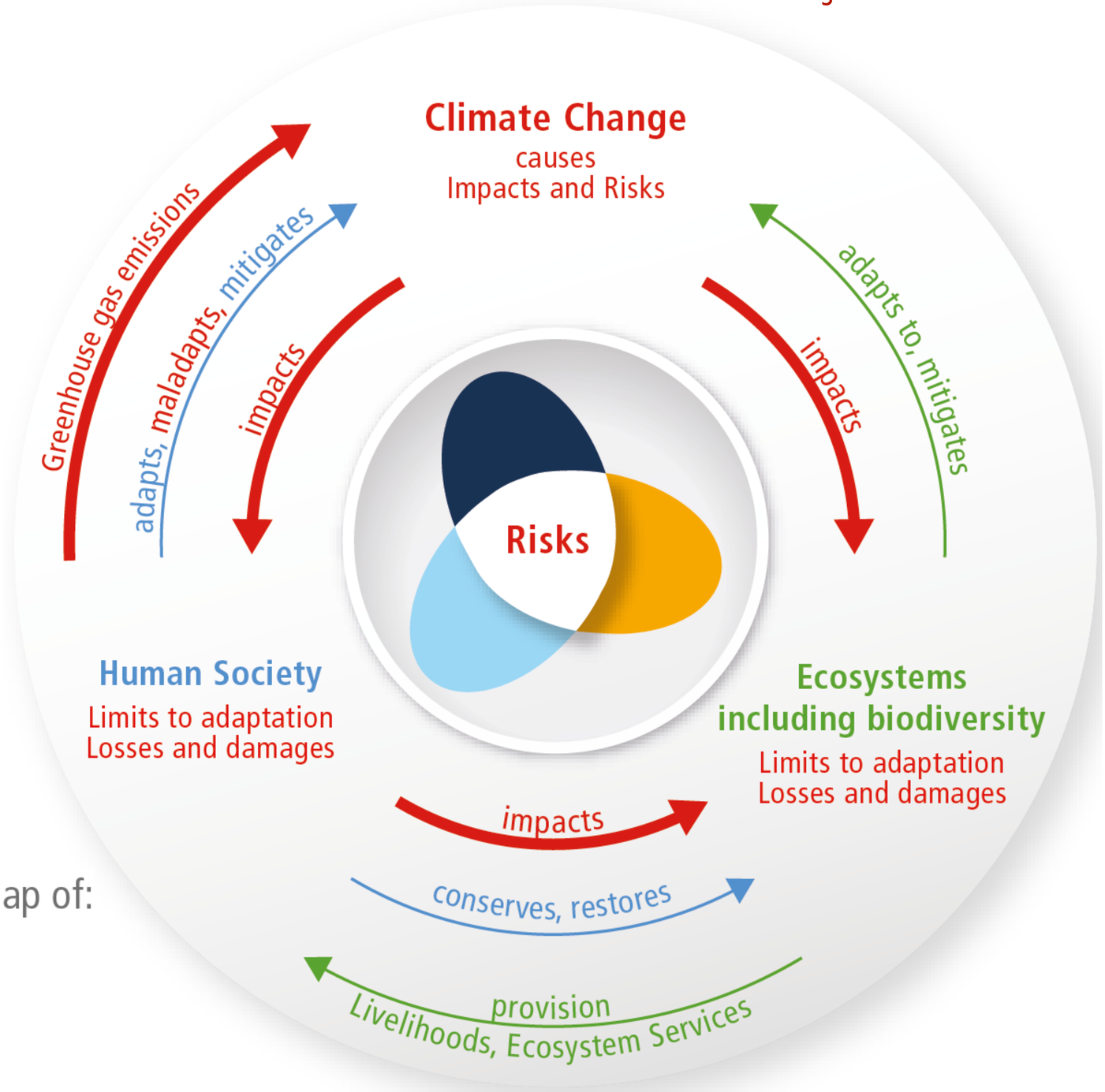
The risk propeller shows that risk emerges from the overlap of:

Climate hazard(s) **Vulnerability** **Exposure**

...of human systems, ecosystems and their biodiversity

https://www.ipcc.ch/report/ar6/wg2/

*Impacts ALSO depend on: where you live (**exposure**), and how well adapted (**vulnerable**) you are*



The risk propeller shows that risk emerges from the overlap of:

Climate hazard(s) **Vulnerability** **Exposure**

...of human systems, ecosystems and their biodiversity

https://www.ipcc.ch/report/ar6/wg2/

Dealing with climate risks involves

Understanding what is happening

(***climate science***)

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Preventing as much warming as we can

(***climate mitigation***)

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Understanding what is happening

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Preventing as much warming as we can

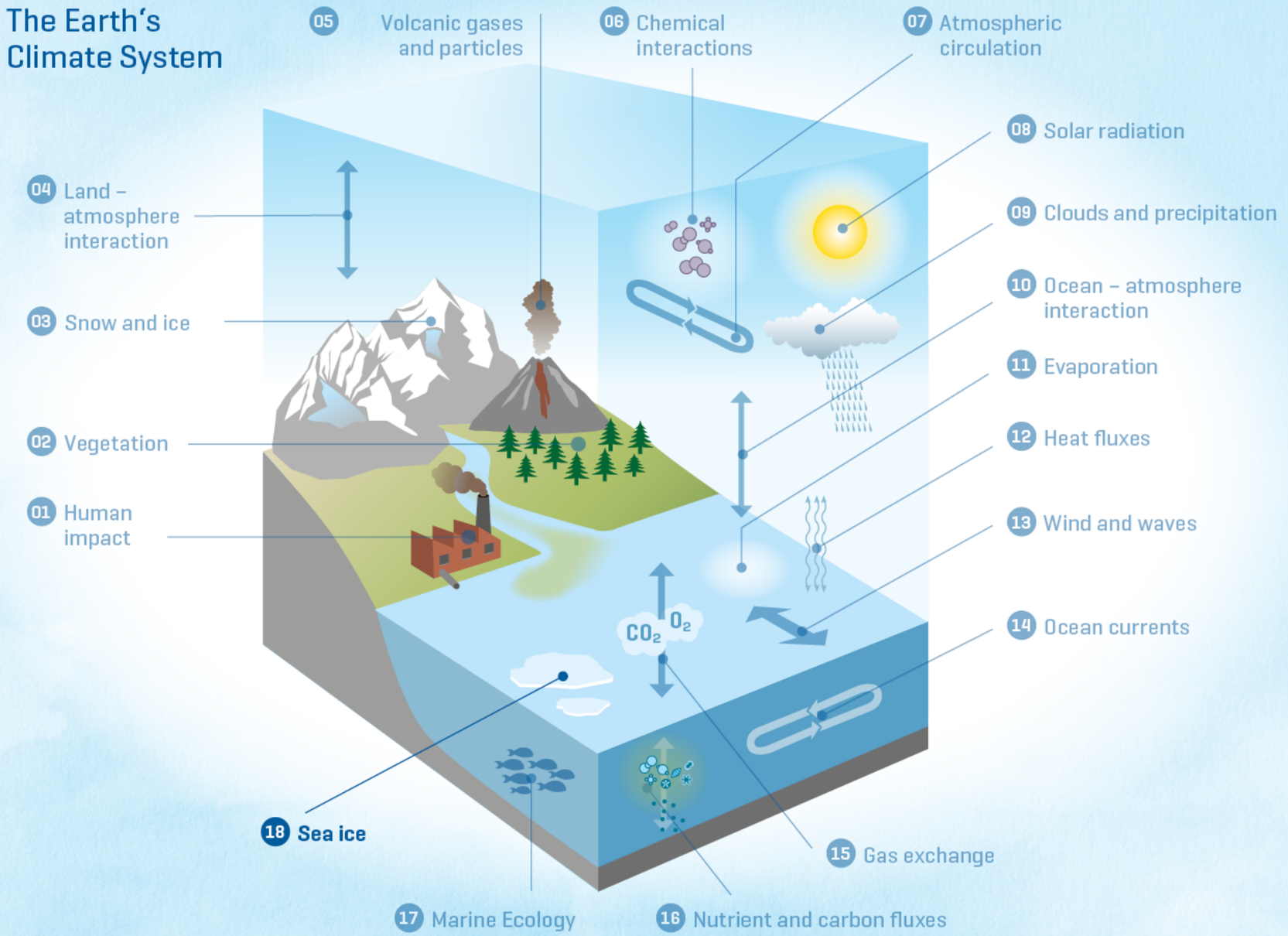
(***climate mitigation***)

Dealing with the changes that do happen

(***climate adaptation***)

CLIMATE SCIENCE

The Earth's Climate System



https://www.geomar.de/en/discover/ocean-and-climate/model-simulations/the-earths-climate-system

What is climate?

WEATHER

WHAT YOU GET

CONDITIONS OF THE ATMOSPHERE OVER A SHORT PERIOD OF TIME

CAN CHANGE WITHIN MINUTES OR HOURS



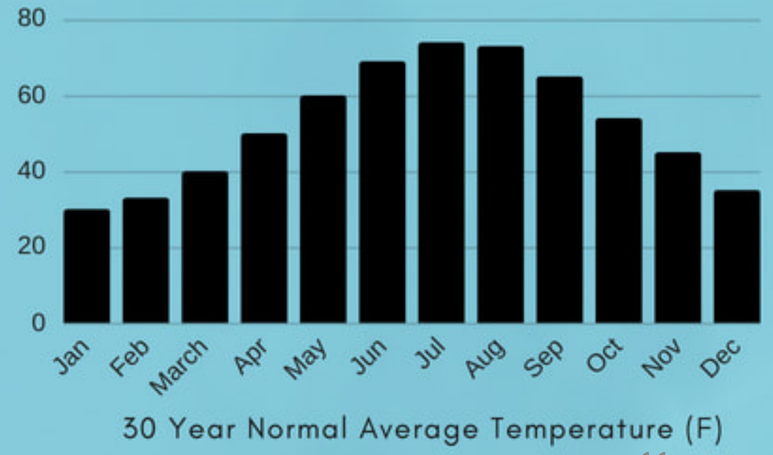
VS

CLIMATE

WHAT YOU EXPECT

HOW THE ATMOSPHERE BEHAVES OVER A LONG PERIOD OF TIME AND SPACE

AVERAGE REGIONAL WEATHER PATTERN OVER DECADES



https://www.alabamawx.com/wp-content/uploads/2019/06/weather-vs-climate_orig.jpg


CLIMATE
is what you expect
WEATHER
is what you get

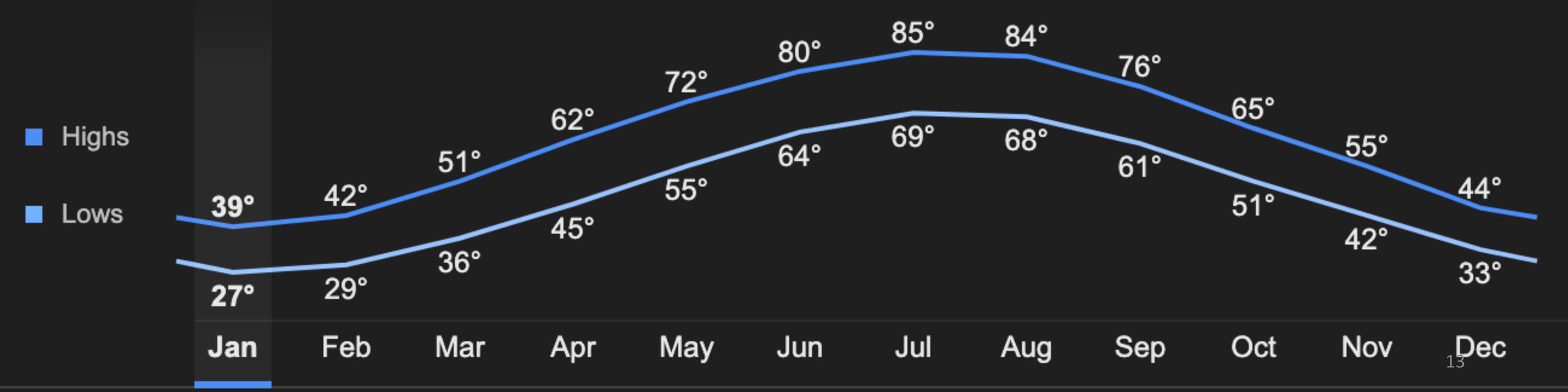
21 °F | °C
Precipitation: 0%
Humidity: 50%
Wind: 14 mph

Weather

Tuesday 2:00 PM
Sunny

Temperature | Precipitation | Wind

Temperatures (°F)



WHEN WE TALK ABOUT CLIMATE CHANGE, WE'RE NOT TRYING TO PREDICT THE WEATHER

Will it rain on April 14, 2091?

How hot will it be on July 21, 2085?

WHEN WE TALK ABOUT CLIMATE CHANGE, WE'RE NOT TRYING TO PREDICT THE WEATHER

Will it rain on April 14, 2091?

-> *What will average April rainfall be in the 2090s?*

How hot will it be on July 21, 2085?

WHEN WE TALK ABOUT CLIMATE CHANGE, WE'RE NOT TRYING TO PREDICT THE WEATHER

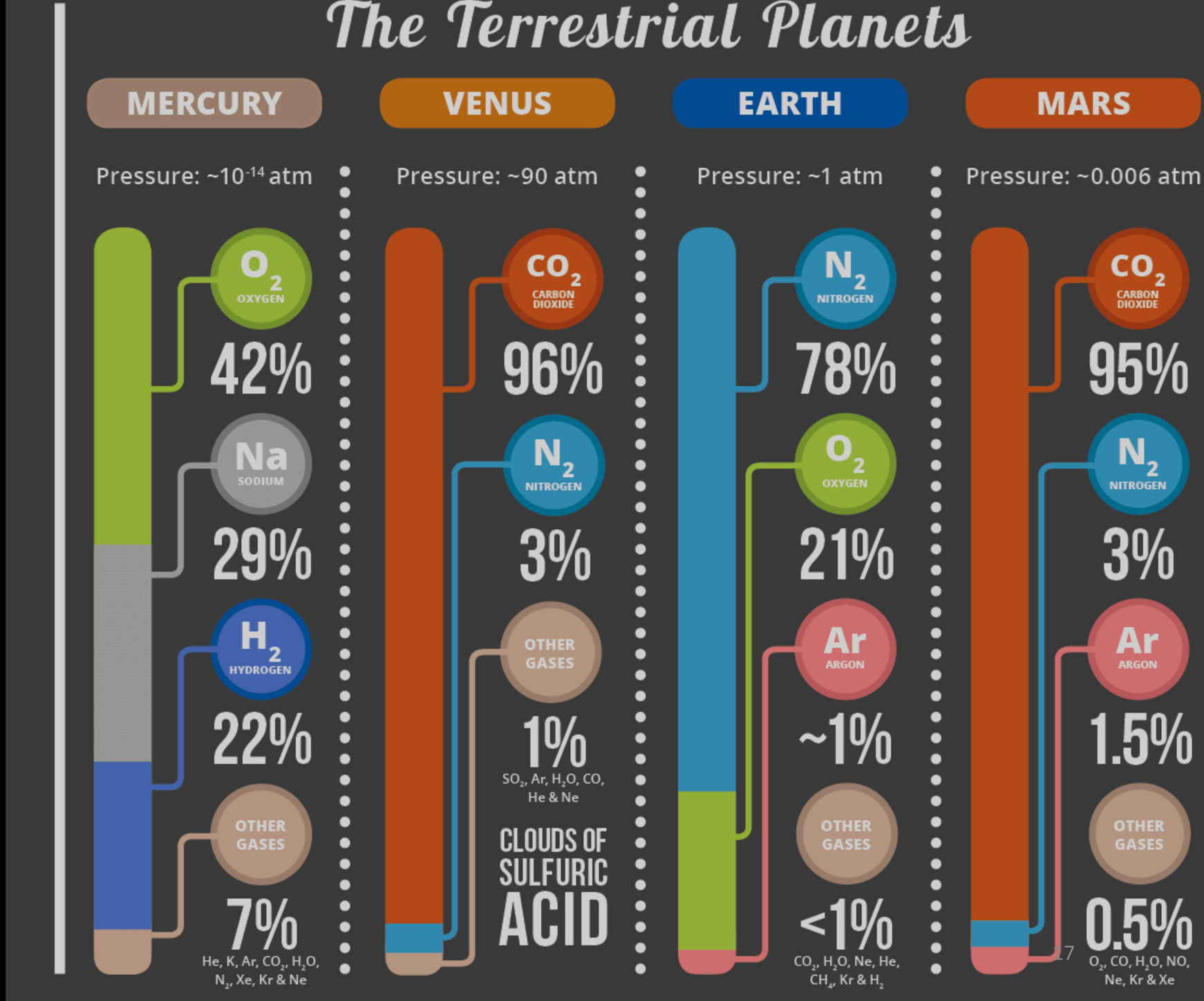
Will it rain on April 14, 2091?

-> ***What will average April rainfall be in the 2090s?***

How hot will it be on July 21, 2085?

-> ***How much higher will the severity of heatwaves be at the end of the 21st century?***

Earth's Atmosphere



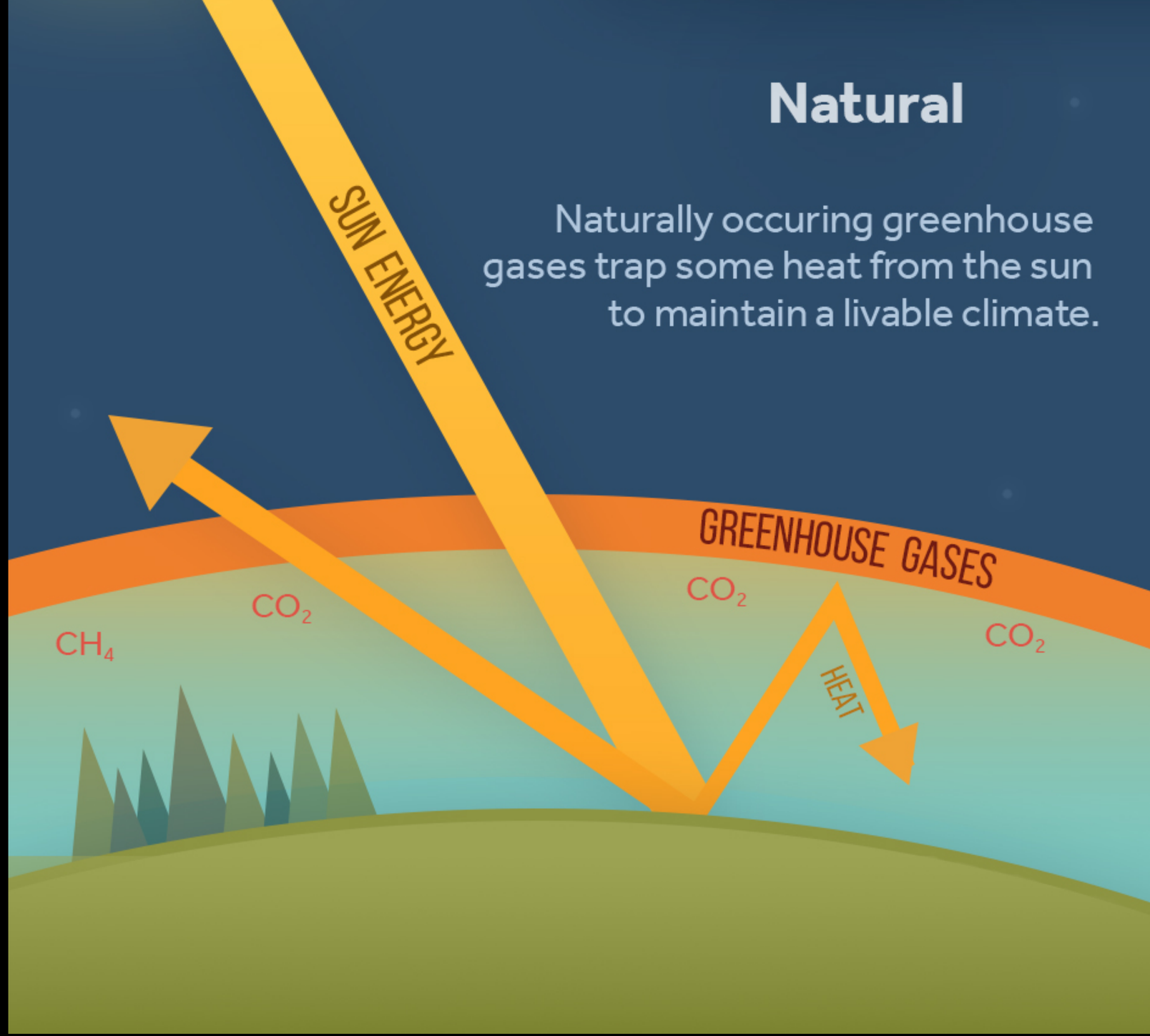
The Greenhouse Gas Effect

water vapor

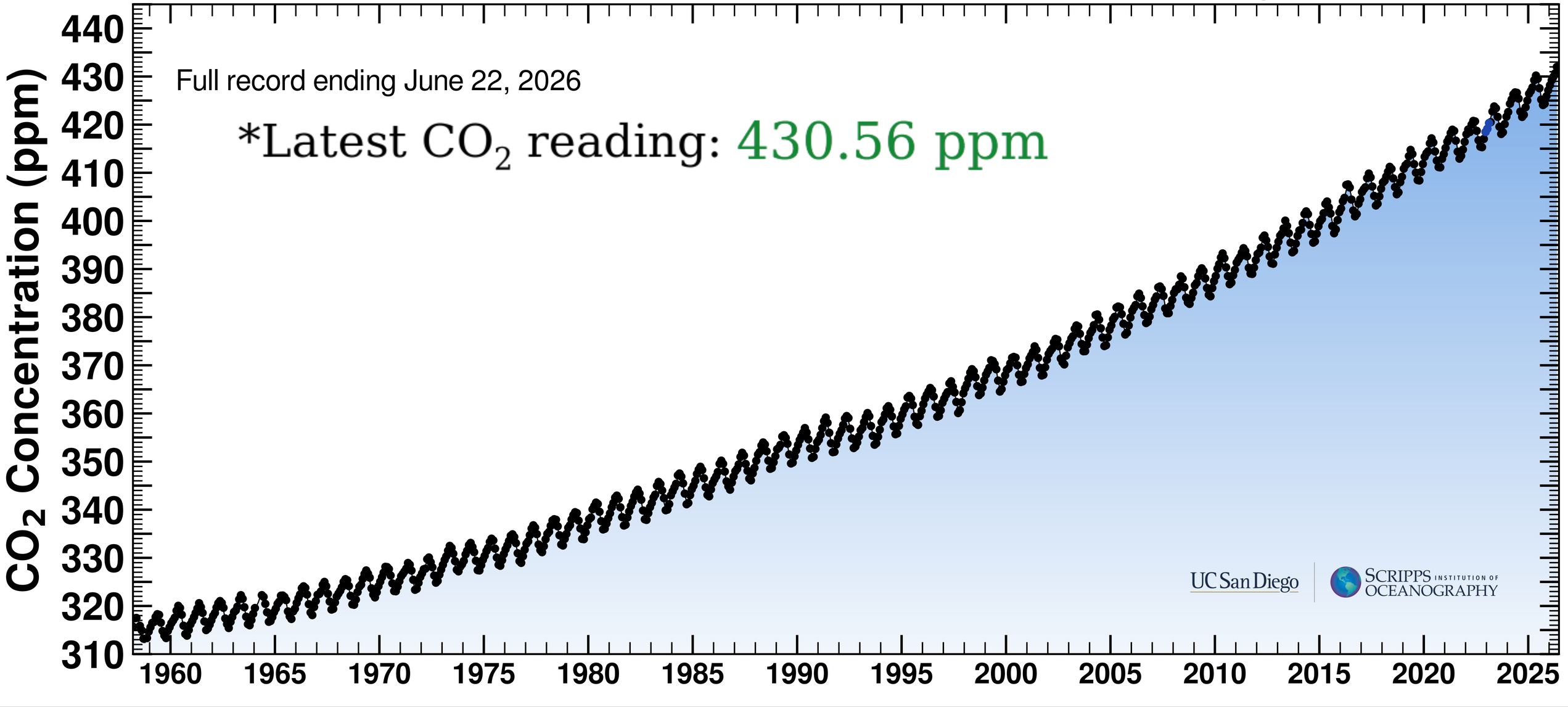
carbon dioxide (CO_2)

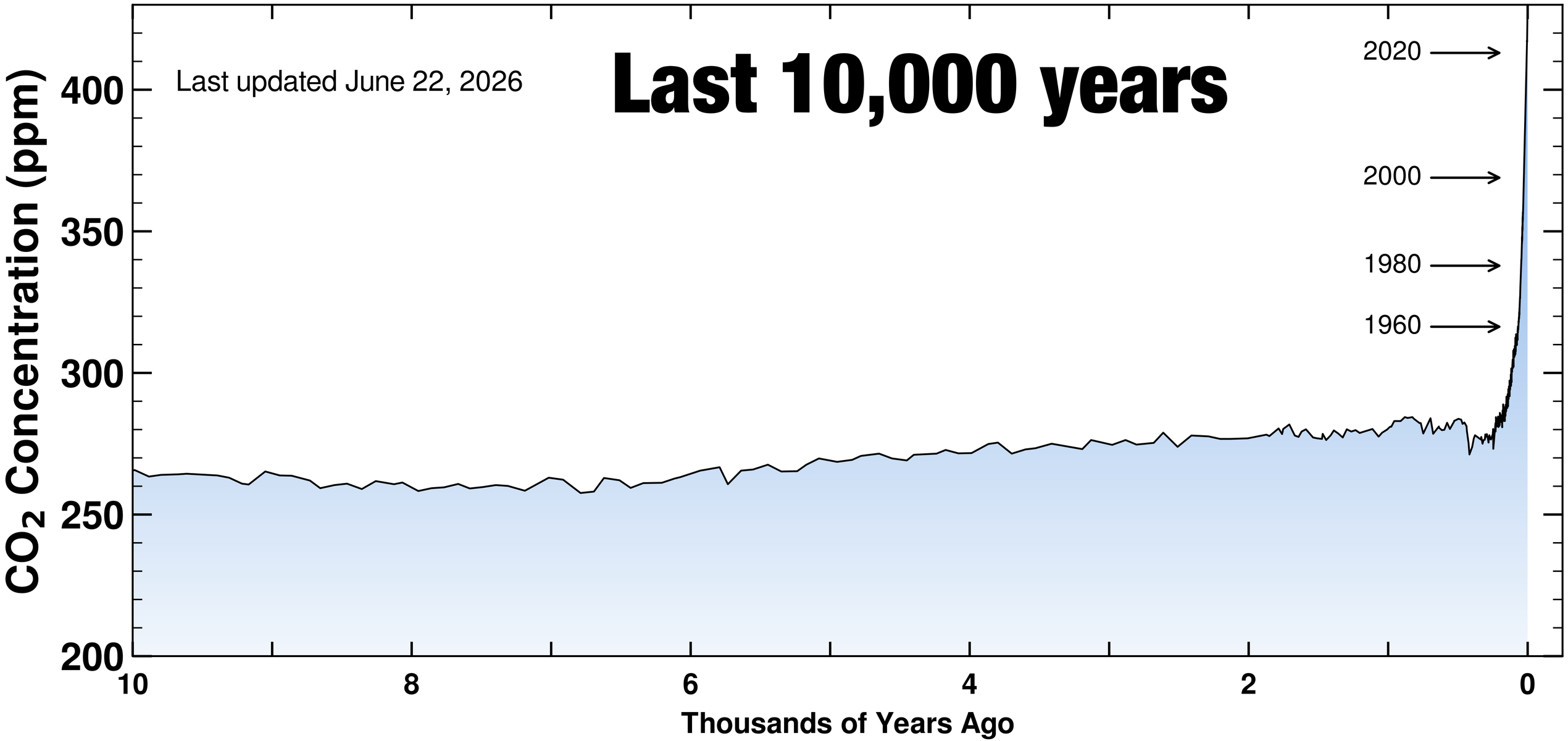
methane (CH_4)

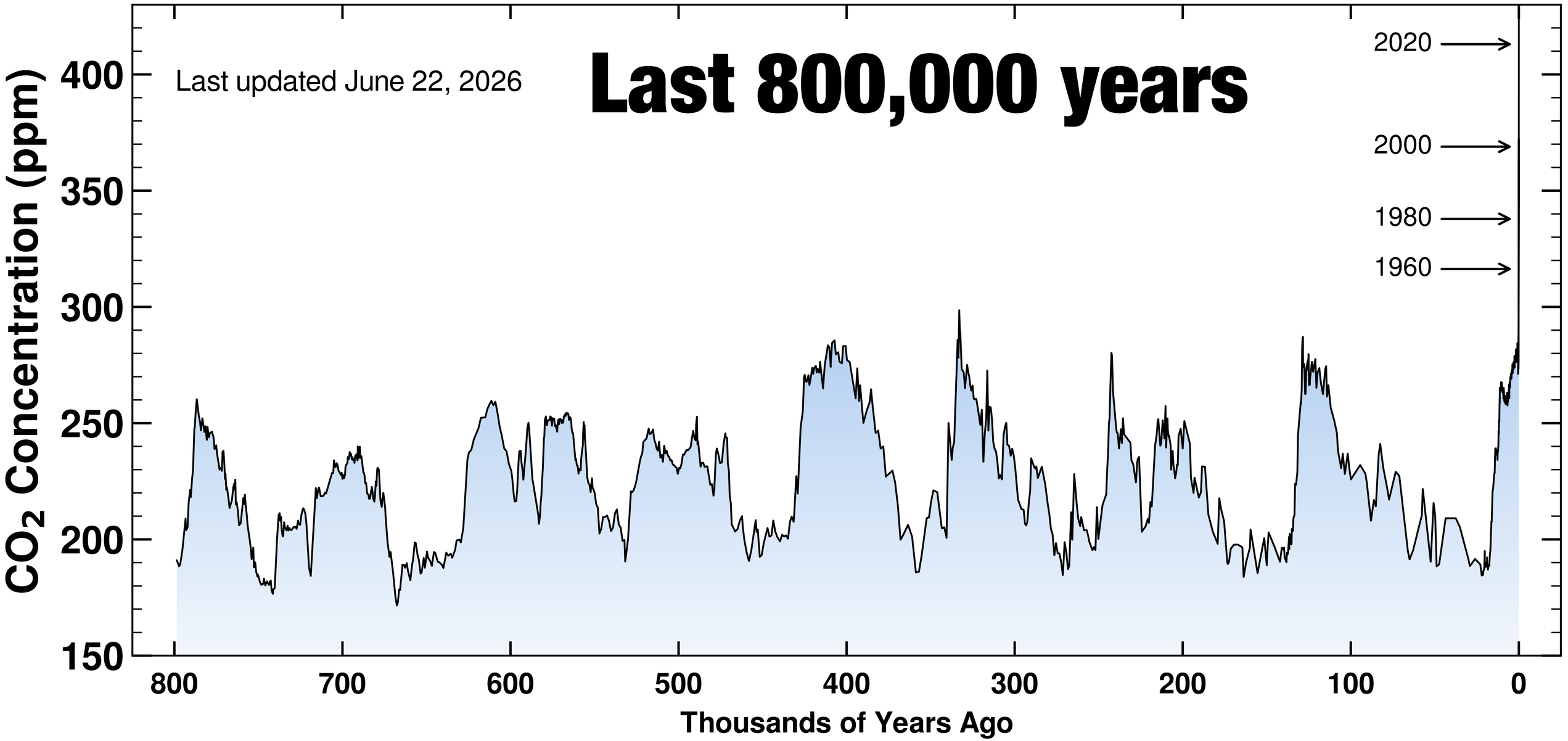
nitrous oxide (N_2O)



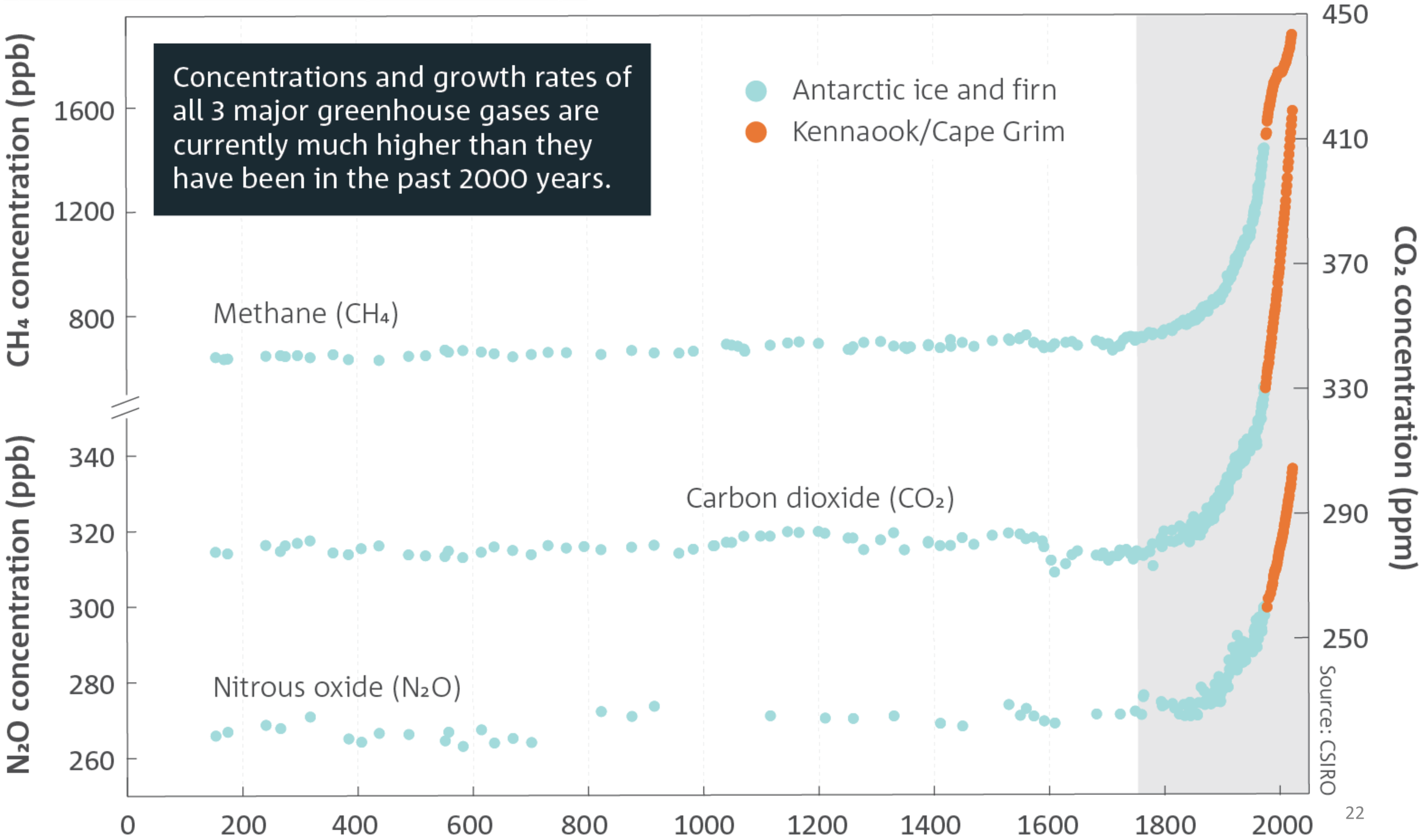
Carbon dioxide concentration at Mauna Loa Observatory*



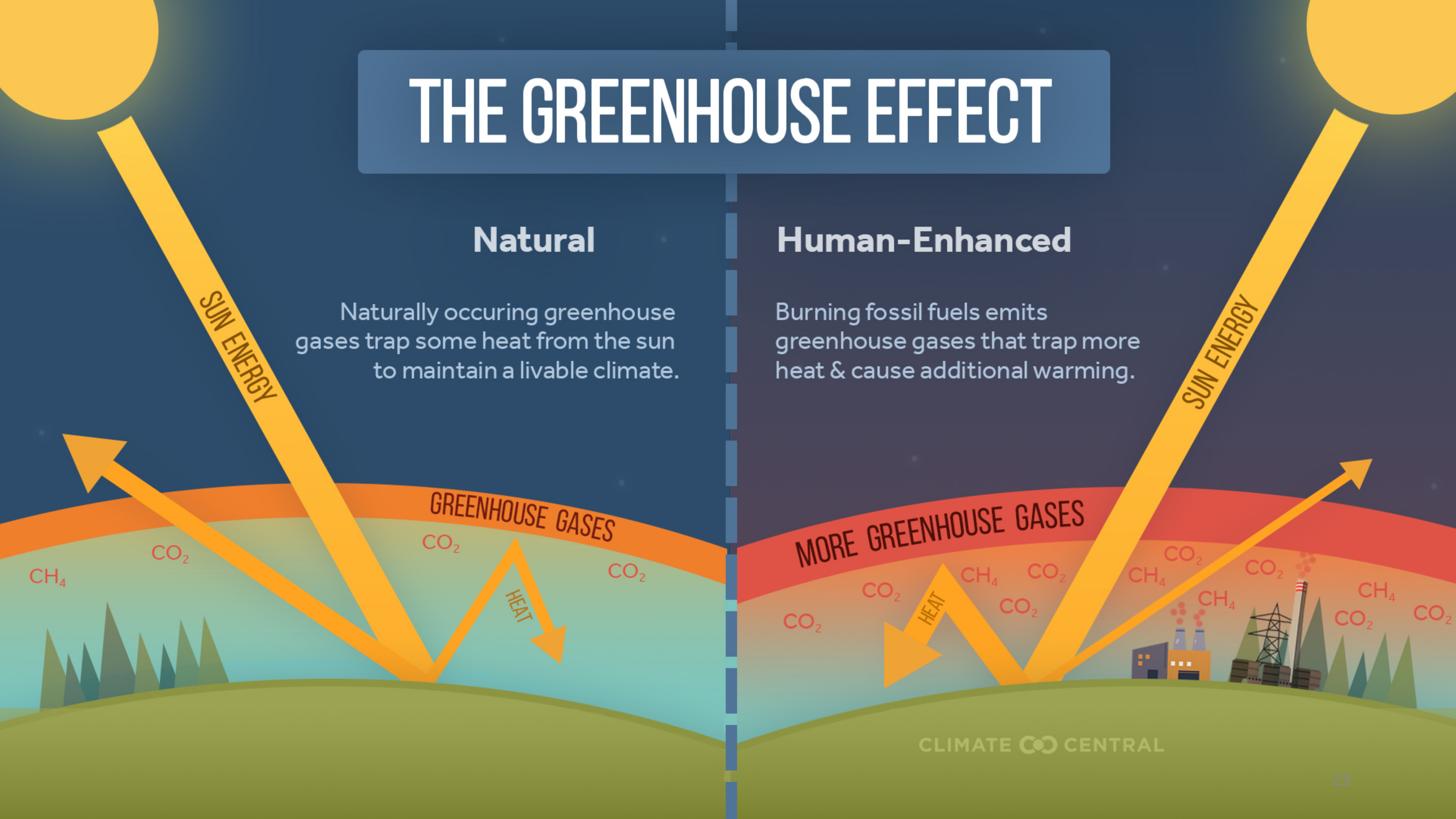

Last 10,000 years
Last updated June 22, 2026
2020
2000
1980
1960
400
350
300
250
200
CO_2 Concentration (ppm)
10
8
6
4
2
0
Thousands of Years Ago


Last updated June 22, 2026
Last 800,000 years
2020
2000
1980
1960
400
350
300
250
200
150
CO2 Concentration (ppm)
800
700
600
500
400
300
200
100
0
Thousands of Years Ago

https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate/Greenhouse-gases



THE GREENHOUSE EFFECT



CLIMATE CENTRAL

The relative warming potential of the most important greenhouse gases

Carbon dioxide = Global warming potential of 1

28 Methane

Comes from both natural and human-caused sources

265 Nitrous oxide

Often used in the medical, food, and automotive industry

11,100

Perfluorocarbons

Often used in industrial processes and semiconductor manufacturing

12,400

Hydrofluorocarbons

Often used in air conditioning and refrigeration systems

23,500

Sulphur hexafluoride

Often used in electrical equipment and semiconductor manufacturing

16,100

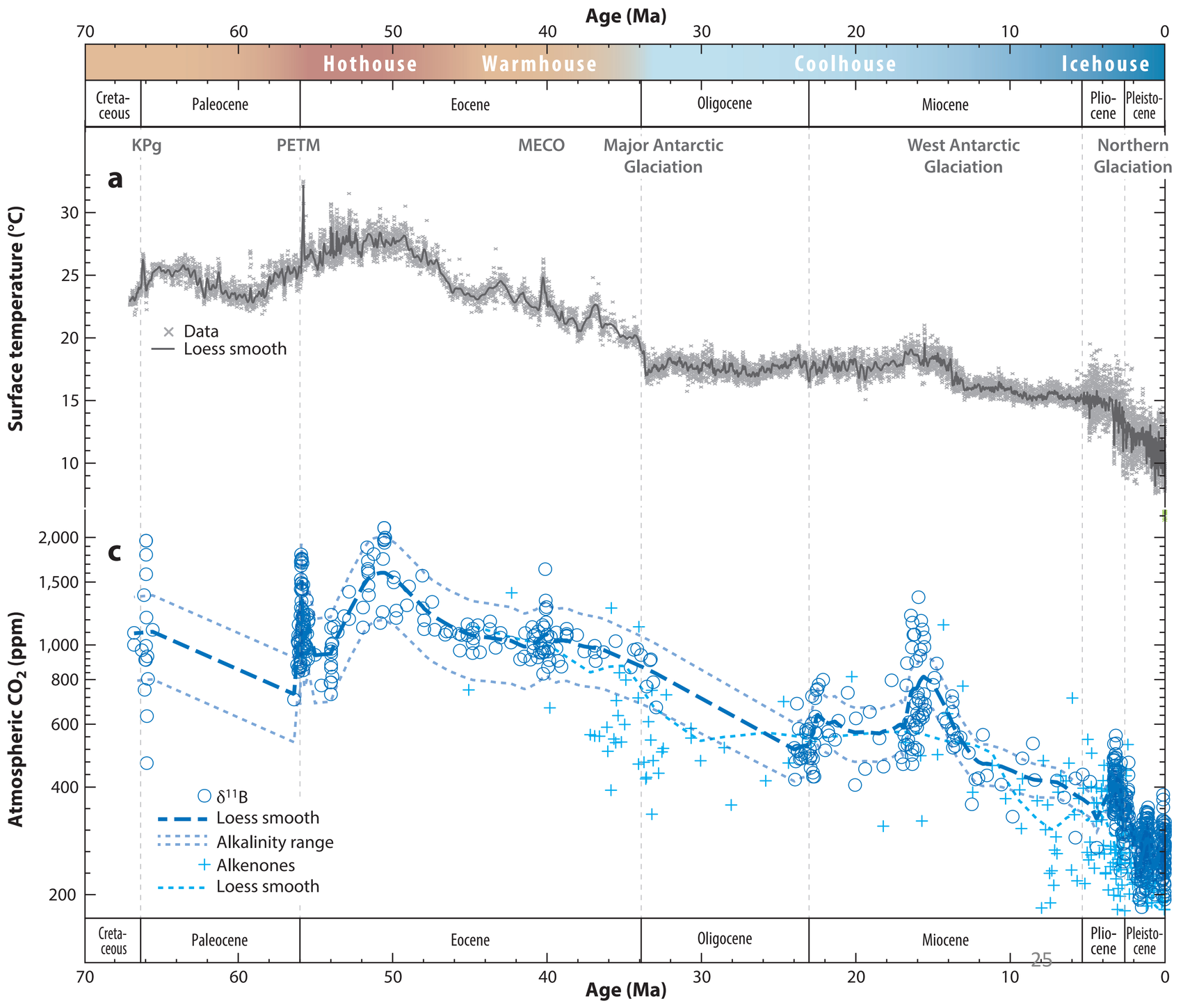
Nitrogen trifluoride

Often used in semiconductor manufacturing and flat-panel displays like LCDs

Source: Global Warming Potentials (GWPs) given for 100 year time horizon, IPCC 2021

https://www.climatepartner.com/en/knowledge/glossary/carbon-dioxide-equivalent

In the past, when CO2 is high, global temperatures are high



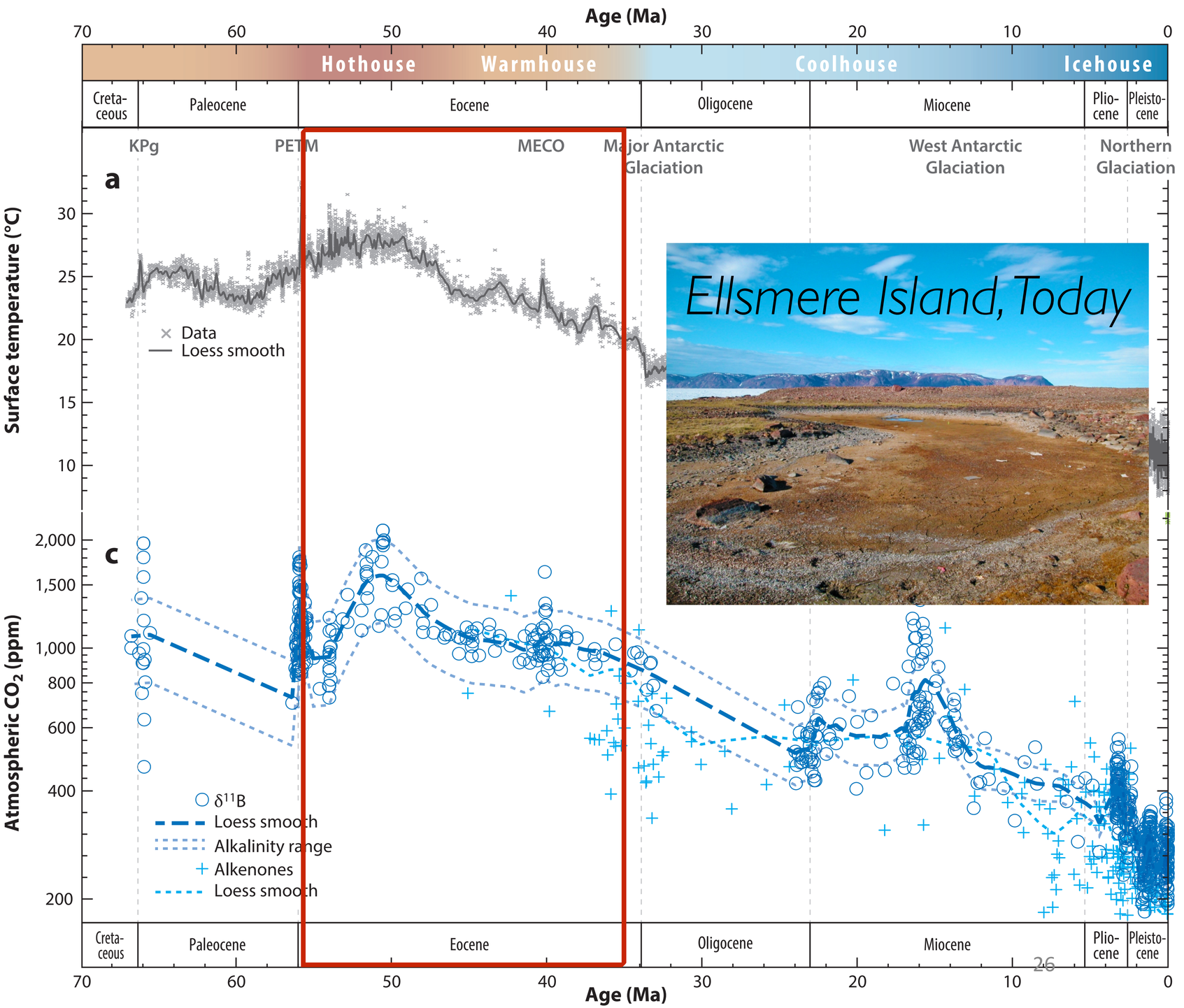
https://www.annualreviews.org/doi/abs/10.1146/annurev-earth-082420-063026

The Eocene

(56-33.9 MYA)

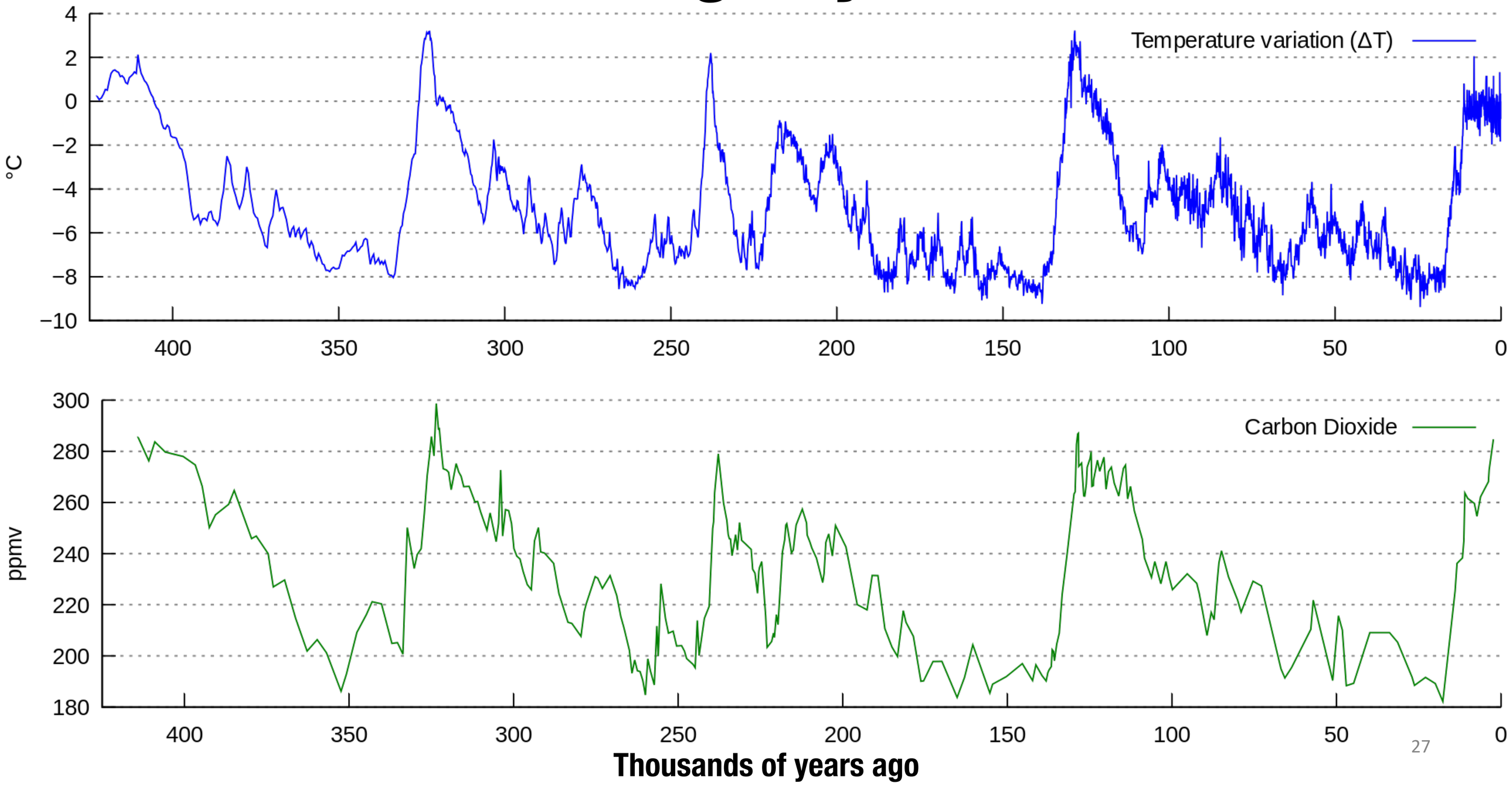
Ellsmere Island, 50 MYA



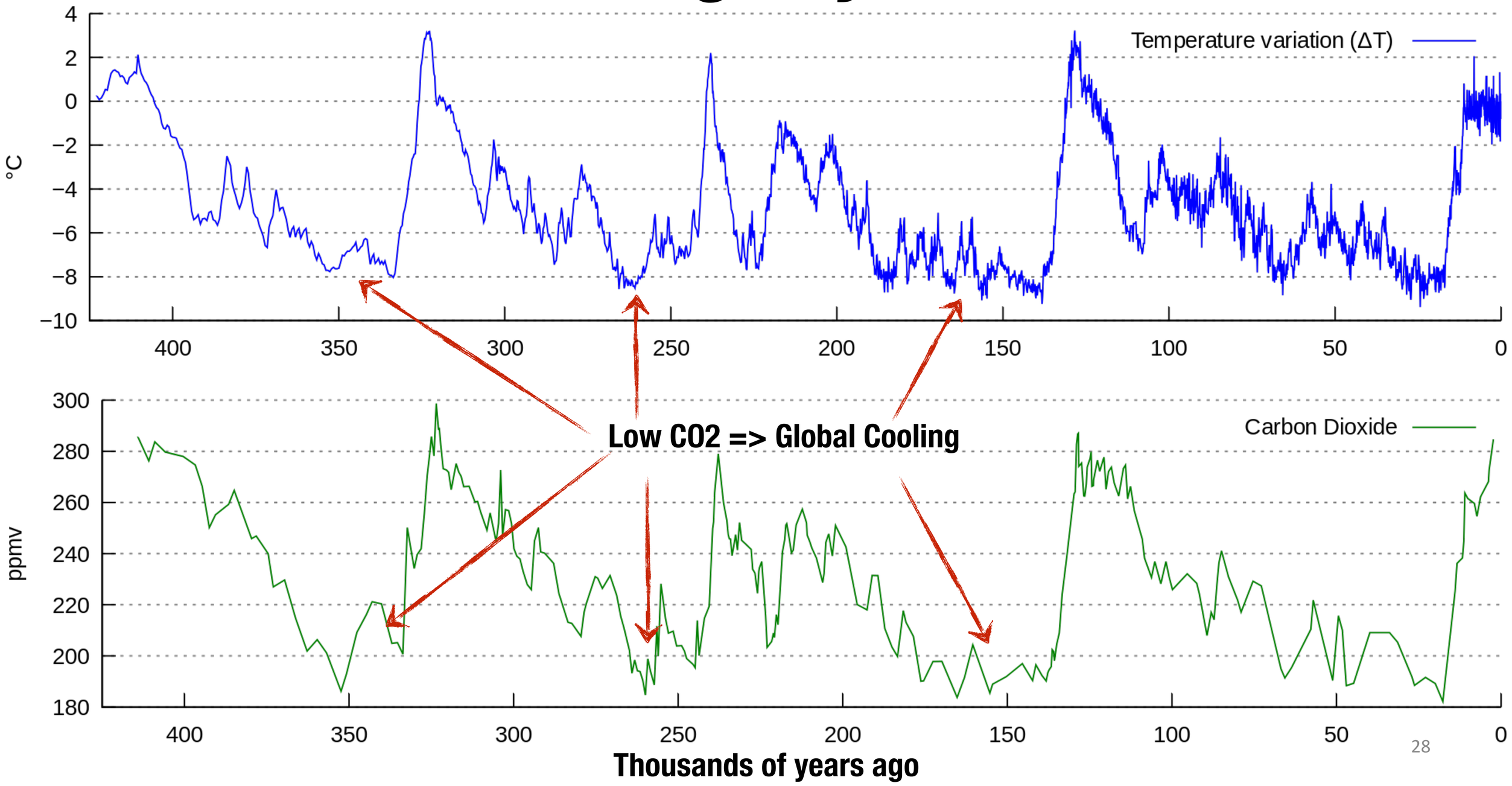


https://www.annualreviews.org/doi/abs/10.1146/annurev-earth-082420-063026

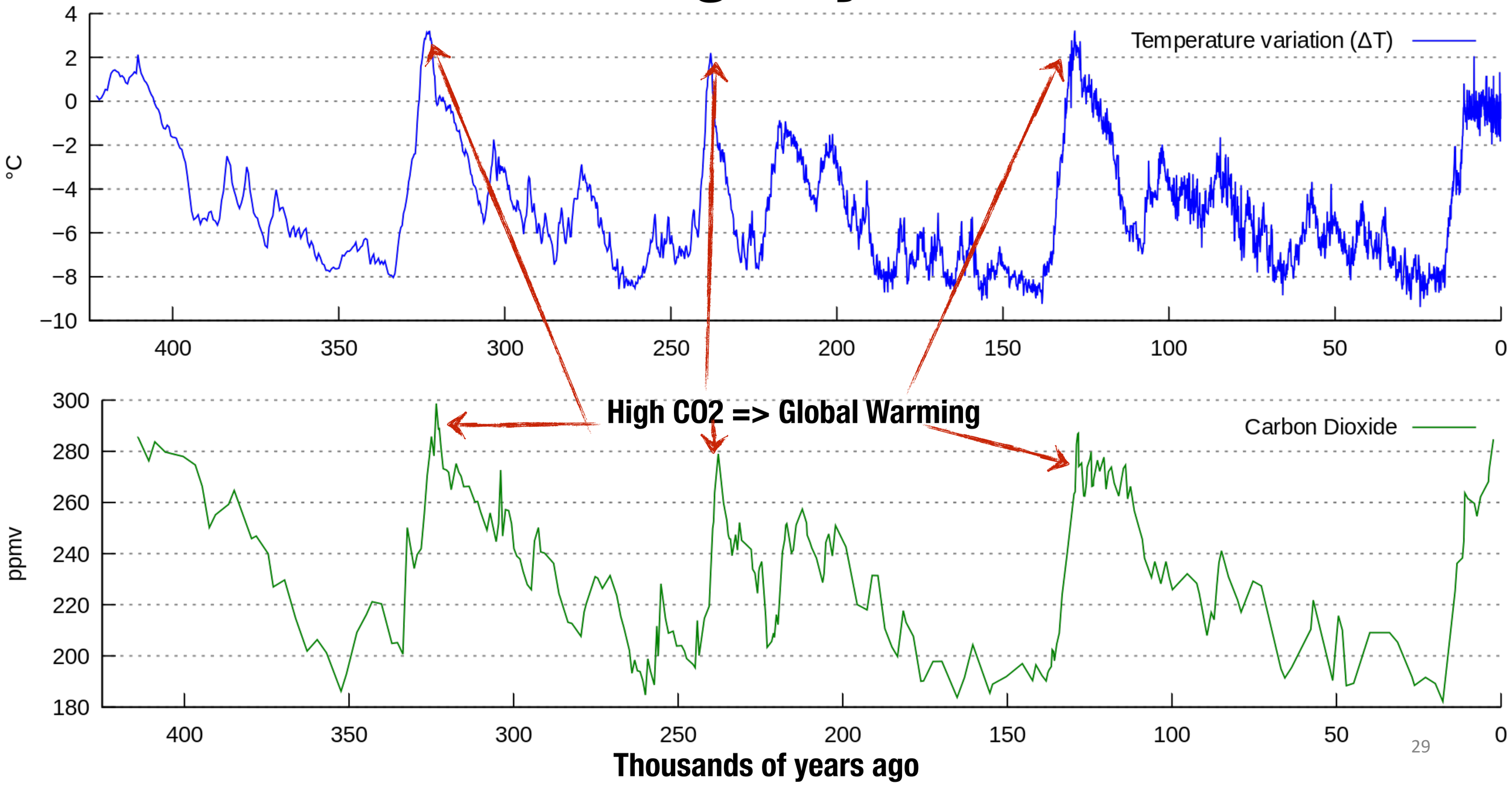
Ice Age Cycles



Ice Age Cycles

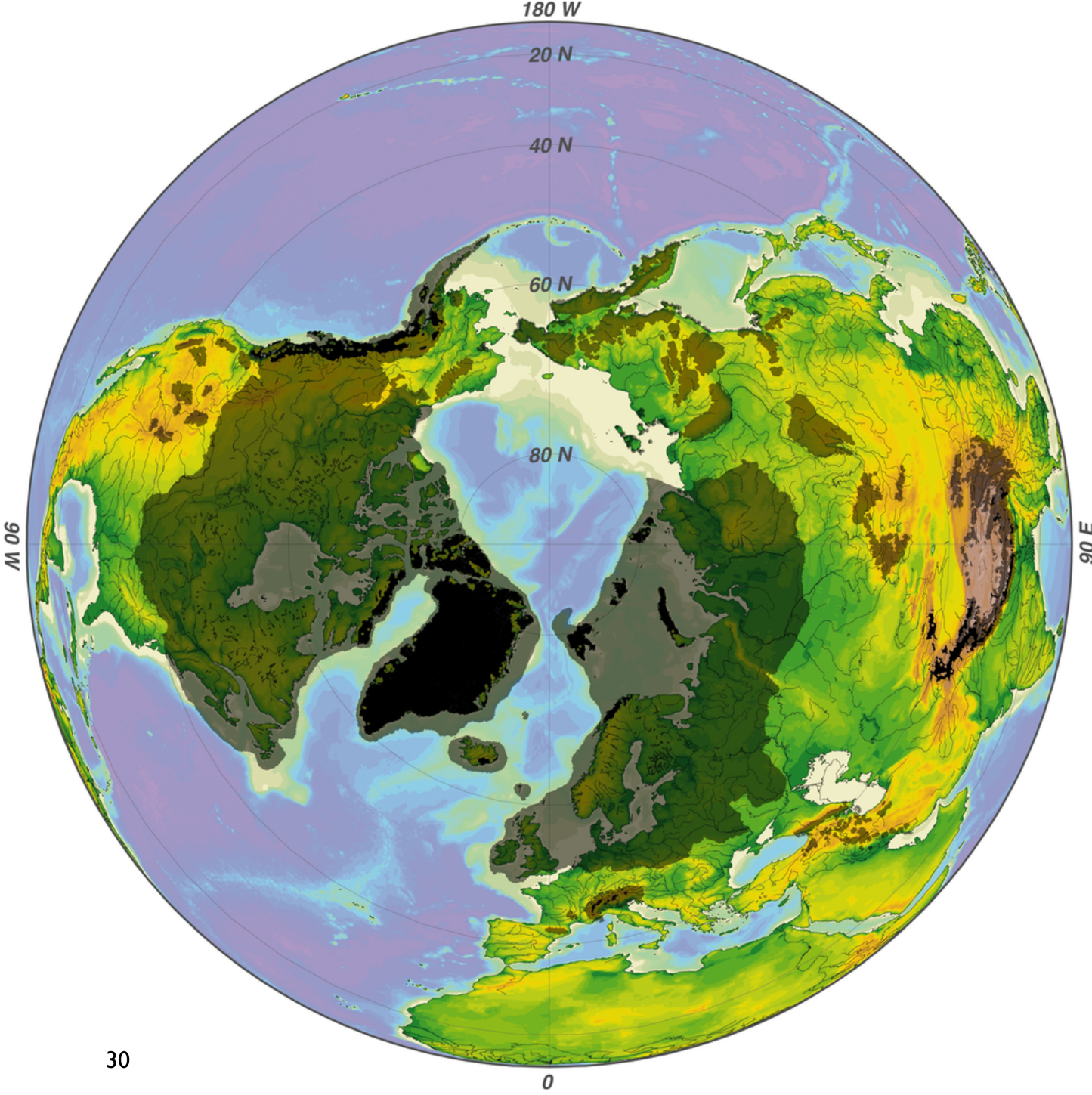


Ice Age Cycles



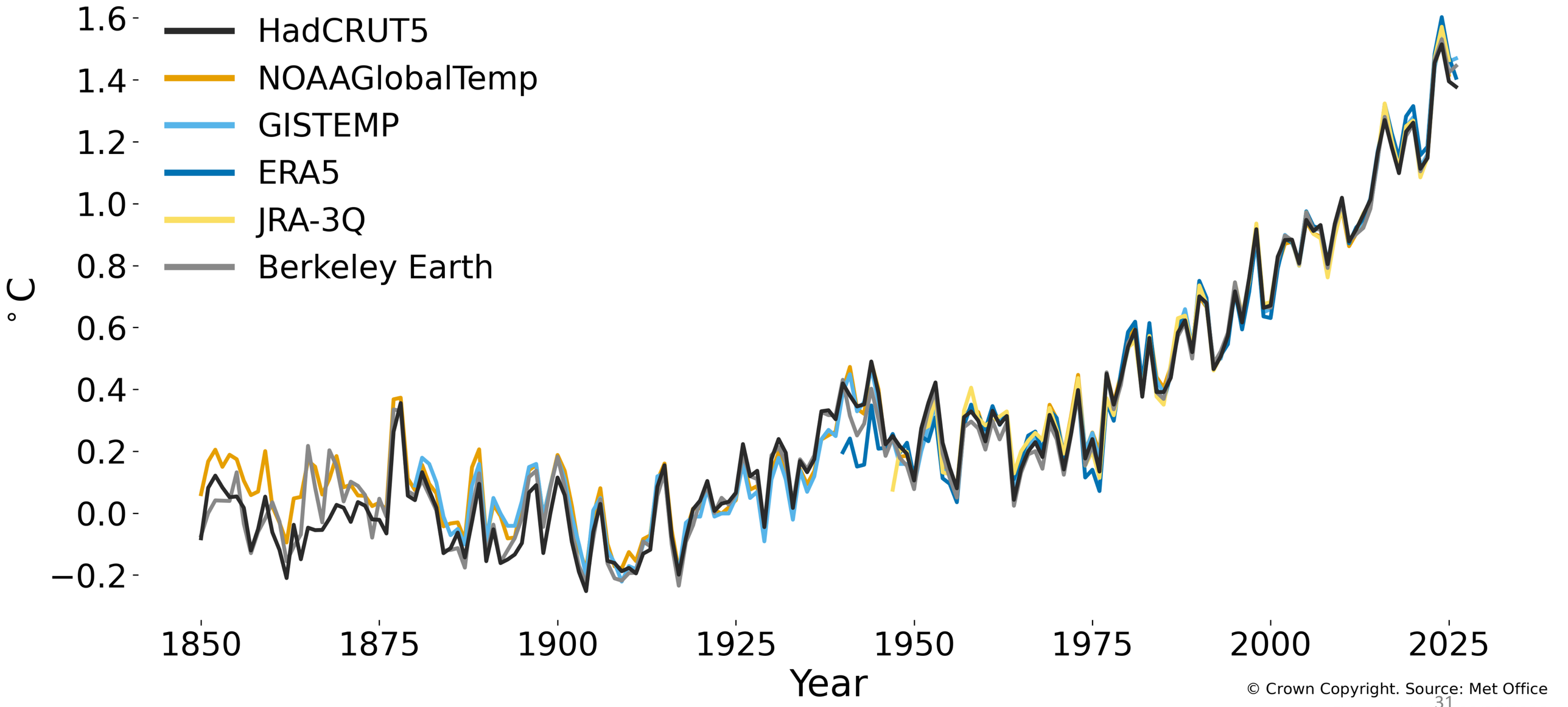
Ice Sheets During the LGM

dark = now
light = ~25 kybp



images from: http://en.wikipedia.org/wiki/Ice_age

THE WORLD IS WARMING

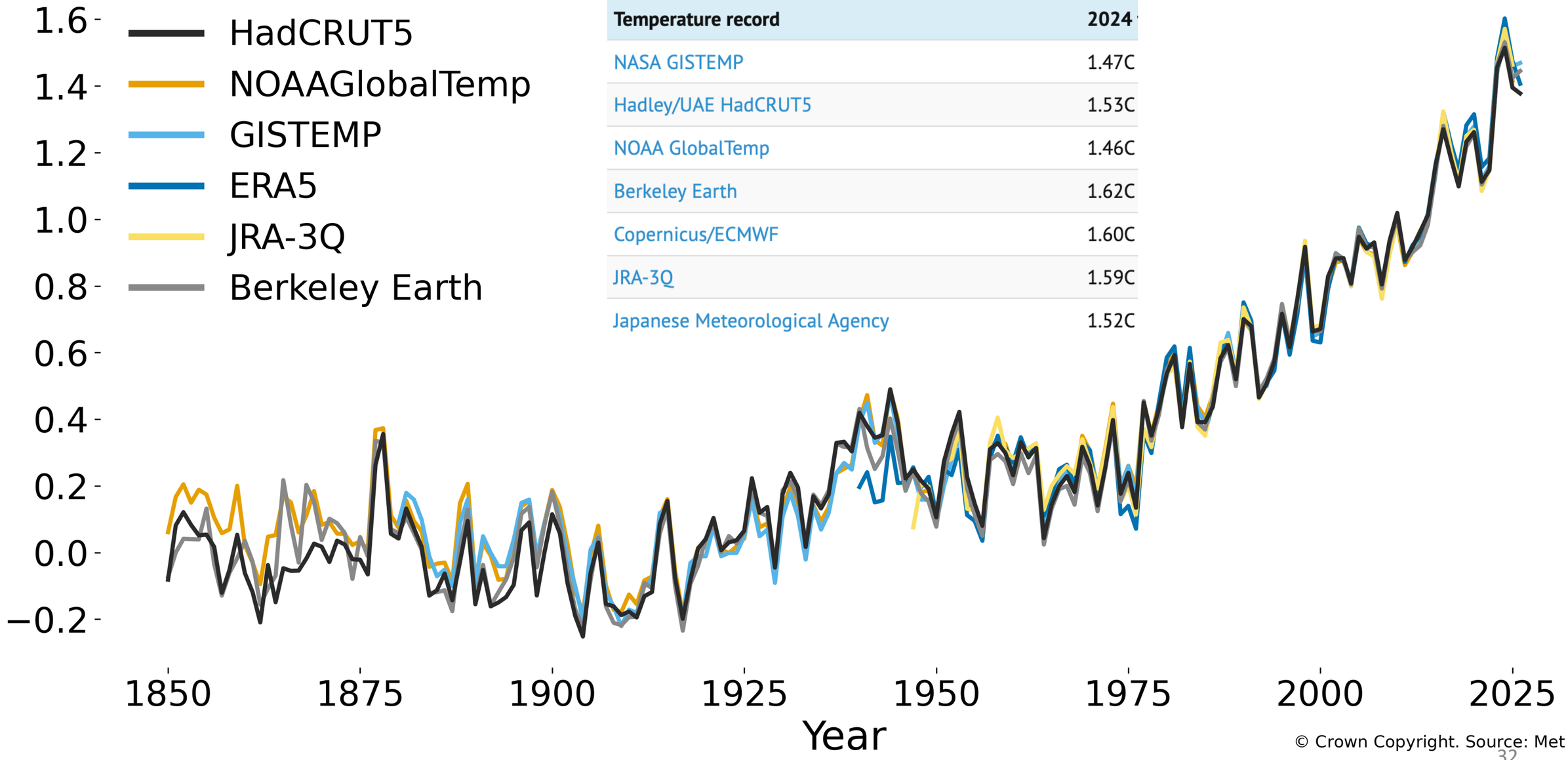


© Crown Copyright. Source: Met Office

Figure updated: 09/06/2026

RECORD HIGH: 2024

Temperature record	2024
NASA GISTEMP	1.47C
Hadley/UAE HadCRUT5	1.53C
NOAA GlobalTemp	1.46C
Berkeley Earth	1.62C
Copernicus/ECMWF	1.60C
JRA-3Q	1.59C
Japanese Meteorological Agency	1.52C



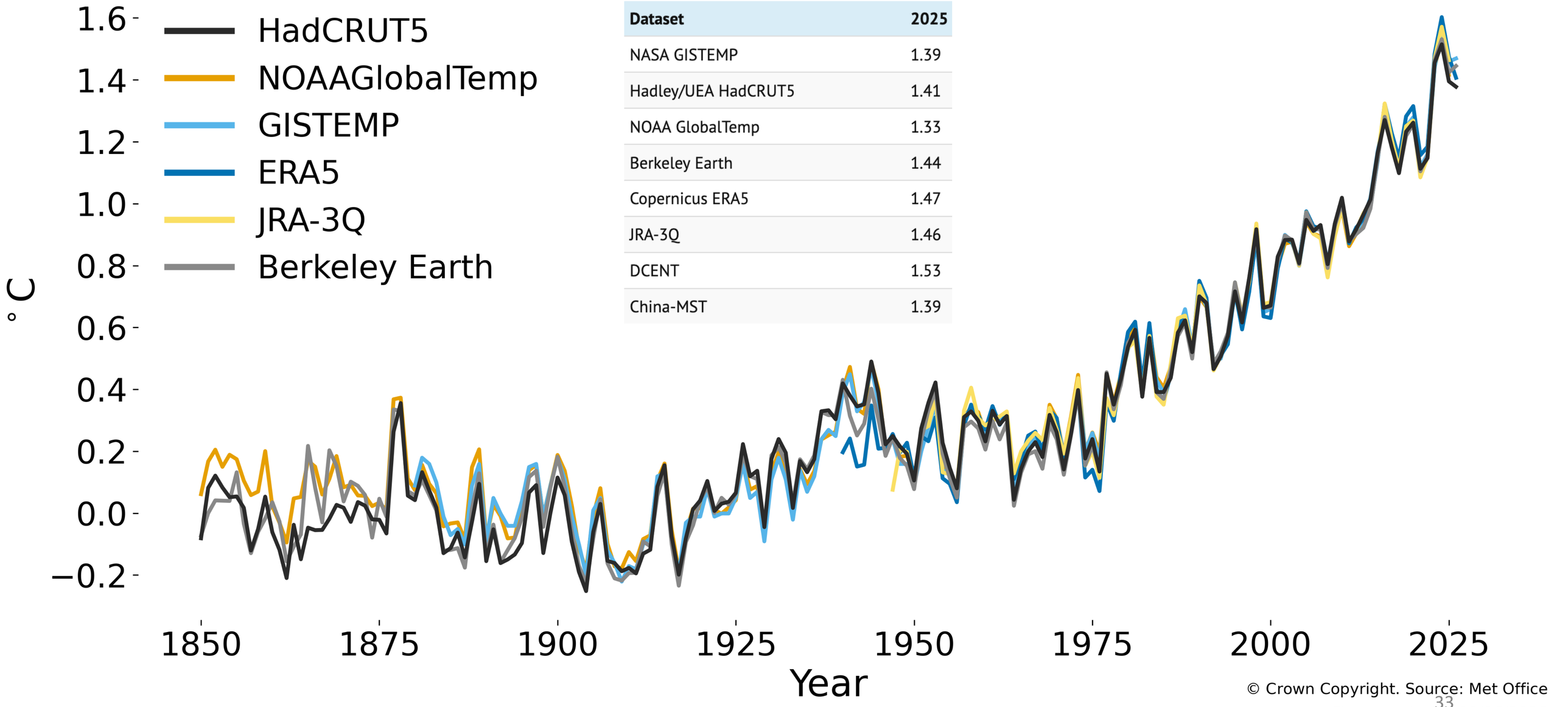
© Crown Copyright. Source: Met Office

Figure updated: 09/06/2026

https://www.carbonbrief.org/state-of-the-climate-2024-sets-a-new-record-as-the-first-year-above-1-5c/

2025: RANK #2 OR #3

Dataset	2025
NASA GISTEMP	1.39
Hadley/UEA HadCRUT5	1.41
NOAA GlobalTemp	1.33
Berkeley Earth	1.44
Copernicus ERA5	1.47
JRA-3Q	1.46
DCENT	1.53
China-MST	1.39

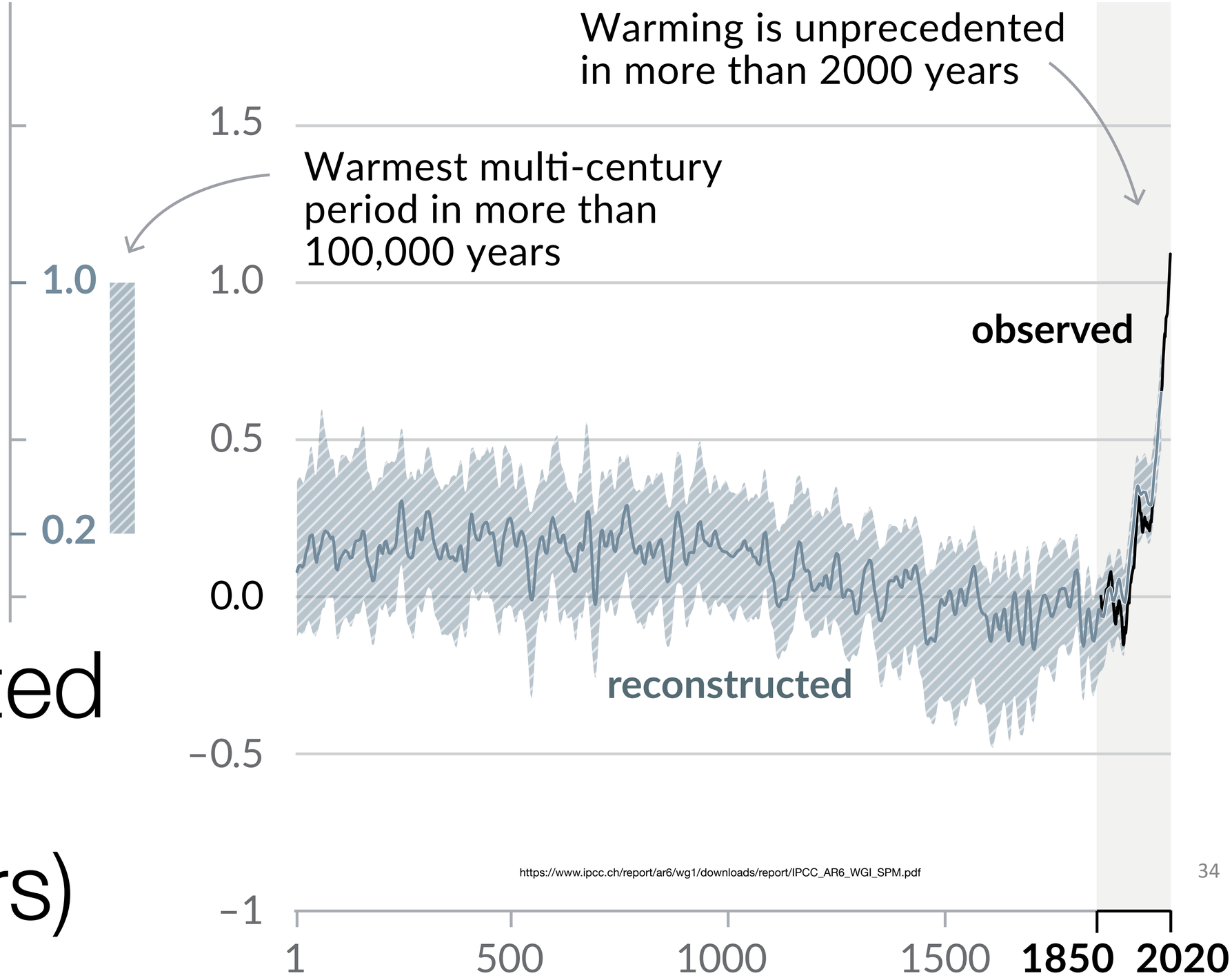


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Figure updated: 09/06/2026

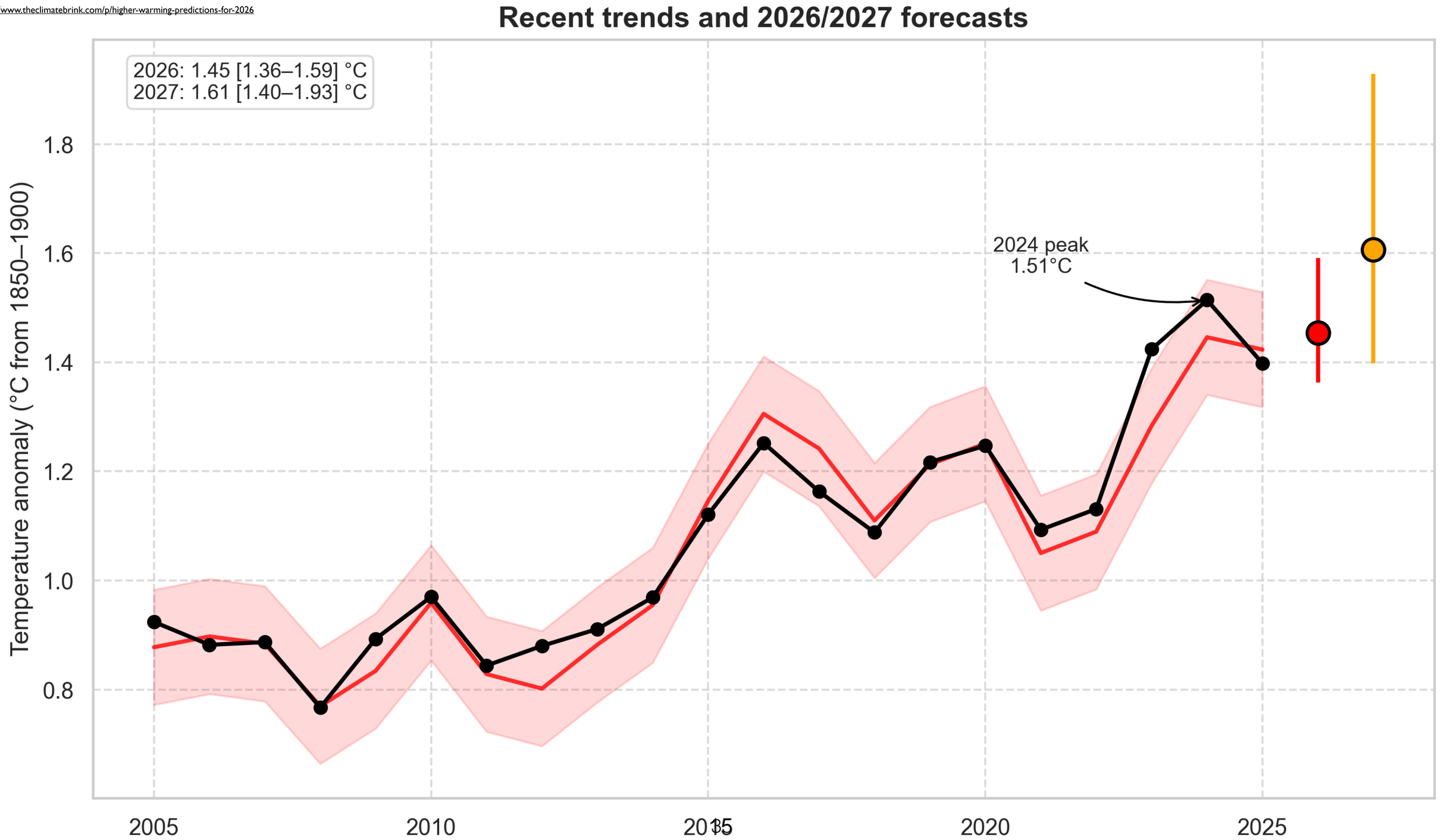
https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges/

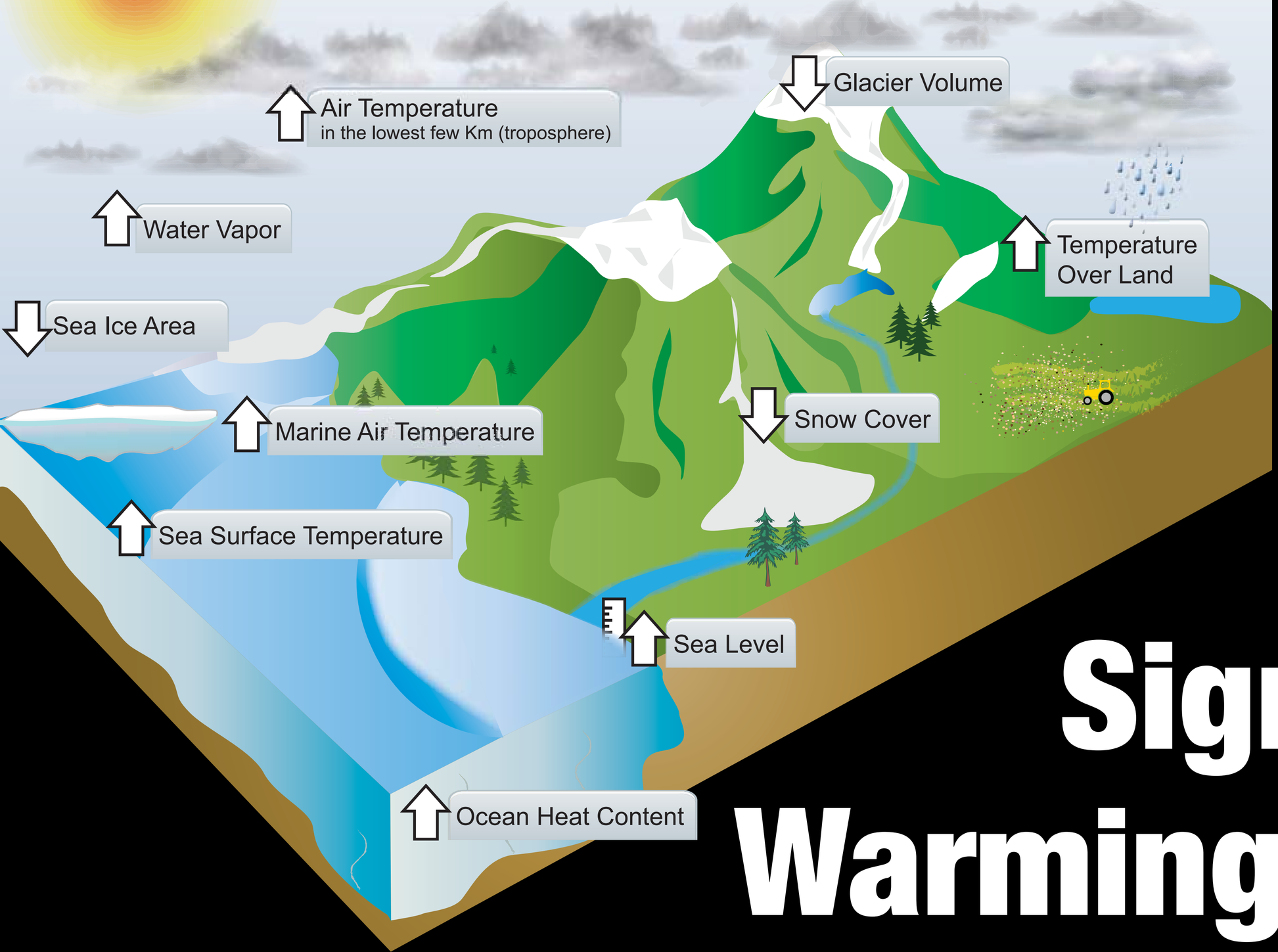
Unprecedented warming (last 2000 yrs)



https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

https://www.theclimatebrink.com/p/higher-warming-predictions-for-2026

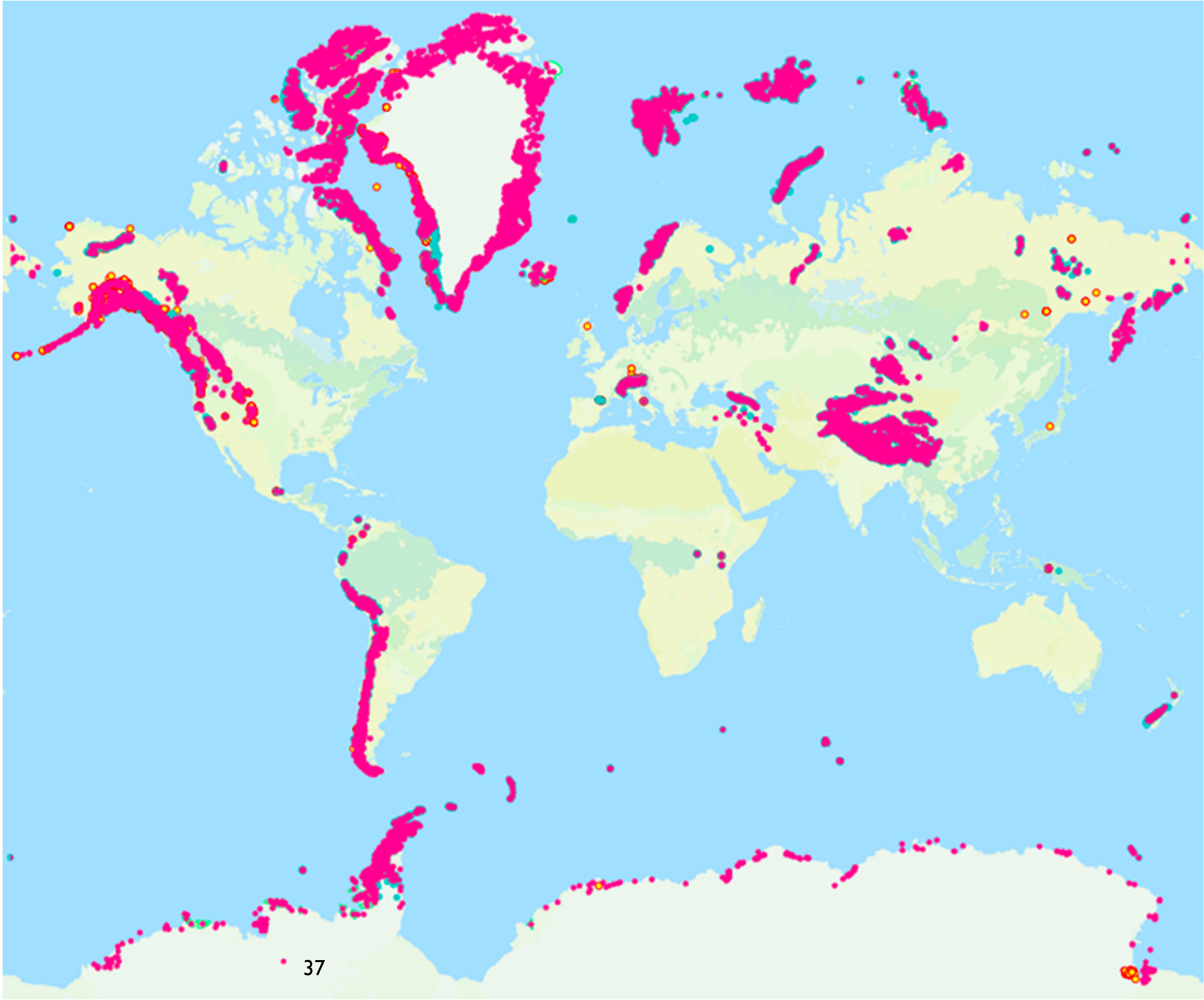




Signs of a Warming World

Glaciers /ice sheets

Huge masses of ice that move slowly over land



https://nsidc.org/cryosphere/glaciers/questions/located.html

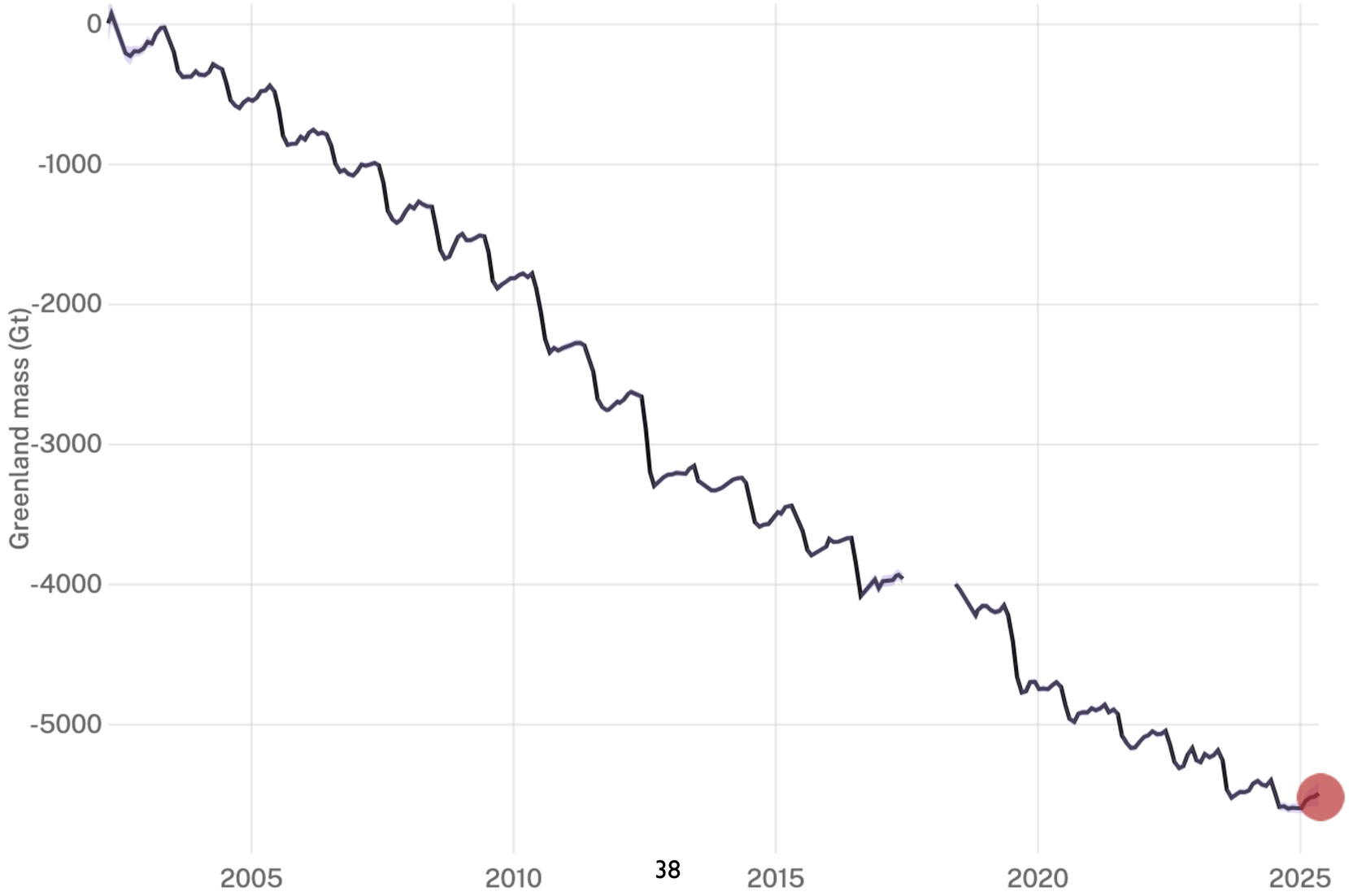
GREENLAND MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's GRACE satellites. **Gap represents time between missions.**
Credit: NASA

RATE OF CHANGE

↓264

billion metric tons per year since 2002

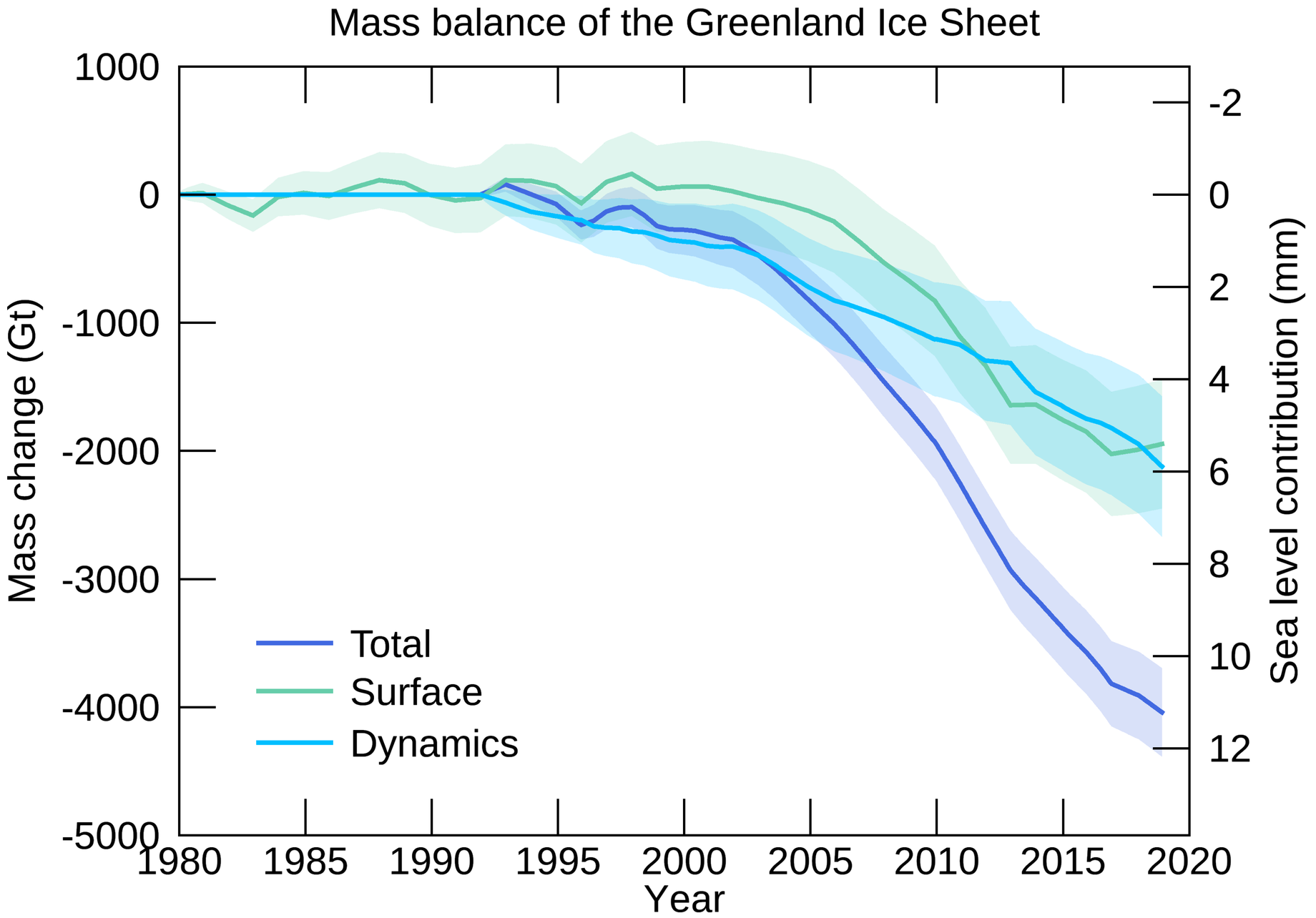


https://climate.nasa.gov/vital-signs/ice-sheets/

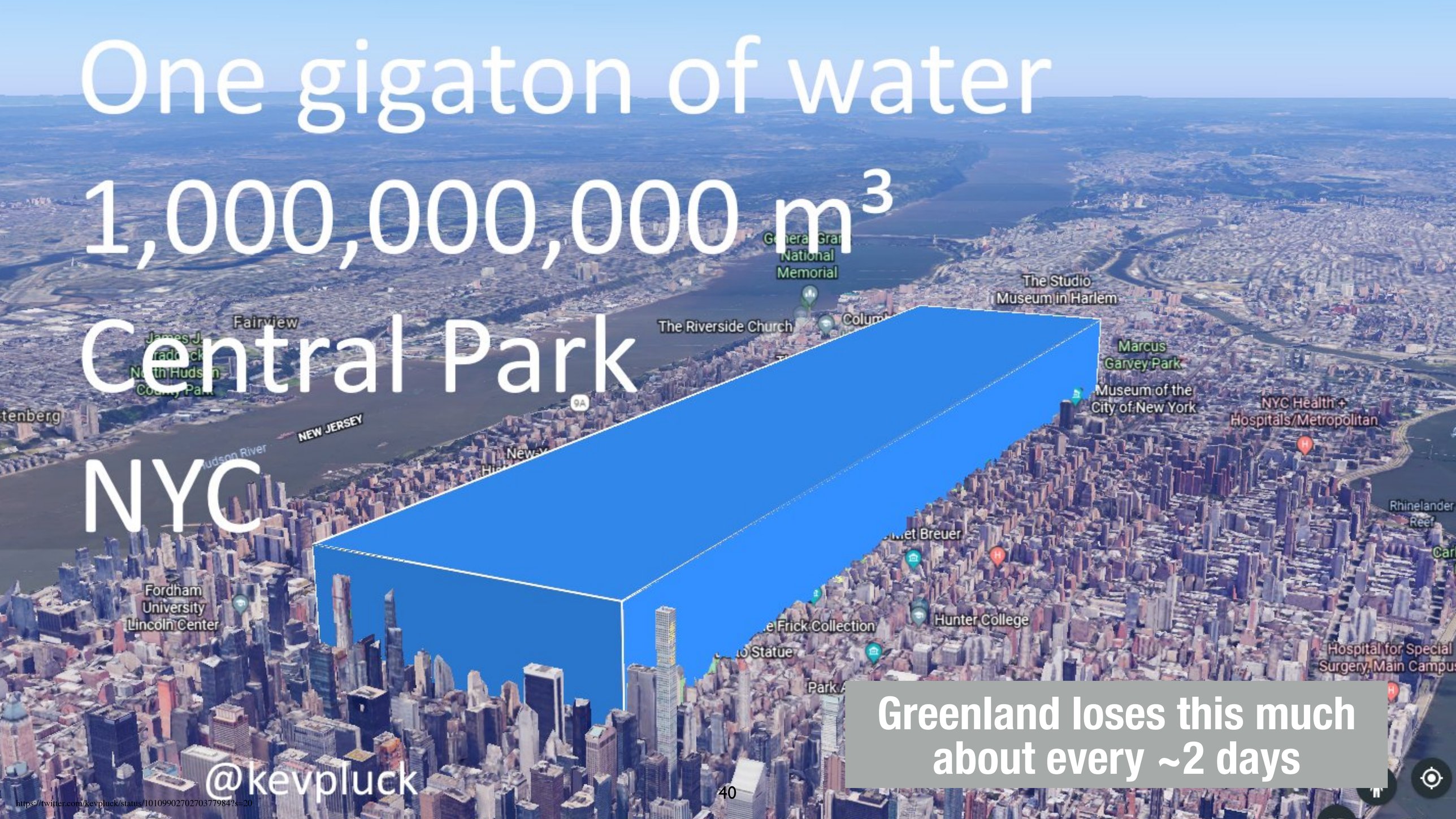
Greenland Ice Sheet

1 Gt =

- Mass of all land mammals on earth (excluding humans)
- 2X mass of all humans on earth
- 5.5 million blue whales
- 3 million Boeing 747 jets



https://energyeducation.ca/encyclopedia/Gigatonne
https://climate.copernicus.eu/ESOTC/2019/ice-sheets
https://www.nature.com/articles/s41586-019-1855-2.pdf



https://twitter.com/kevpluck/status/1010990270270377984?s=20

McCarty Glacier, Alaska





http://www.windows2universe.org/teacher_resources/teach_glacier.html

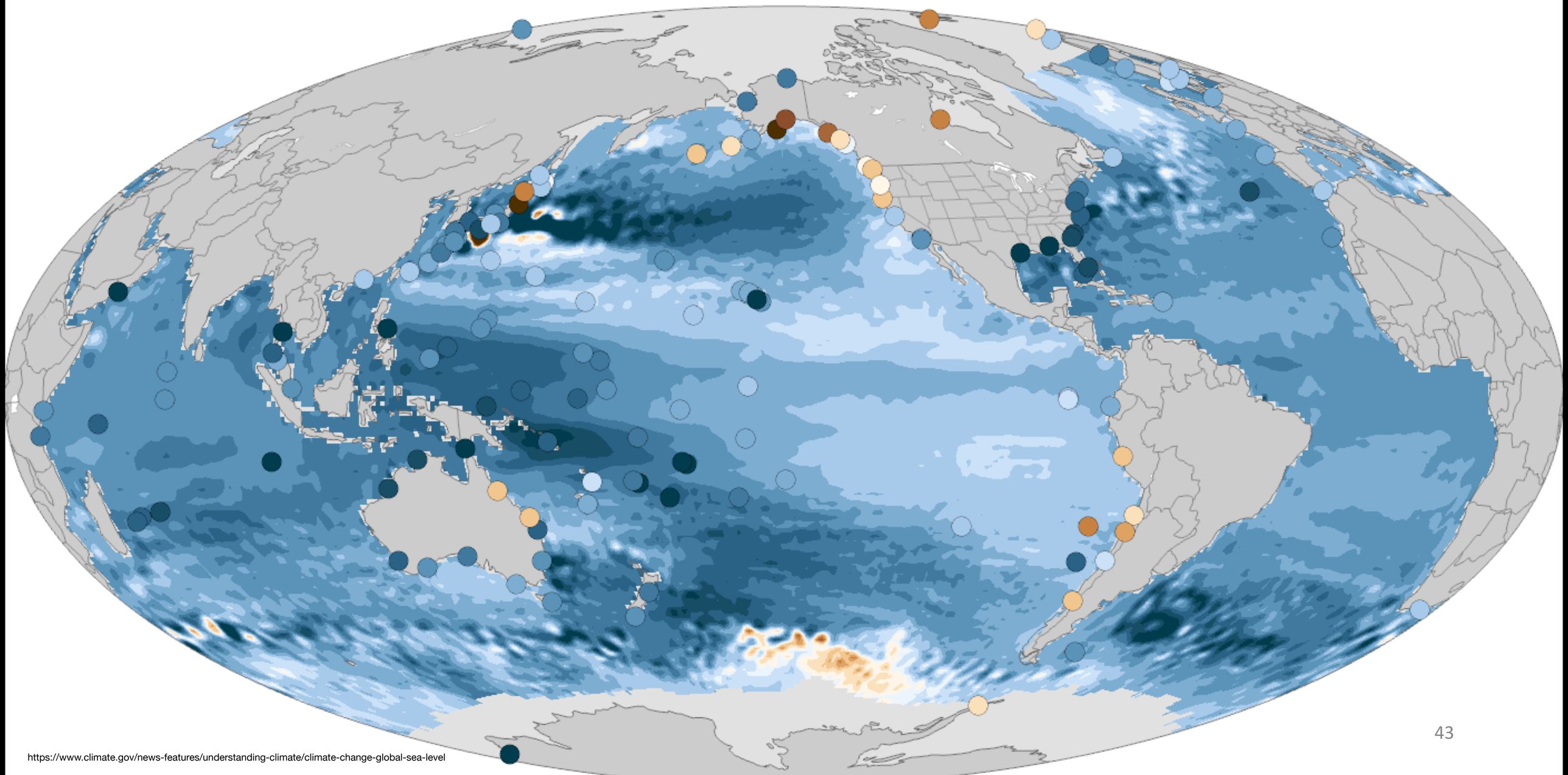
Blomstrandbreen Glacier
Svalbard, Norway





https://www.theguardian.com/environment/2024/nov/05/people-do-not-want-to-believe-it-is-true-the-photographer-capturing-the-vanishing-of-glaciers

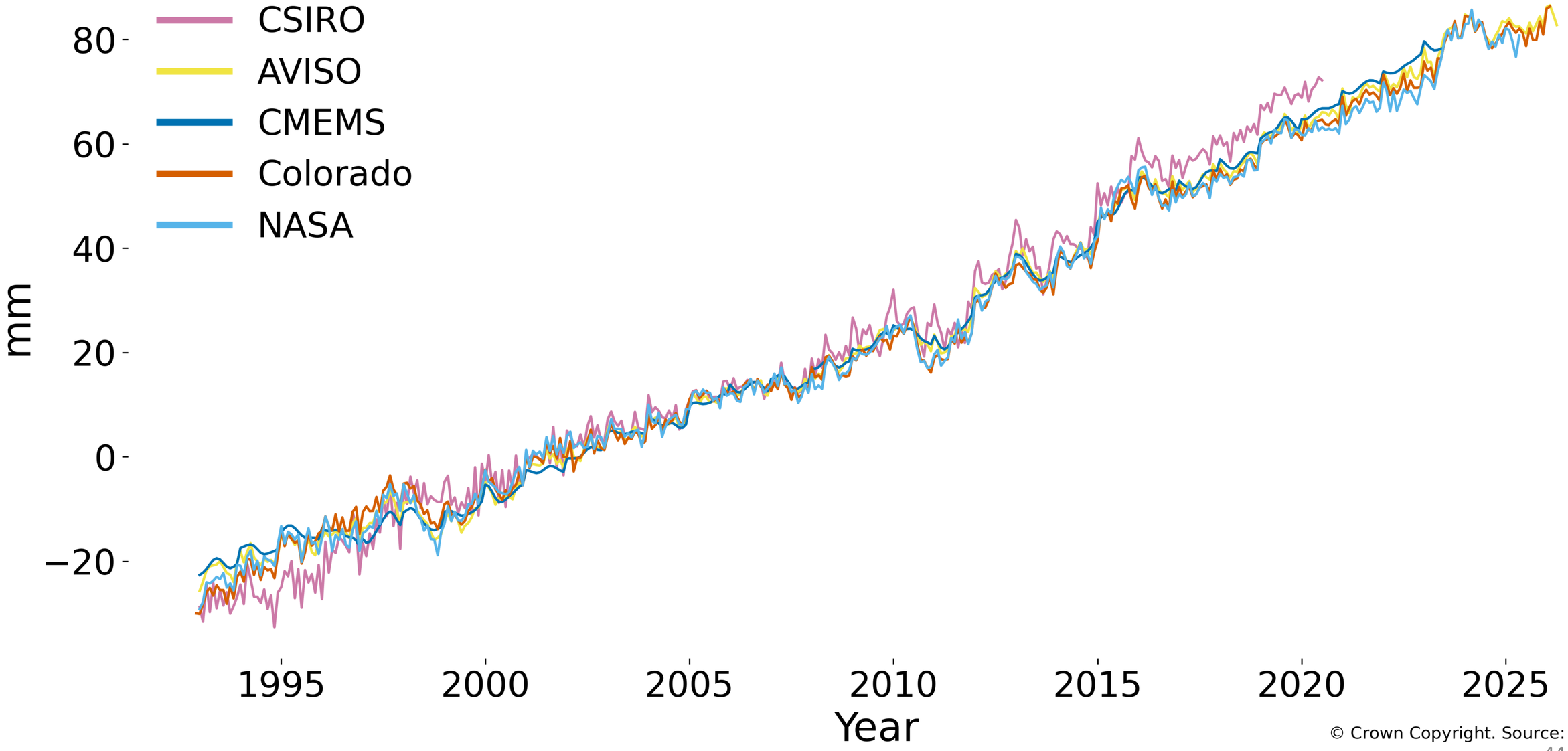
Change in Sea level (cm, 1993-2023)



https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Met Office

Global sea level difference from 1993-2010 (mm)

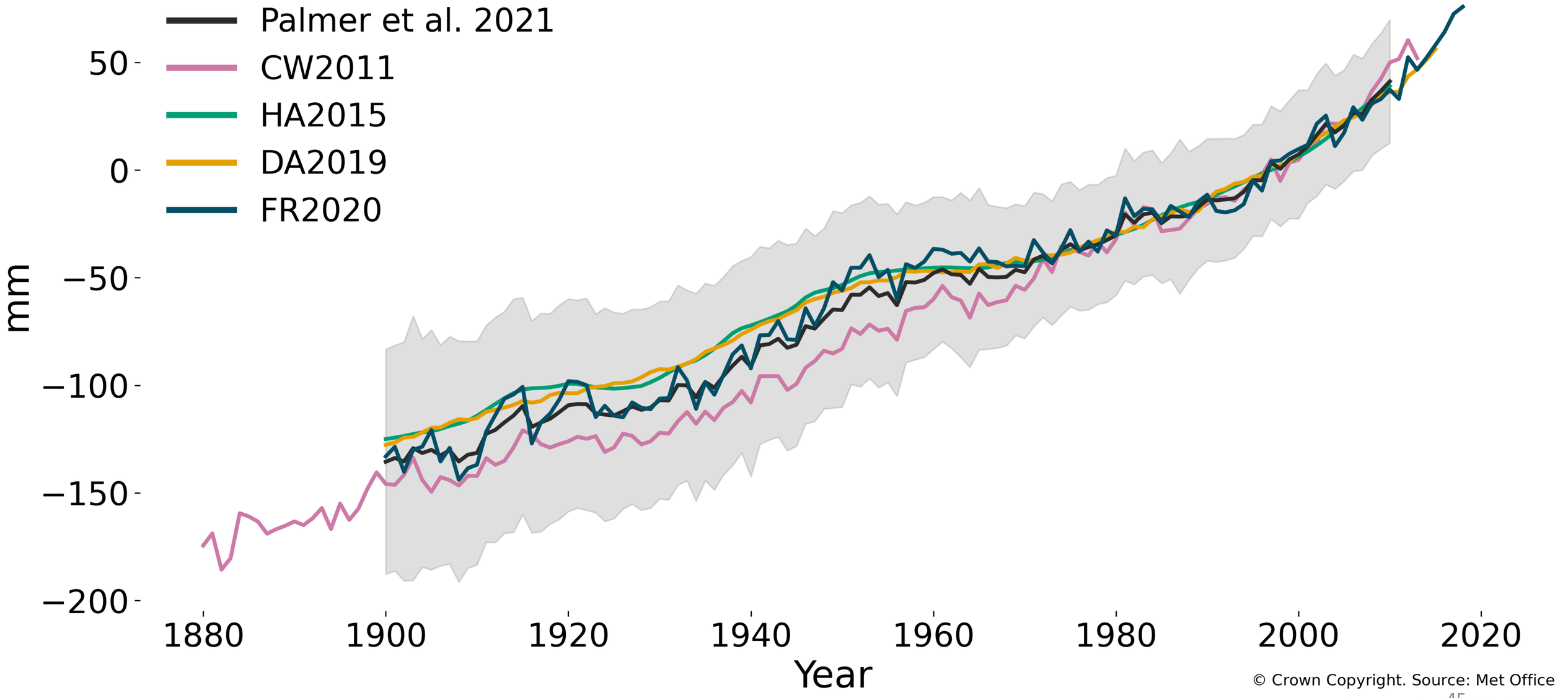


© Crown Copyright. Source: Met Office

Figure updated: 09/06/2026

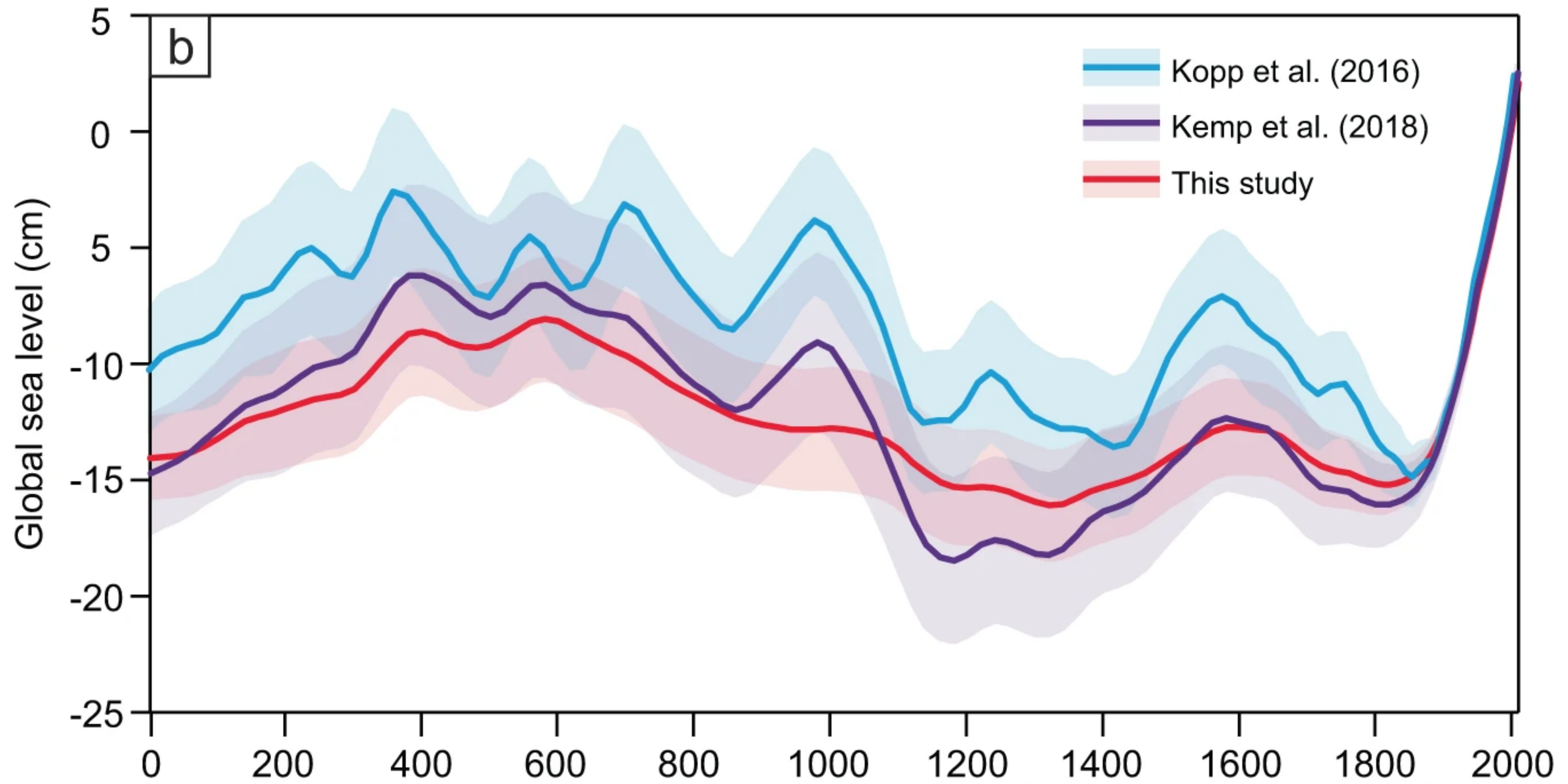
Met Office

Global sea level difference from 1981-2010 (mm)



© Crown Copyright. Source: Met Office

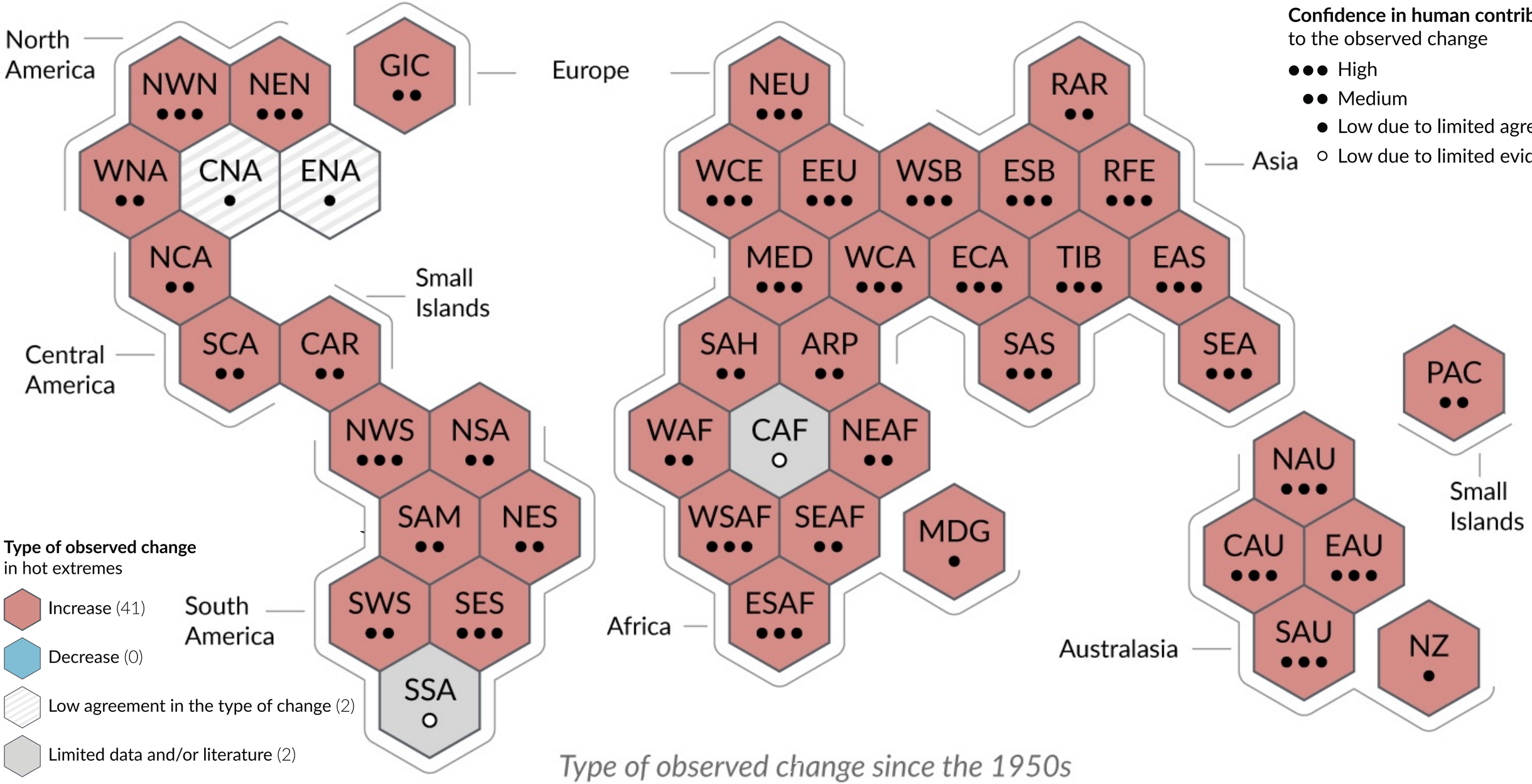
Figure updated: 09/06/2026



highest of last 2000 years

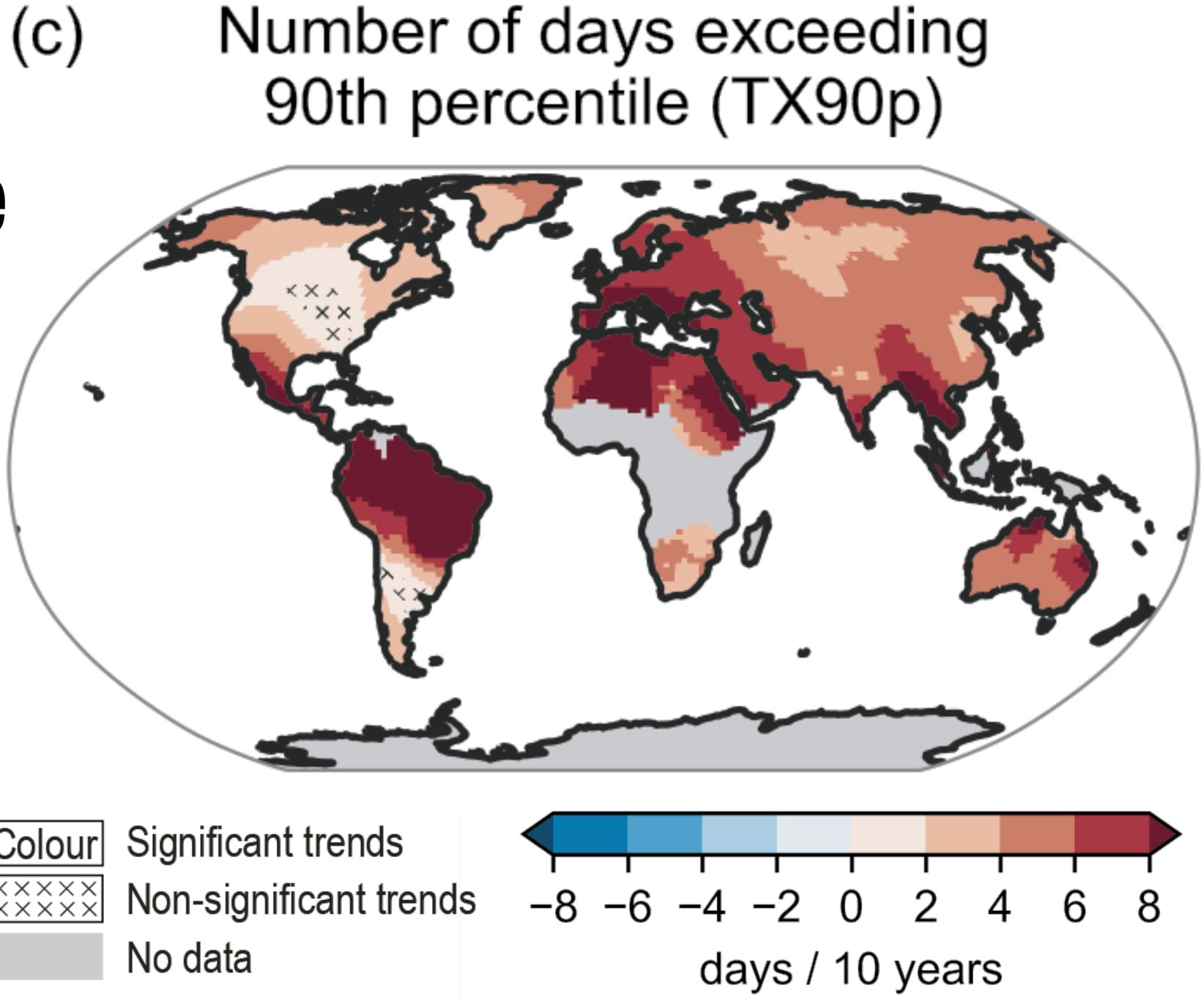
https://www.nature.com/articles/s41467-021-22079-2/

Heat Waves Are Increasing Almost Everywhere



Type of observed change since the 1950s

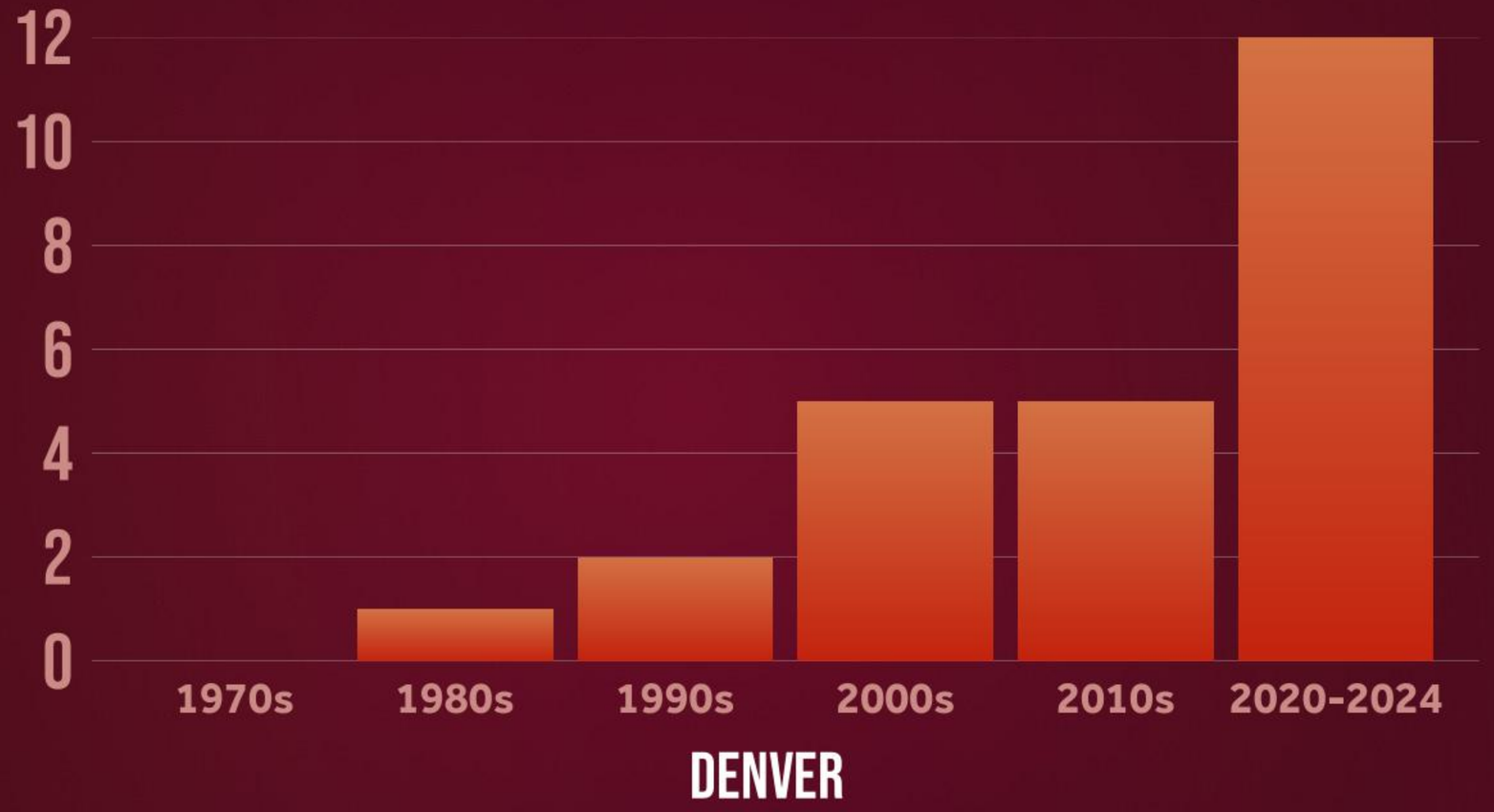
Trend, Extreme Heat days (1960-2018)



https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/

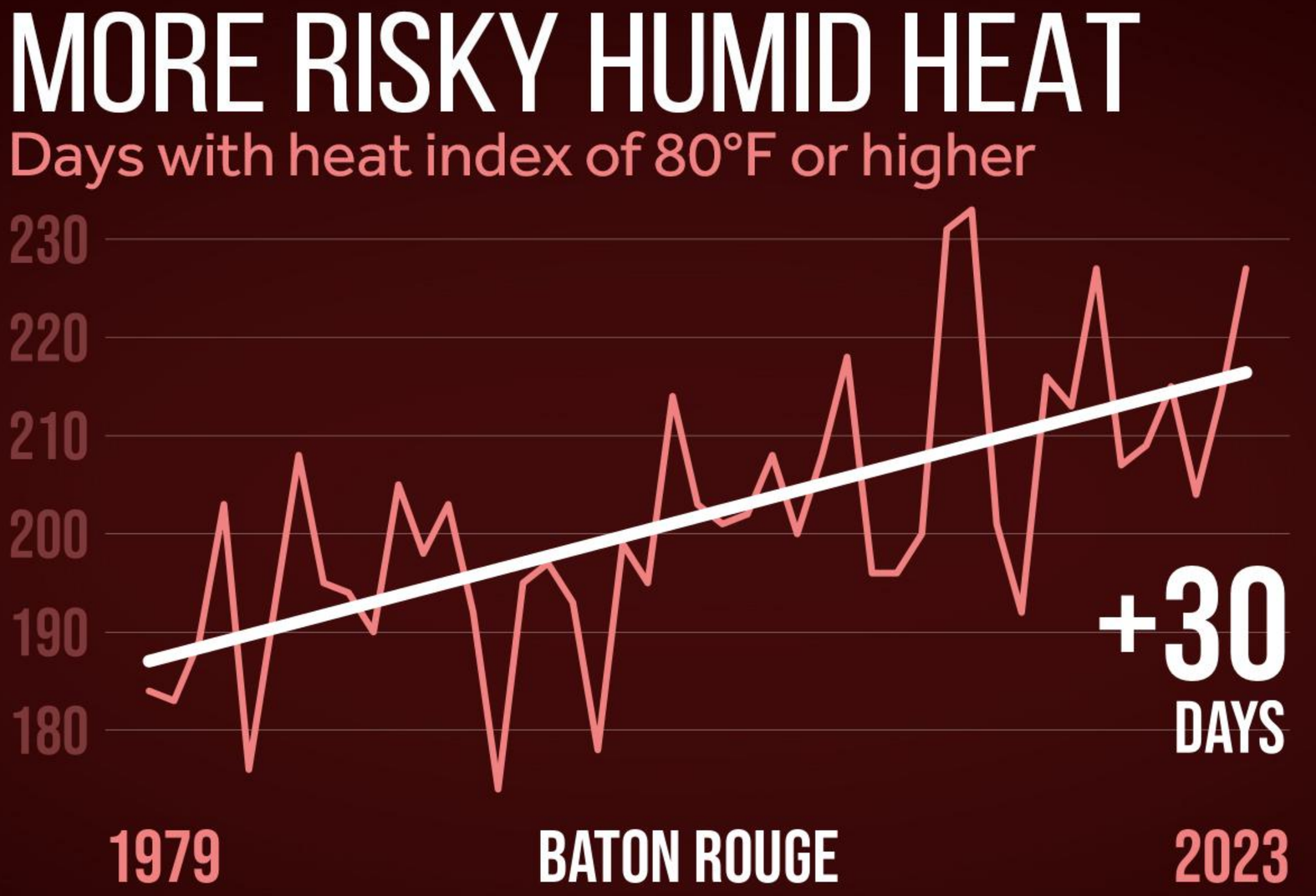
CLIMATE CHANGE-FUELED EXTREME HEAT

Average annual extremely hot summer days made at least 2x more likely by climate change

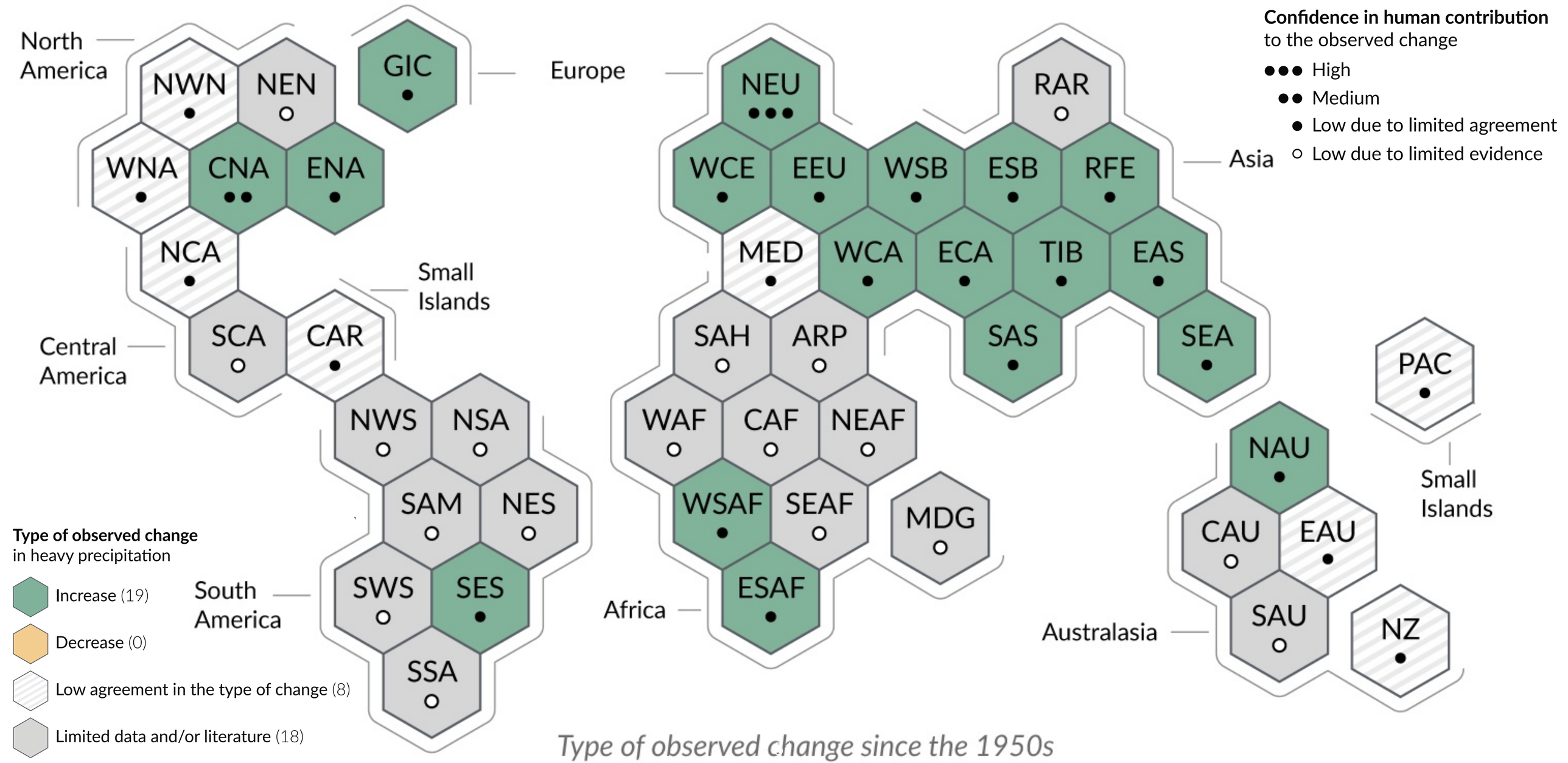


Average annual summer (June-August) days with maximum temperatures at or above 96.1°F (local 95th percentile) and a Climate Shift Index level of 2 or higher.
Source: ERA5 and Climate Central's Climate Shift Index system.

CLIMATE CENTRAL


MORE RISKY HUMID HEAT
Days with heat index of 80°F or higher
230
220
210
200
190
180
+30
DAYS
1979
BATON ROUGE
2023
Annual count of days with a heat index of 80°F or higher.
Source: gridMET
CLIMATE CENTRAL

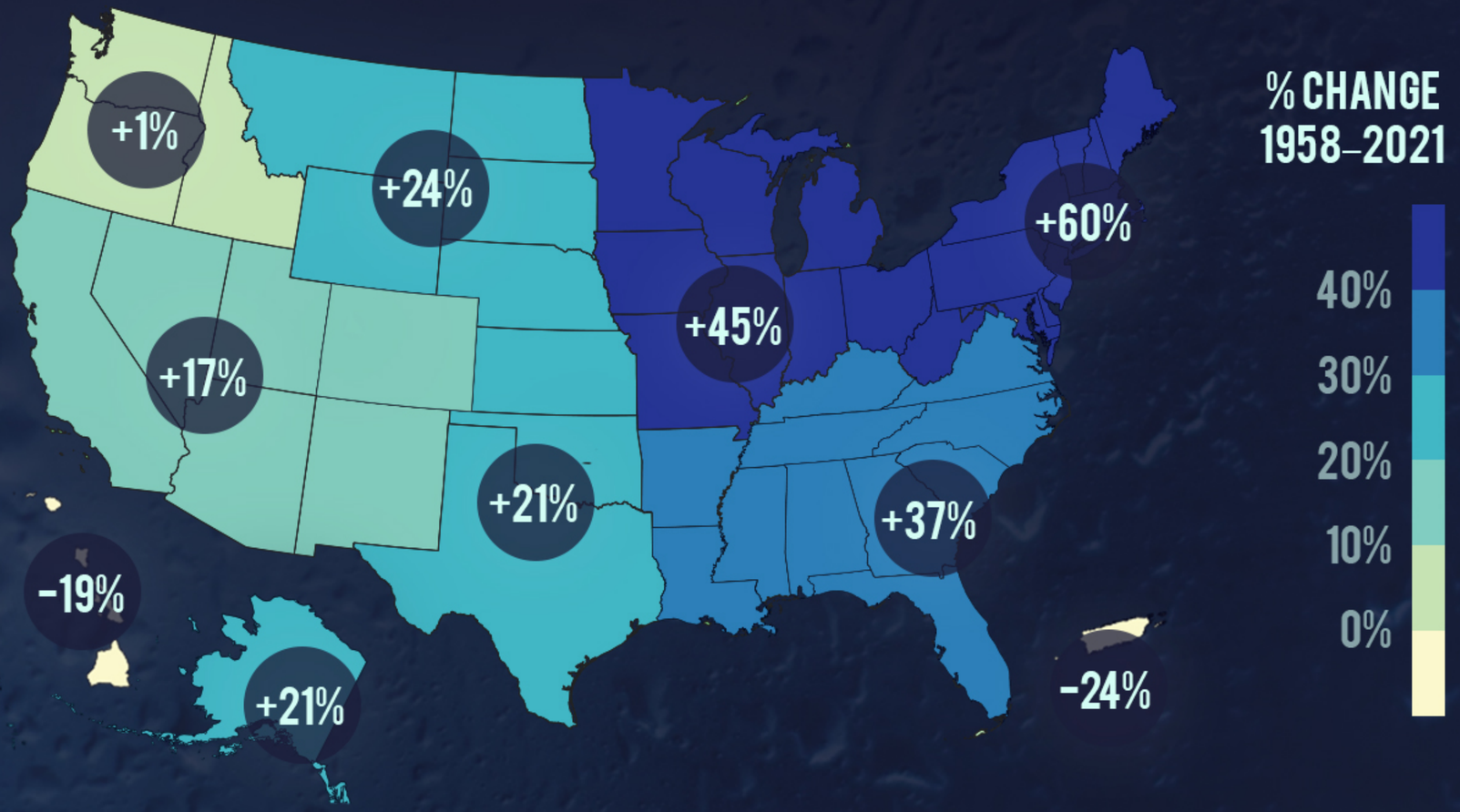
More Intense Storms In Some Regions



Type of observed change since the 1950s

HEAVIER DOWNPOURS

Change in precipitation on heaviest 1% of days



Change in total precipitation falling on the heaviest 1% of days, 1958–2021.
Source: USGCRP, 2023: Fifth National Climate Assessment.

CLIMATE CENTRAL

How do we know the changes we are seeing are from human activities?

Detection: HOW have things changed?

Ex: is it getting warmer?

Attribution: WHY have things changed?

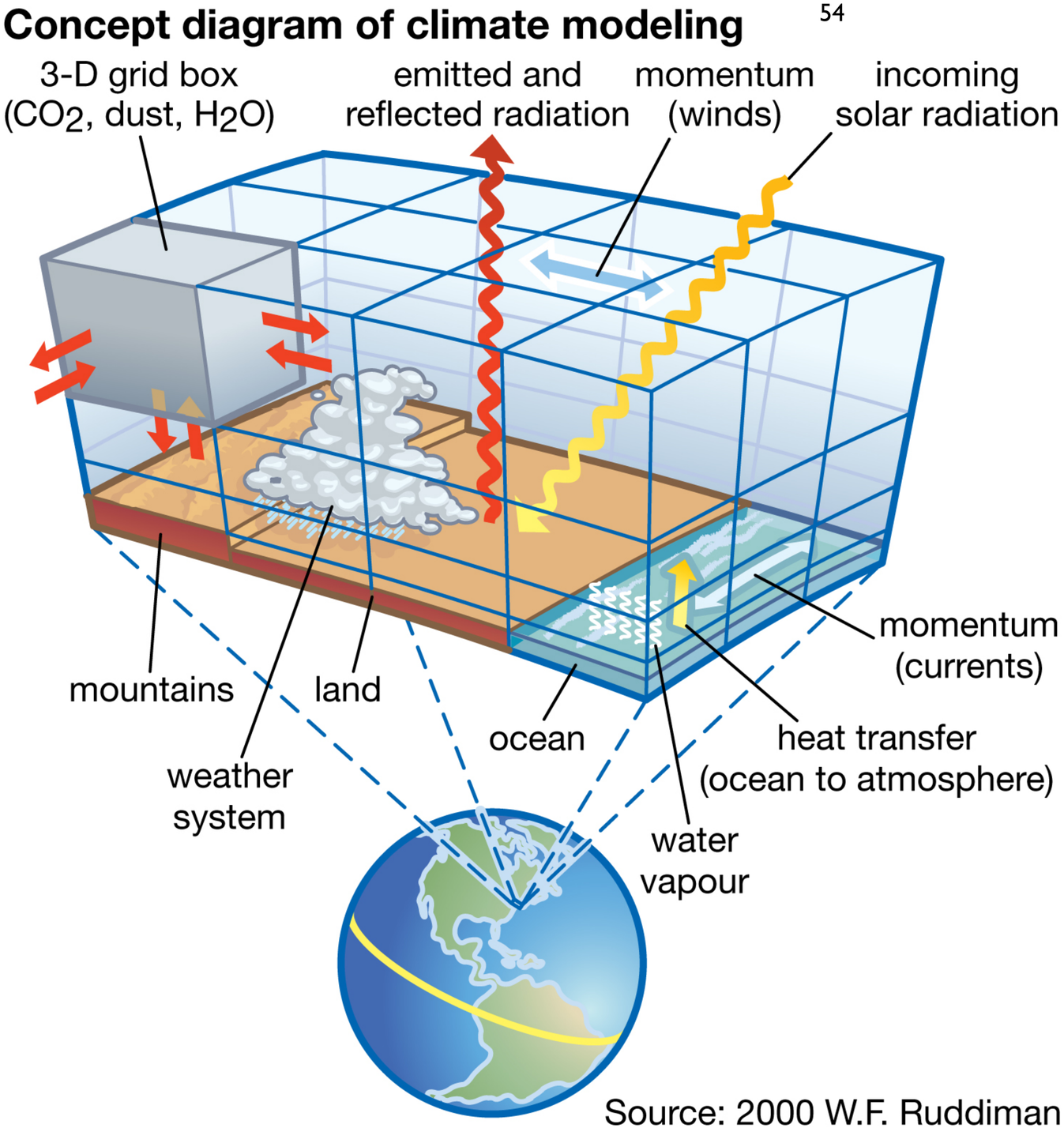
Ex: is it getting warmer because of anthropogenic greenhouse gas emissions?

Climate Models

computer programs used to simulate the state of the climate system based on prescribed forcings (volcanos, GHGs, solar variability, etc)

Important tools for attribution and studying future climate

most common class of climate model is the general circulation model (GCM)



https://www.nature.com/articles/s41612-025-00955-8

Hotter

What's Really Warming the World?

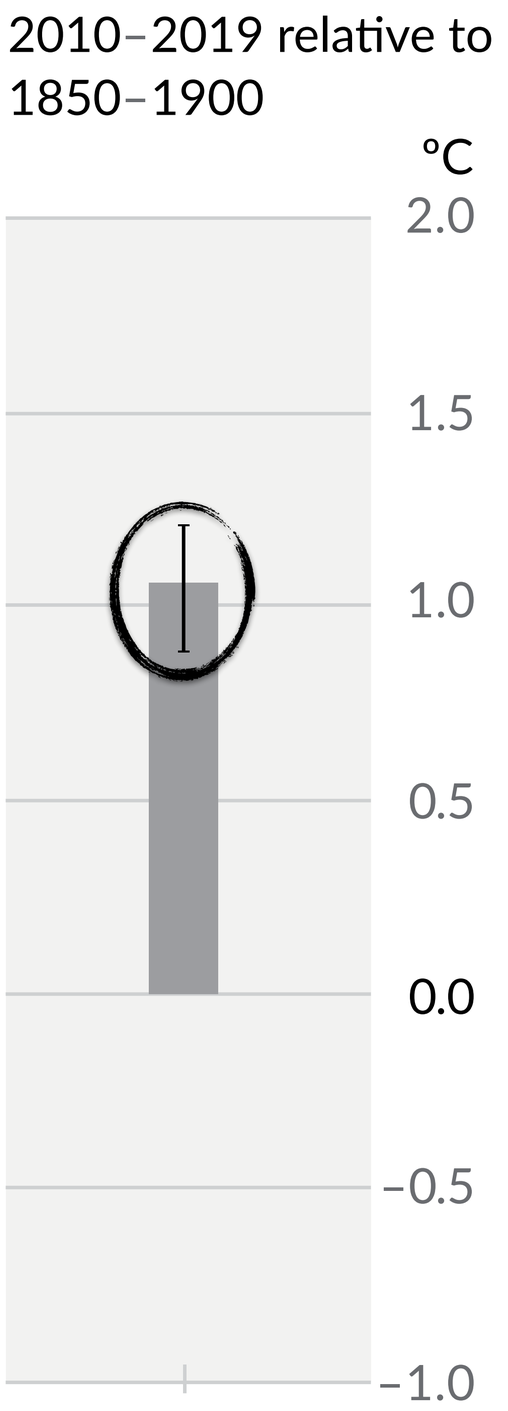
Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet's rising temperature? Watch to see how much different factors, both natural and industrial, contribute to global warming, based on findings from NASA's Goddard Institute for Space Studies.

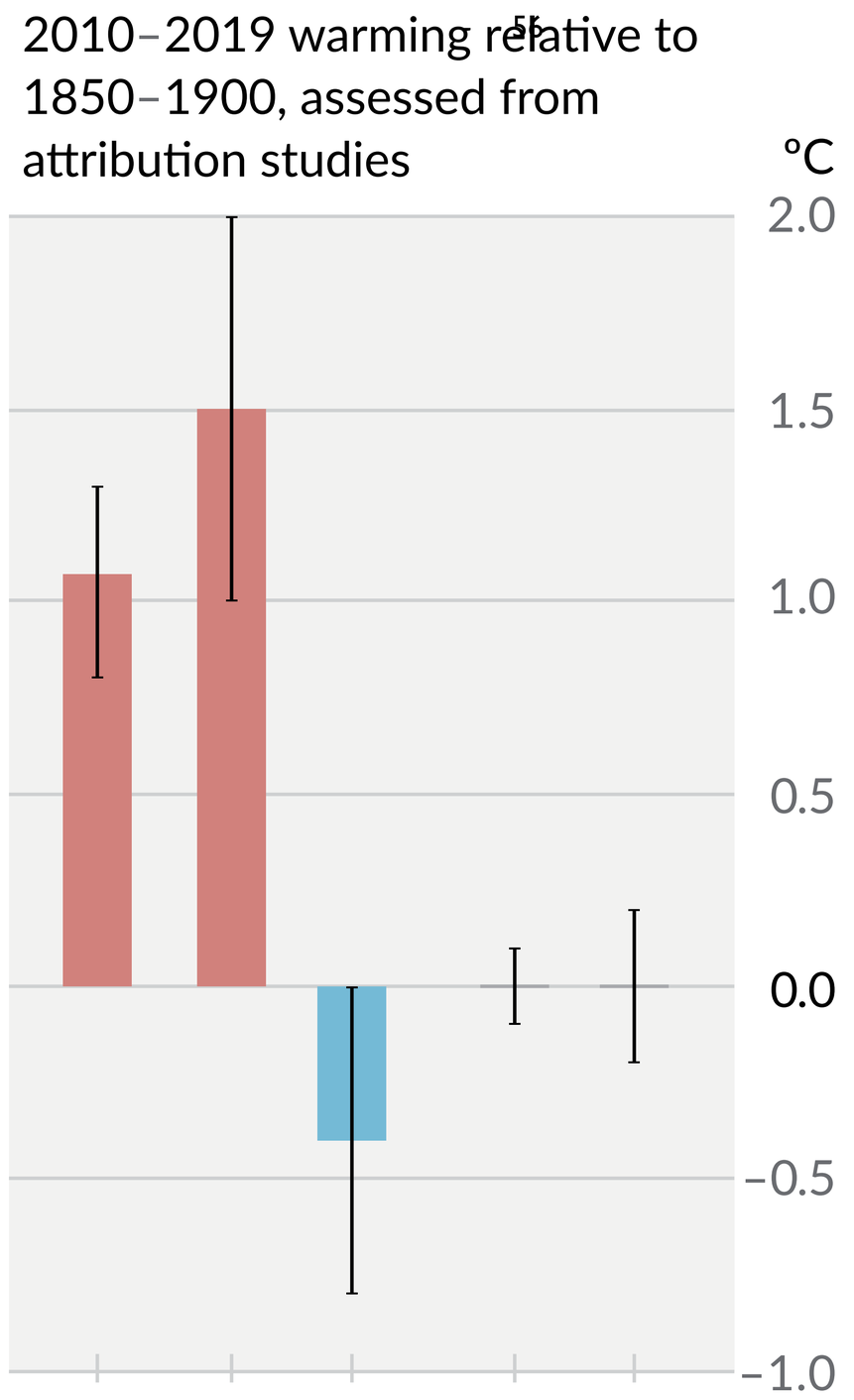


Colder

Based on an interactive by Bloomberg

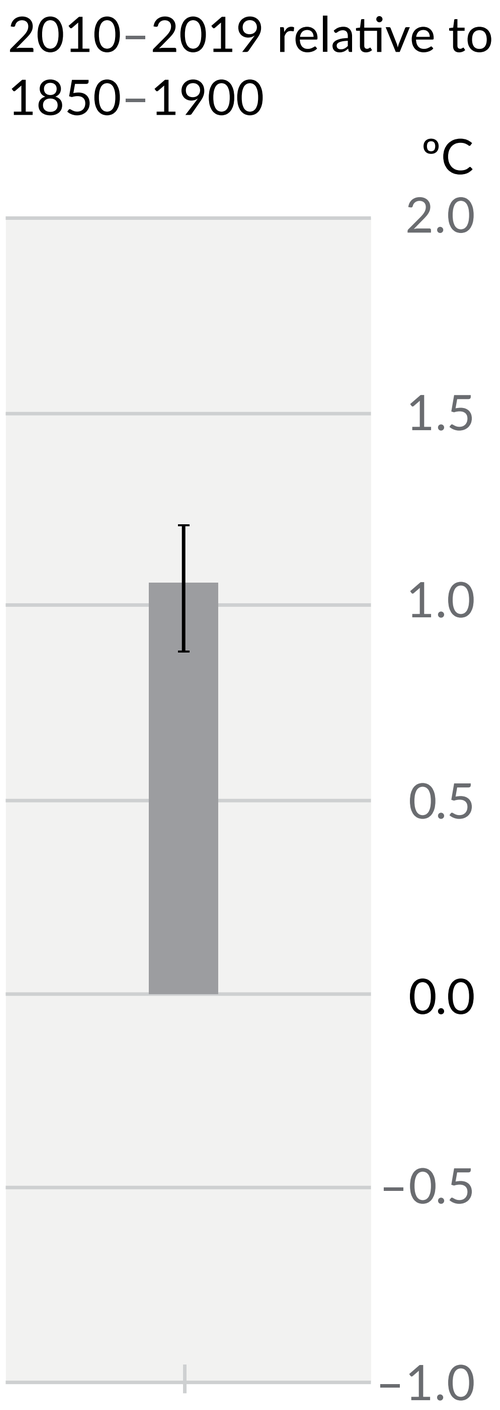
As of 2019, world warmed ~1.1°C since 1850-1990

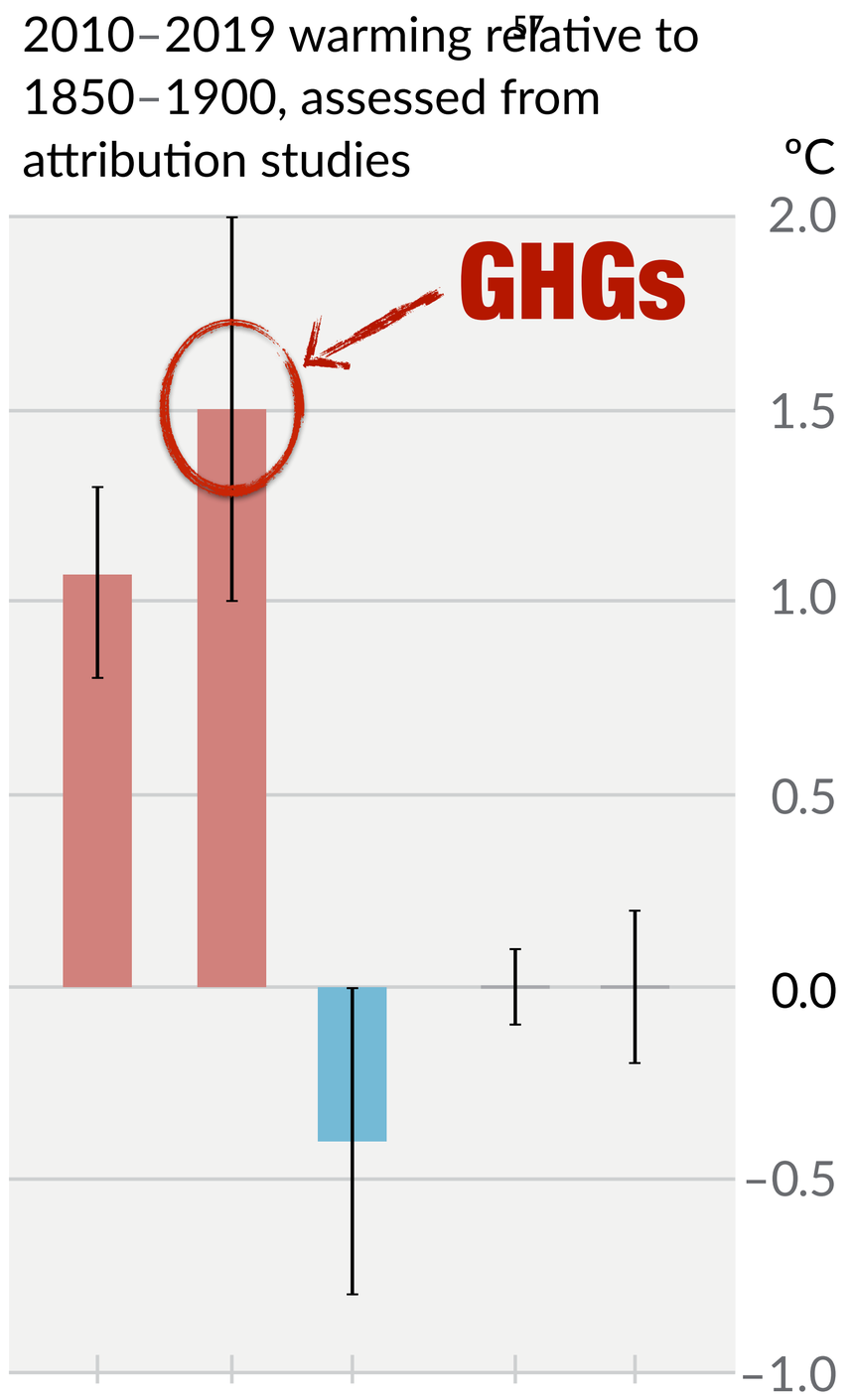




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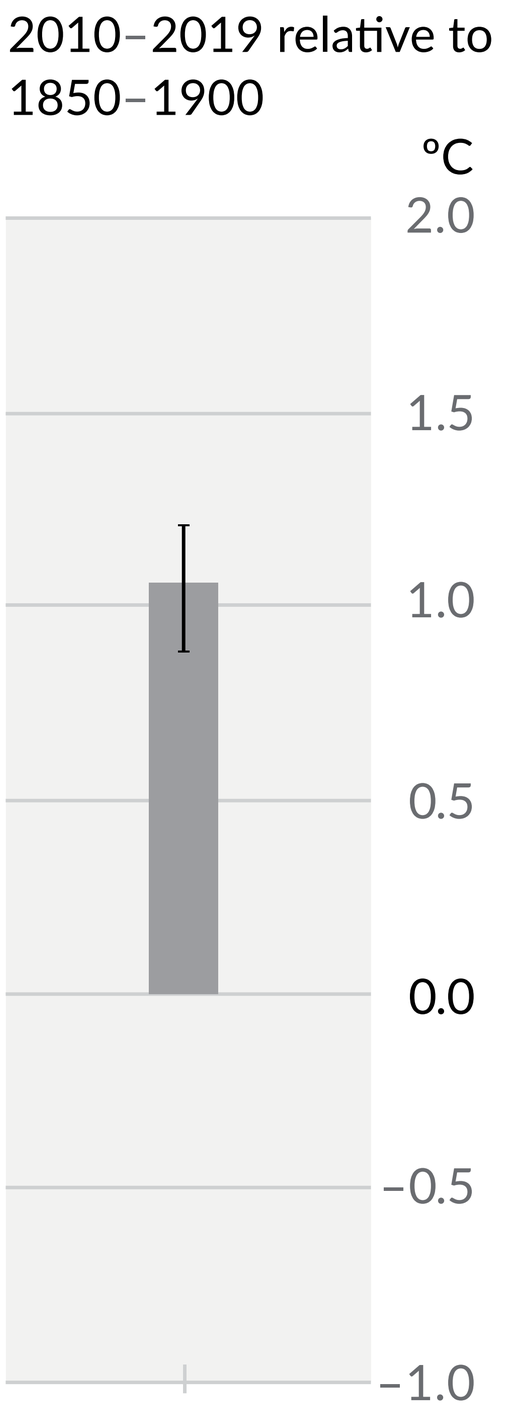
Human GHGs alone would have warmed world by 1.5°

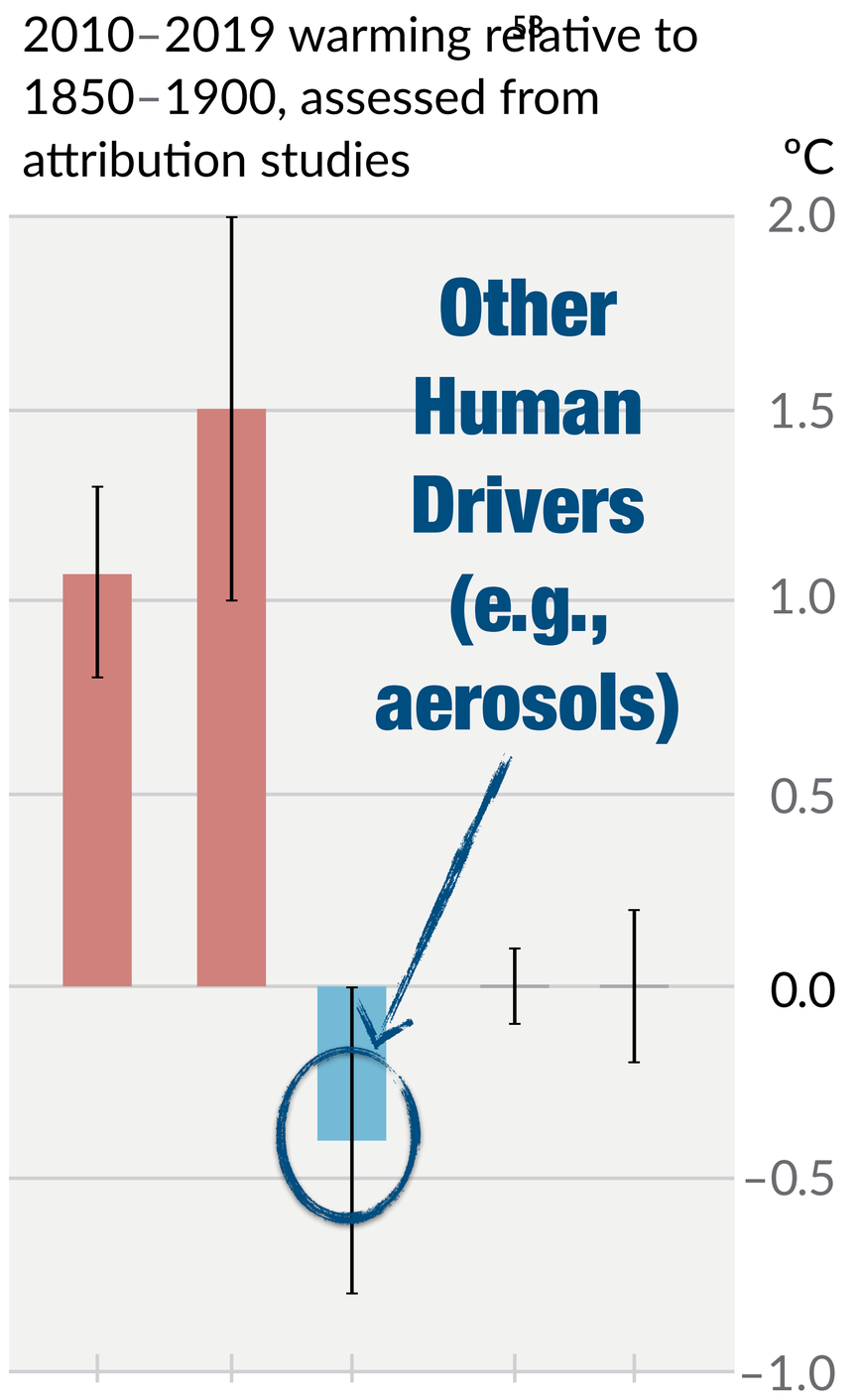




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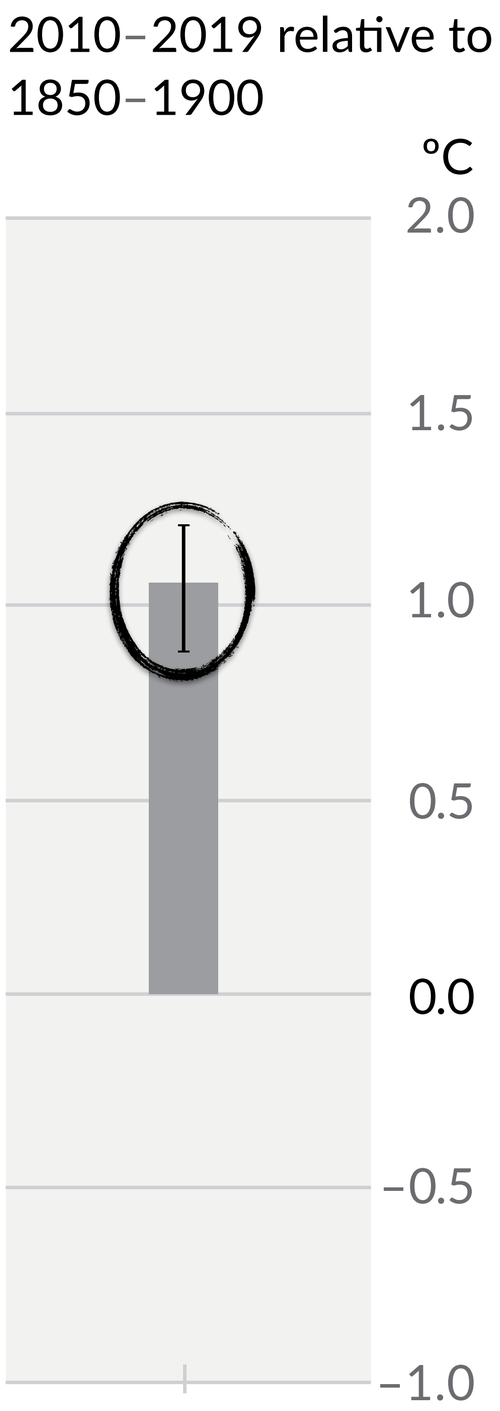
However, other human drivers (aerosols, land use change) counteracted some of this warming

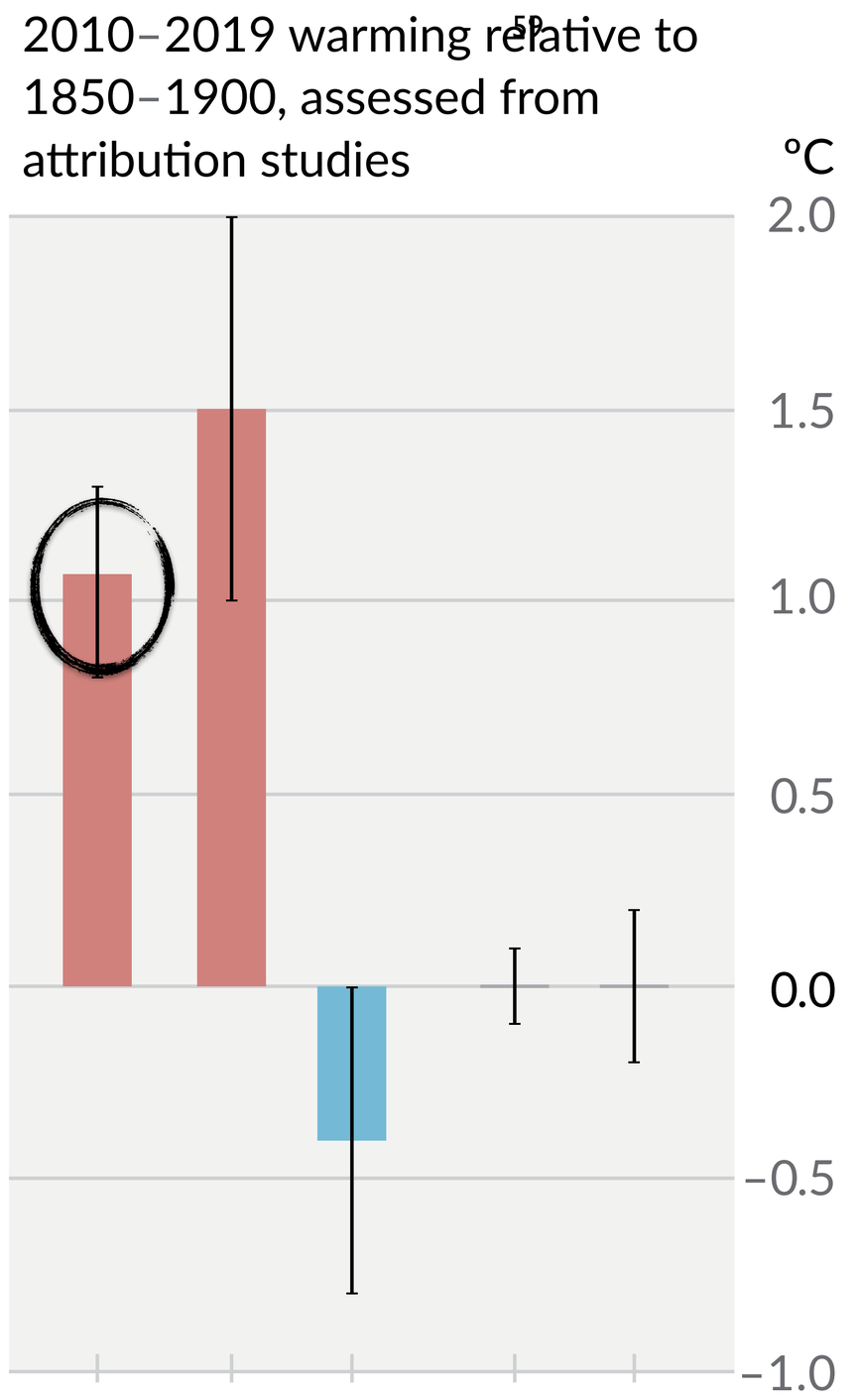




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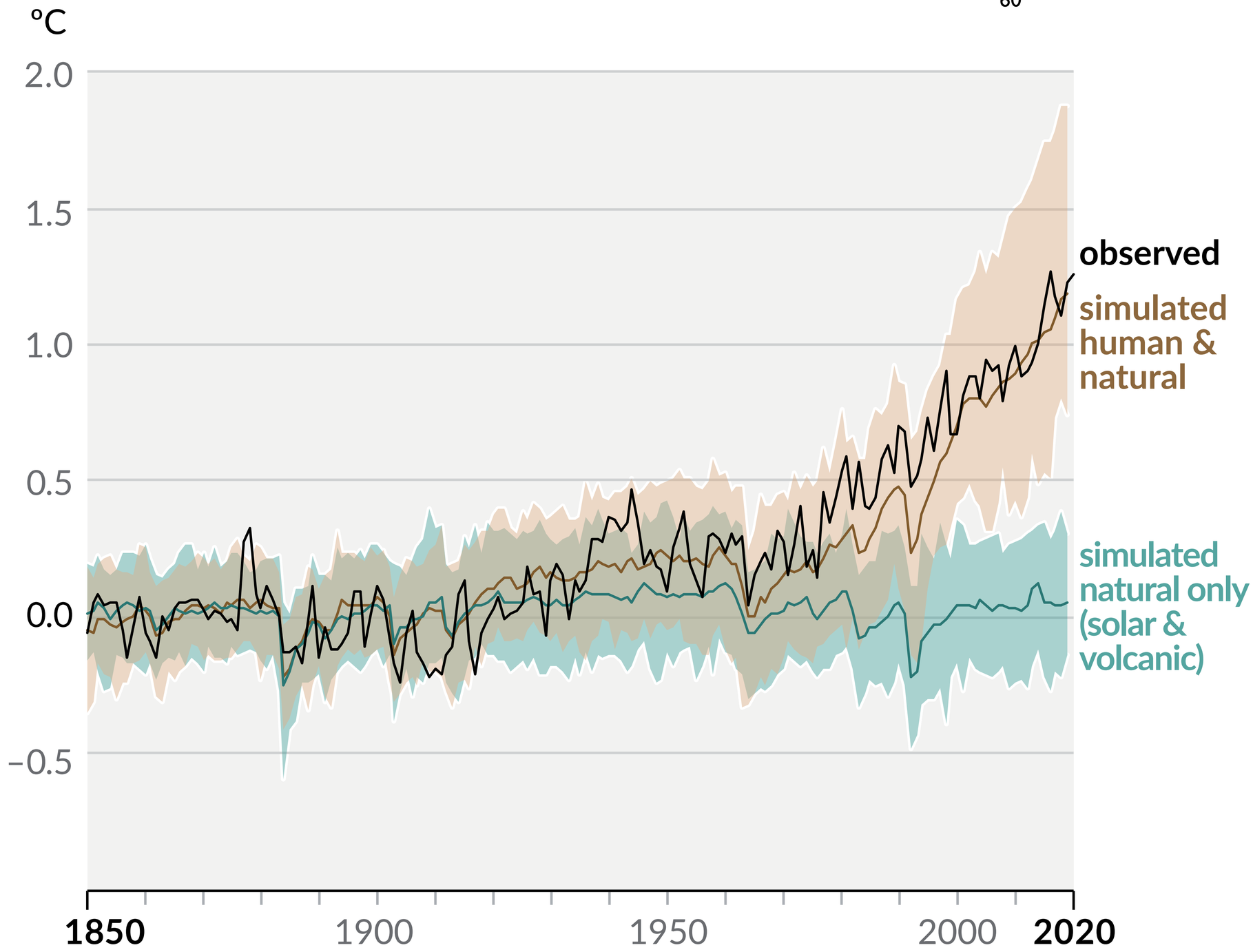
Combined, all human forcings have warmed the globe by 1.1°





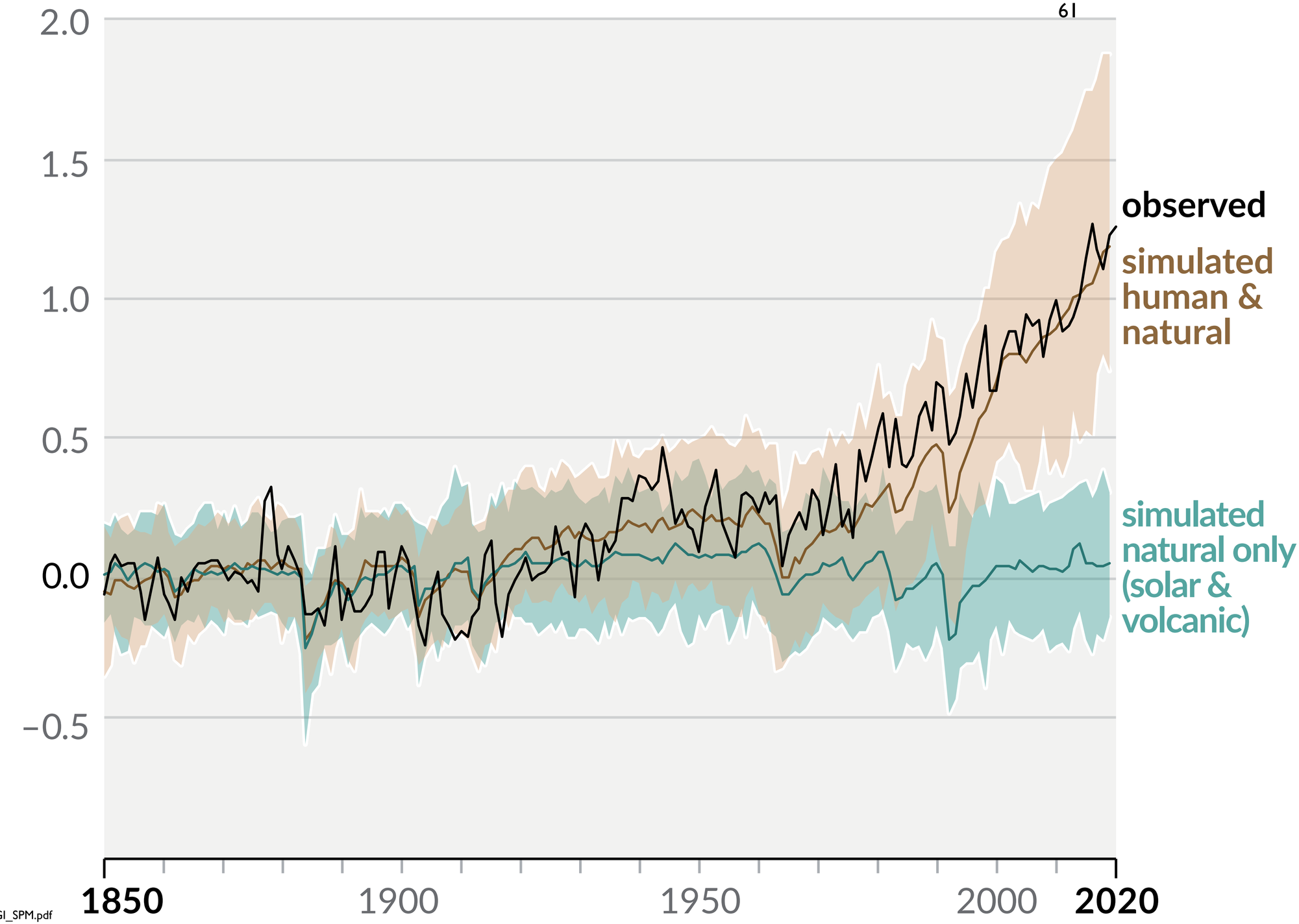
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ONLY models that include human factors can come close to reproducing the observed warming



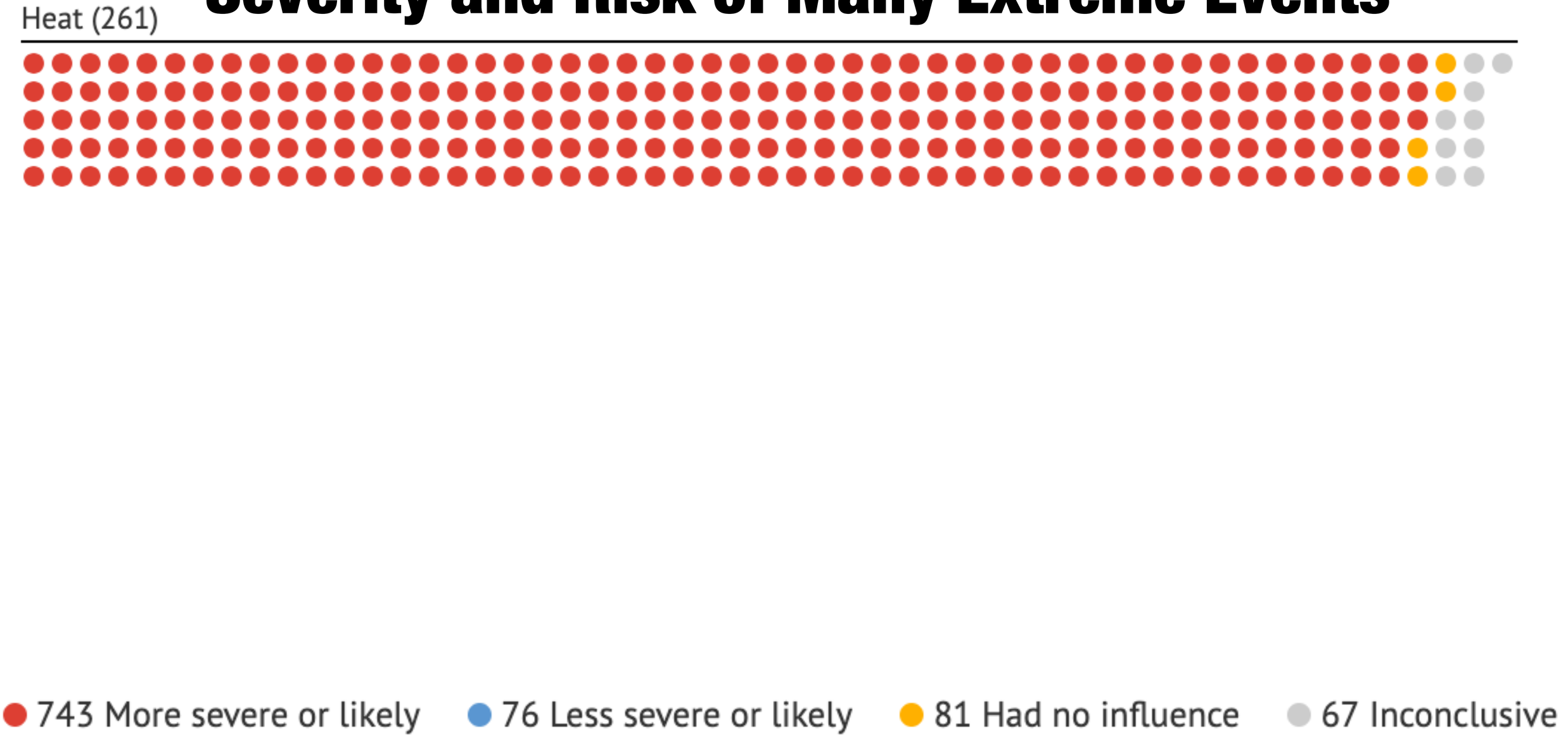
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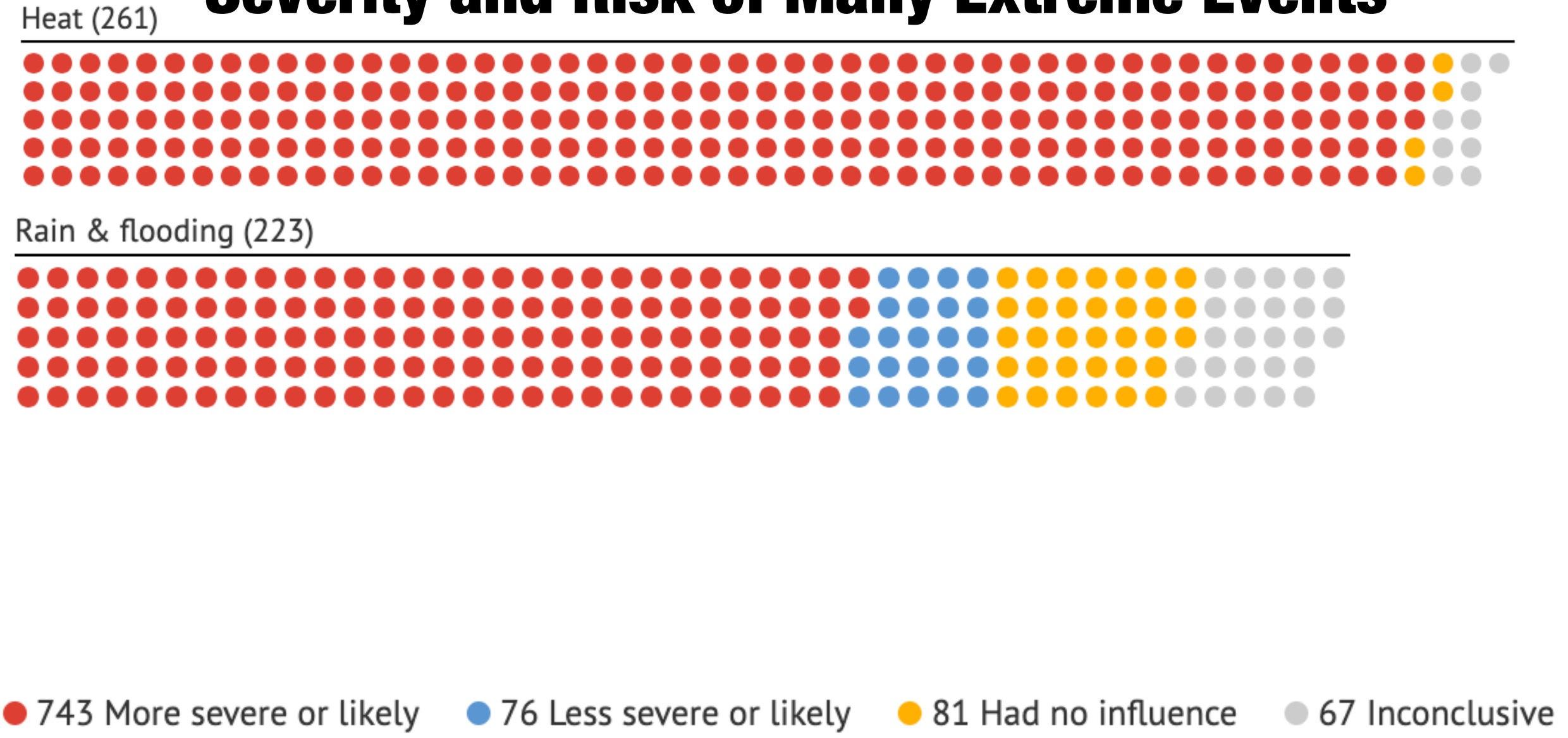
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Climate Change is Already Increase the Severity and Risk of Many Extreme Events



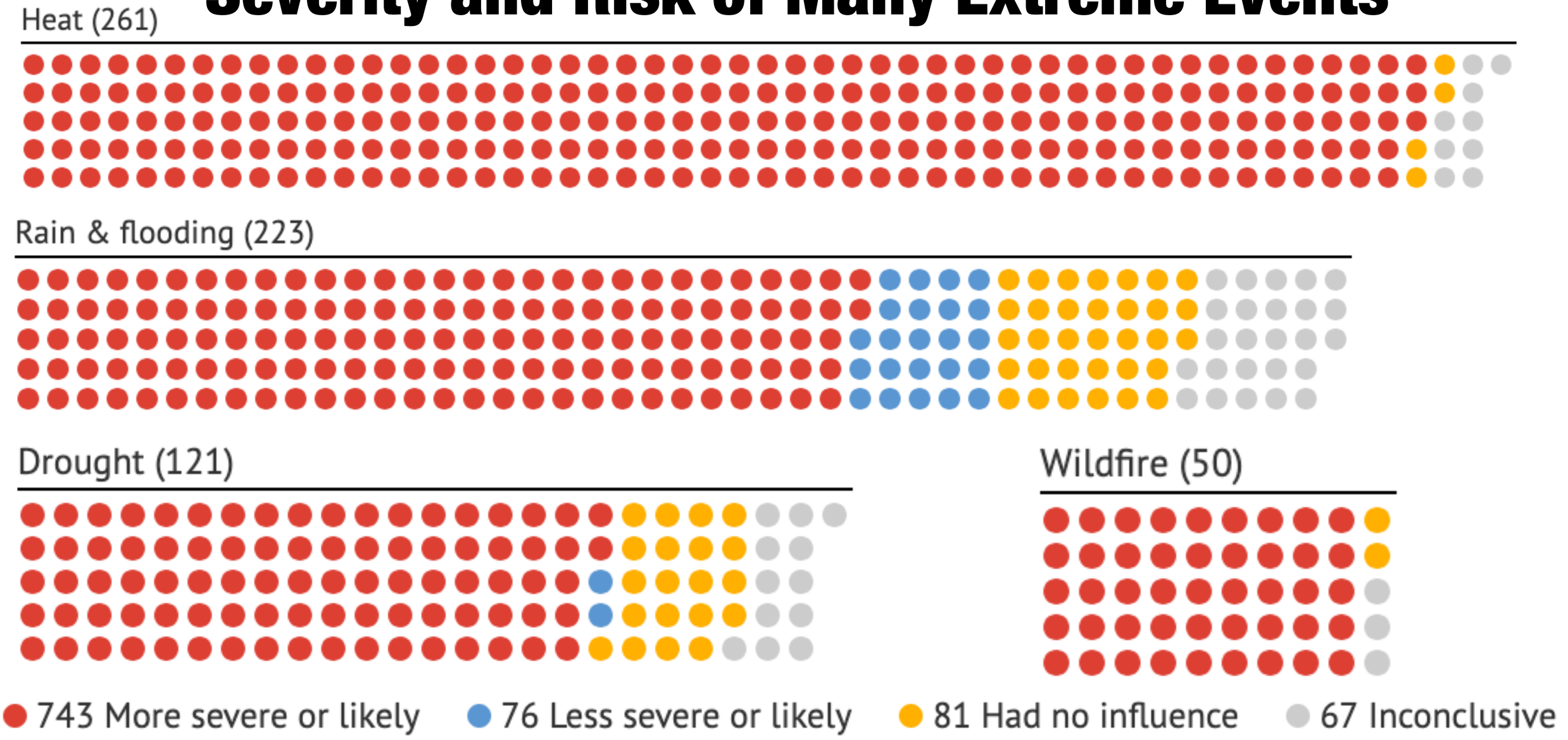
https://interactive.carbonbrief.org/attribution-studies/index.html

Climate Change is Already Increase the Severity and Risk of Many Extreme Events



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Climate Change is Already Increase the Severity and Risk of Many Extreme Events



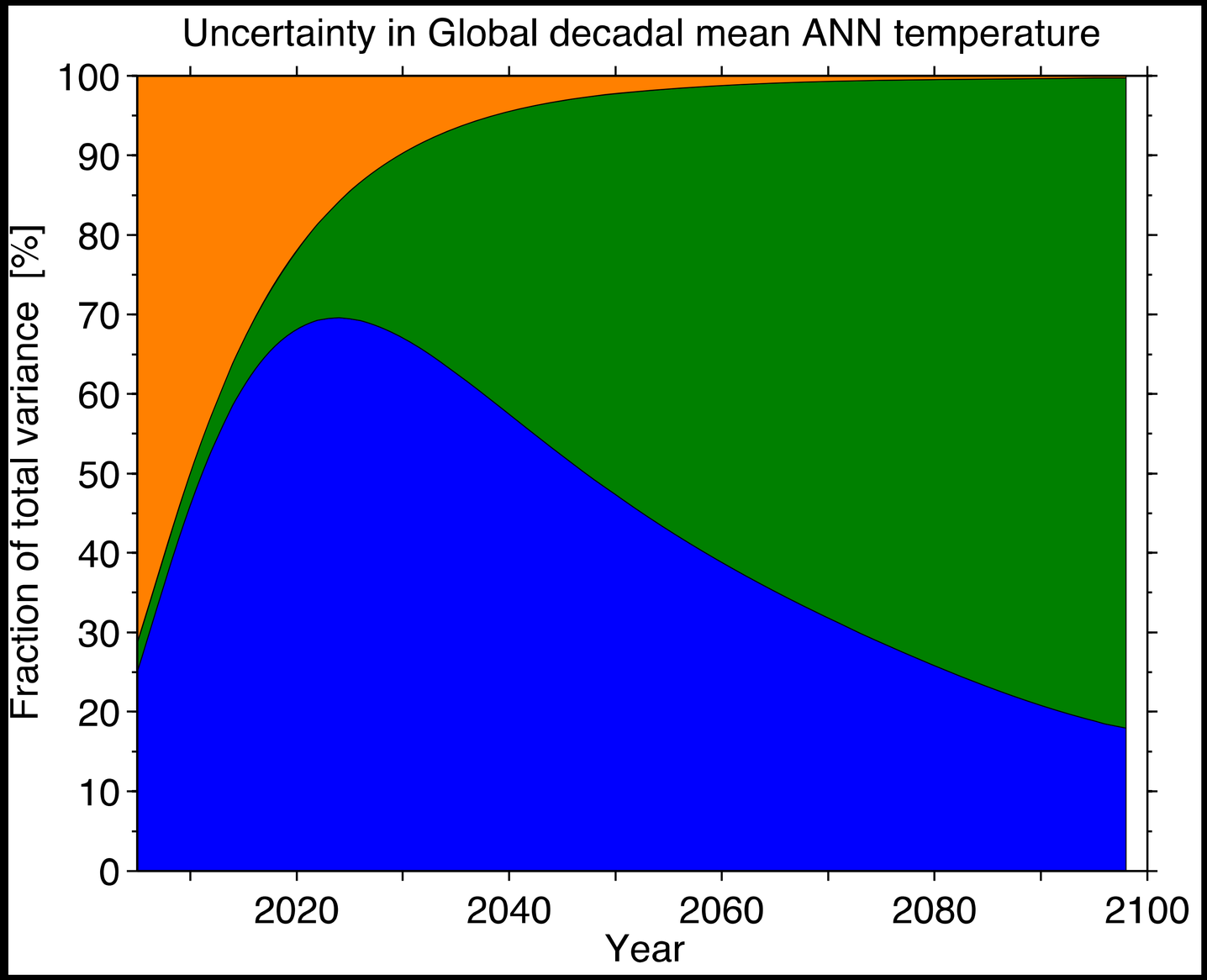
https://interactive.carbonbrief.org/attribution-studies/index.html

What does the future look like?

Climate models are our main tool

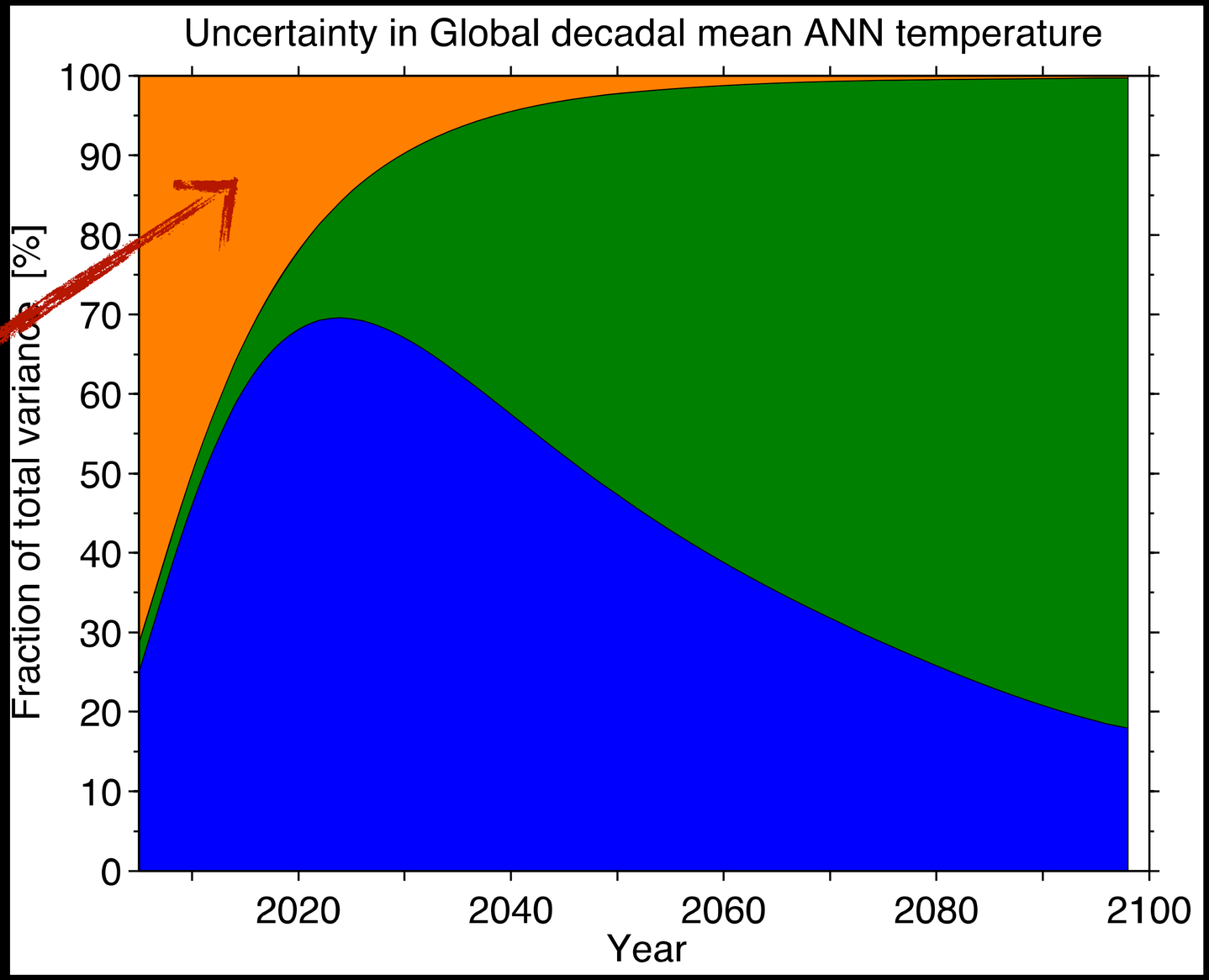
Lots of sources of uncertainty

Uncertainty does **NOT** mean we don't know



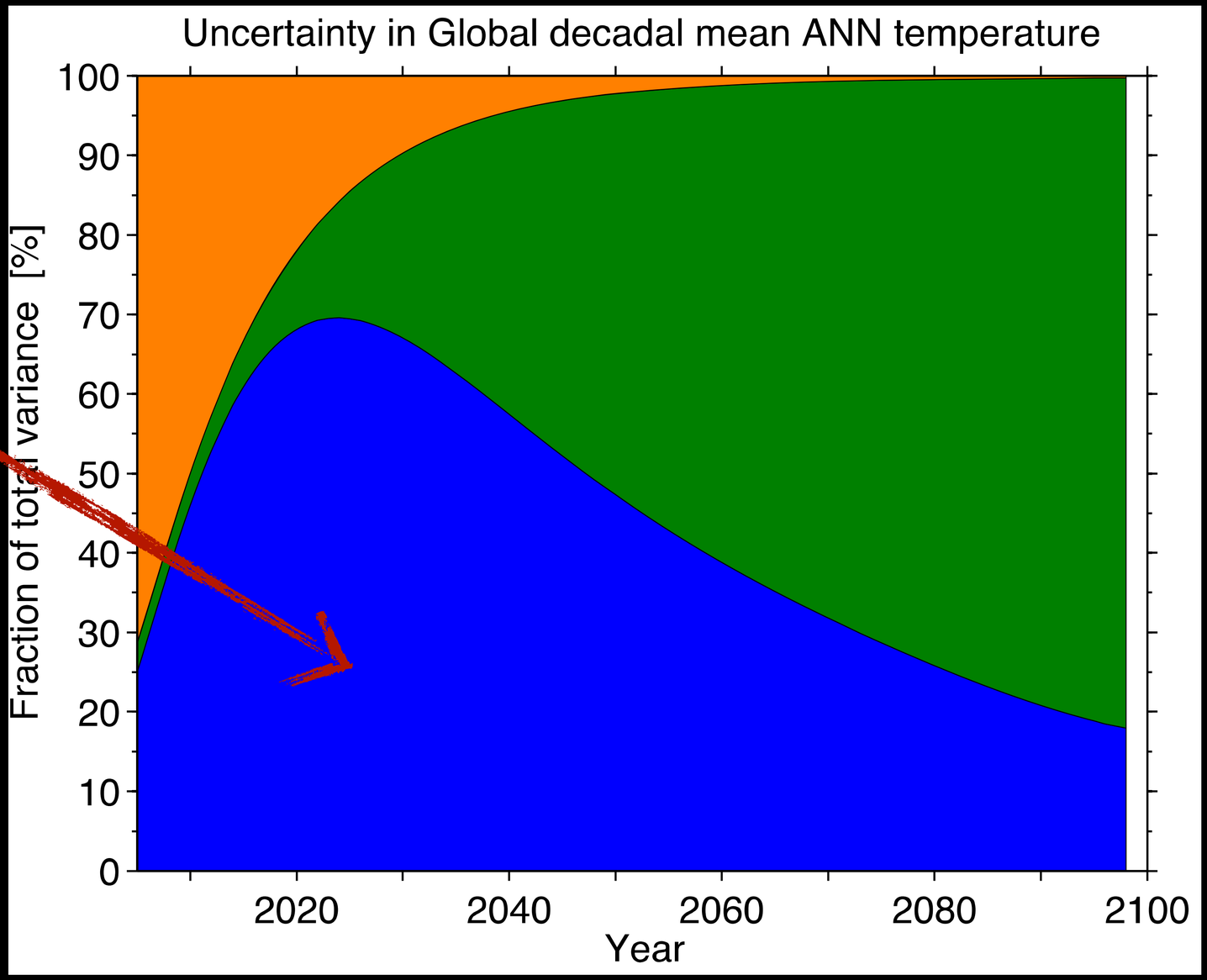
Most Important Uncertainties Change over Time

Natural variations in weather & climate ***(internal variability)***



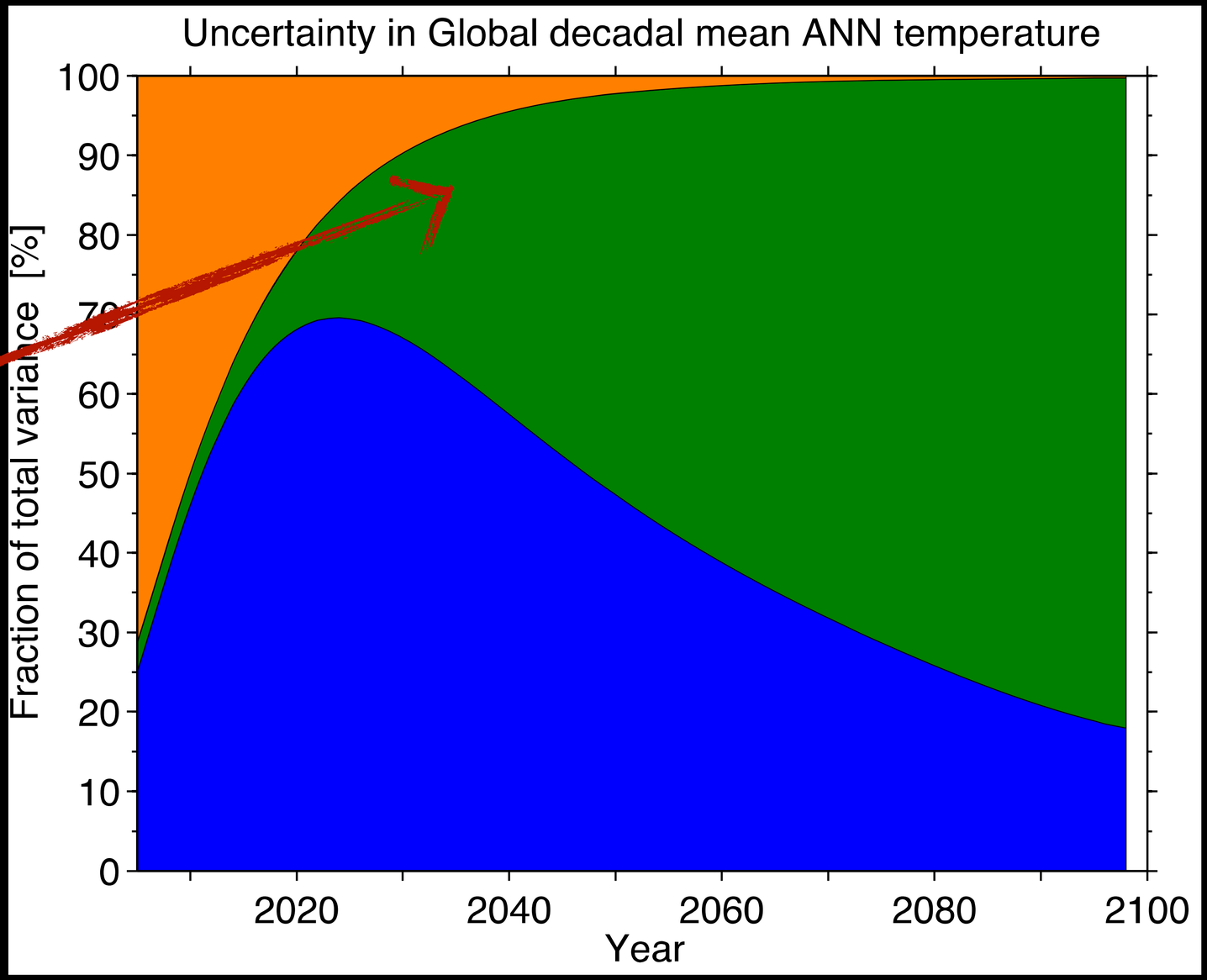
Most Important Uncertainties Change over Time

How well our models agree or not ***(structural uncertainty)***



Most Important Uncertainties Change over Time

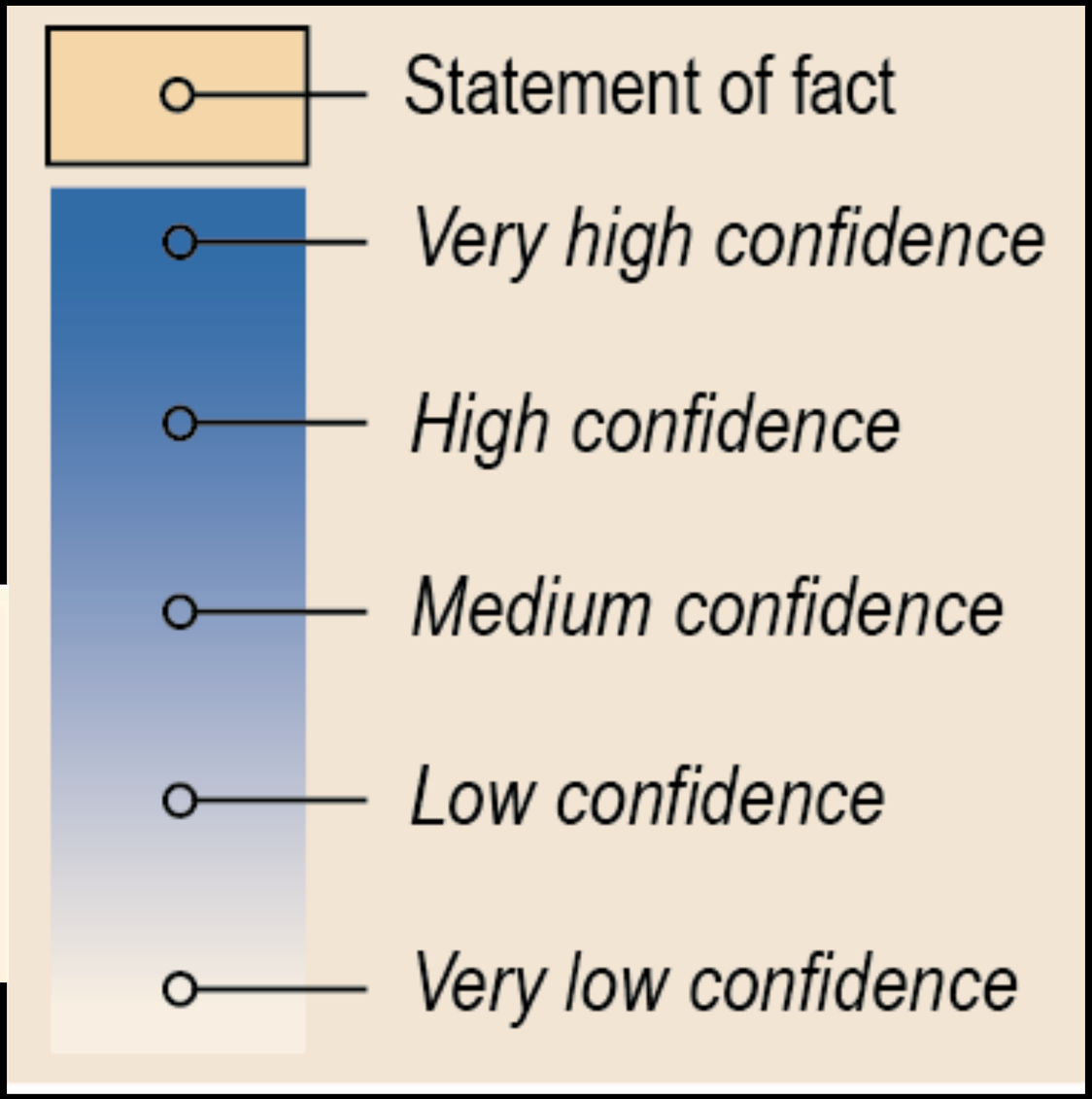
What GHG emissions trajectory do we follow ***(scenario uncertainty)***



Confidence

"In the IPCC reports, confidence is expressed qualitatively and tells us ***how certain we are that scientific findings are valid****. The level of confidence is determined by the type, amount, quality and consistency of evidence"*

Confidence Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance



https://theconversation.com/lost-in-translation-confidence-and-certainty-in-climate-science-17181

https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/

Likelihood

*"The **certainty of scientific findings is then described using likelihoods**. Findings are assessed probabilistically using observations, modelling results or expert judgement."*

Allison Crimmins:

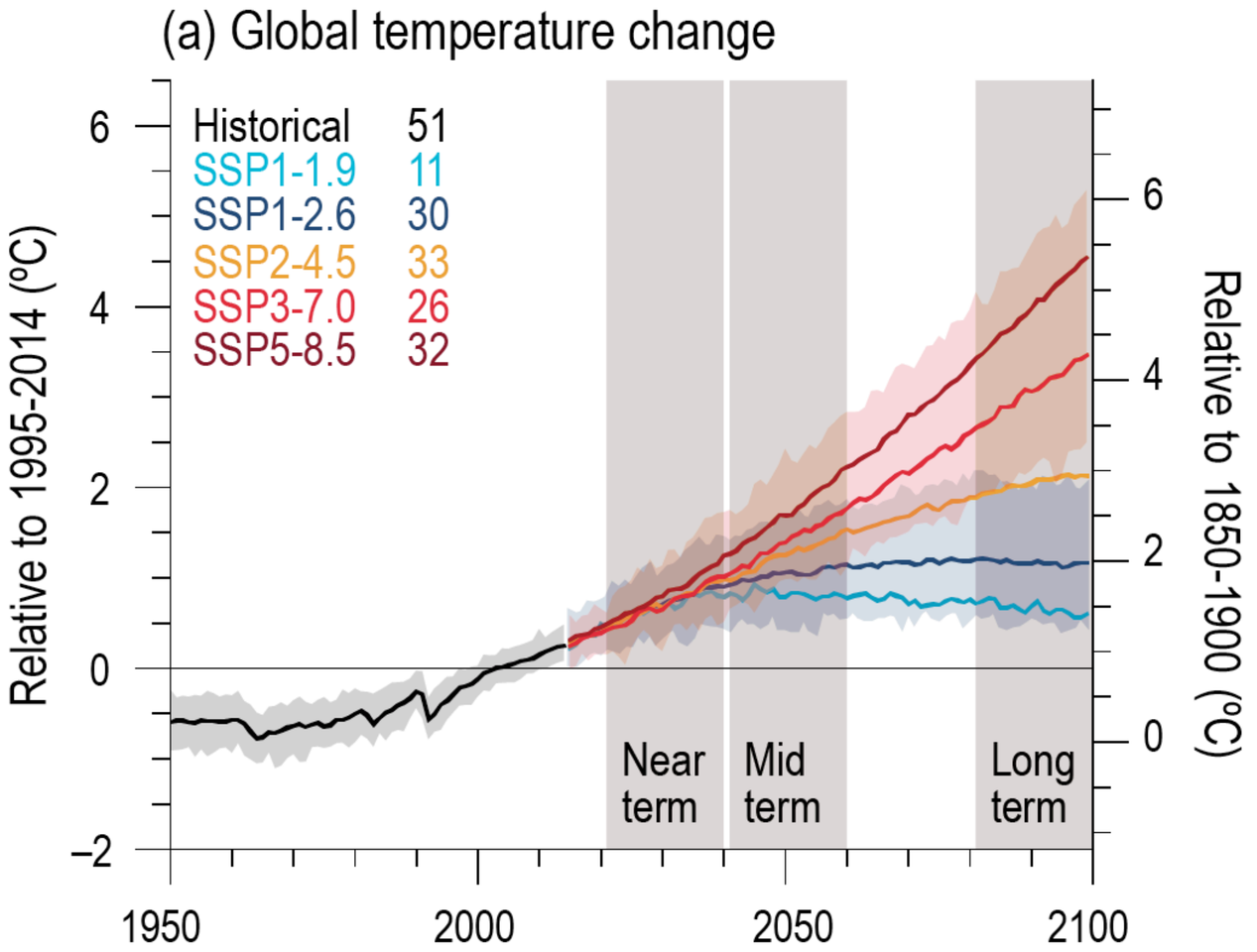
"When you look at a product on Amazon, the number of stars it has is the **likelihood** and the number of reviews it has is the **confidence**."

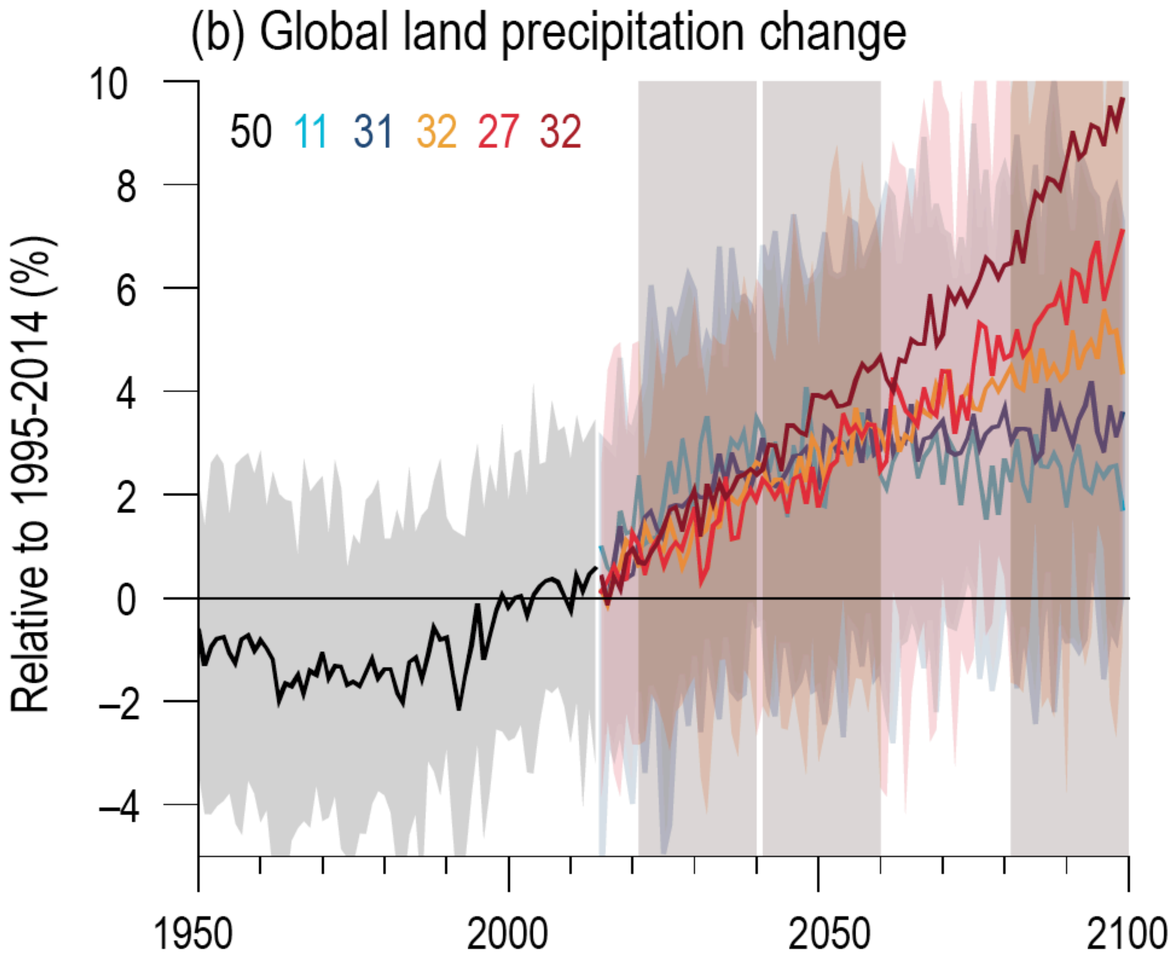
Likelihood	Outcome probability
Virtually certain	99-100%
Extremely likely	95-100%
Very likely	90-100%
Likely	66-100%
More likely than not	>50-100%
About as likely as not	33-66%
Unlikely	0-33%
Very unlikely	0-10%
Extremely unlikely	0-5%
Exceptionally unlikely	0-1%

https://theconversation.com/lost-in-translation-confidence-and-certainty-in-climate-science-17181

https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/

Temperature & Precipitation (land)





https://www.ipcc.ch/report/ar6/wg1/figures/chapter-4/figure-4-2

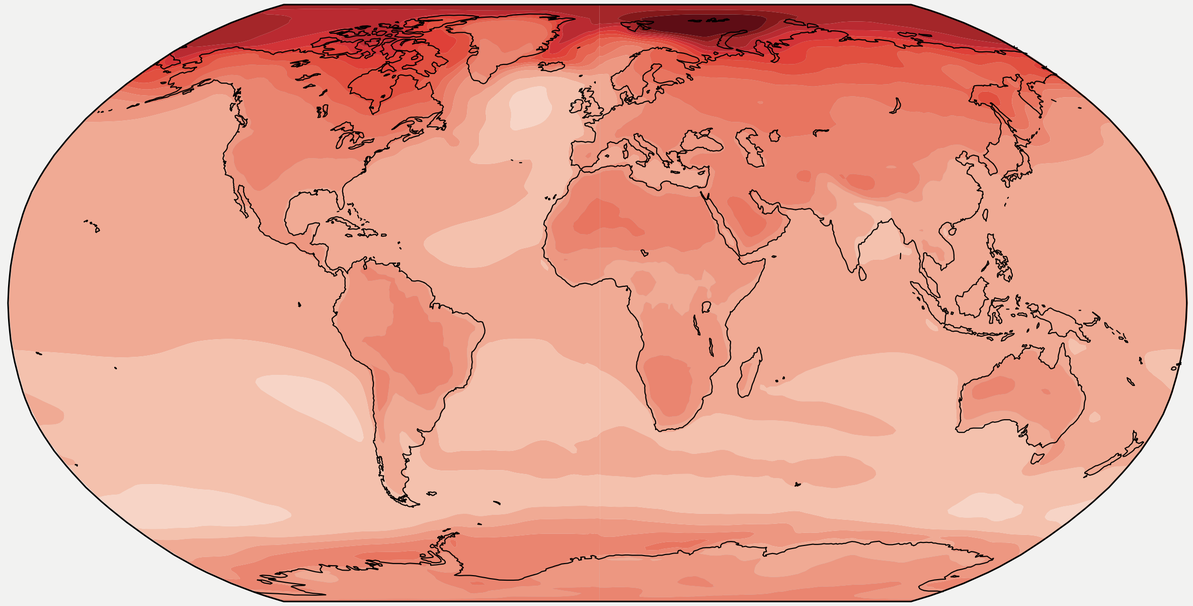
Temperature

Widespread, unidirectional; Robust model response;

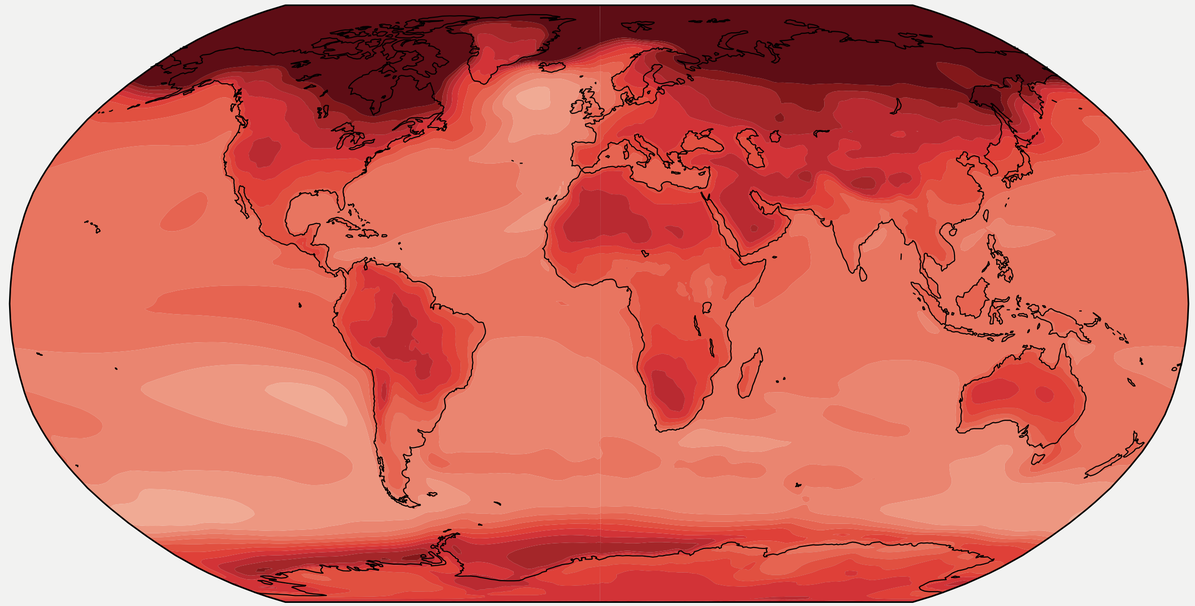
Consistent with observed patterns (e.g., enhanced warming over land, polar amplification)

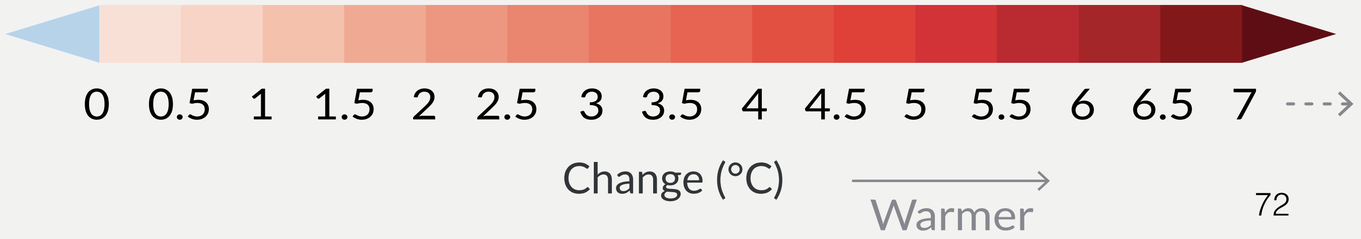
https://www.ipcc.ch/report/ar6/wg1/#SPM

Simulated change at **2°C** global warming

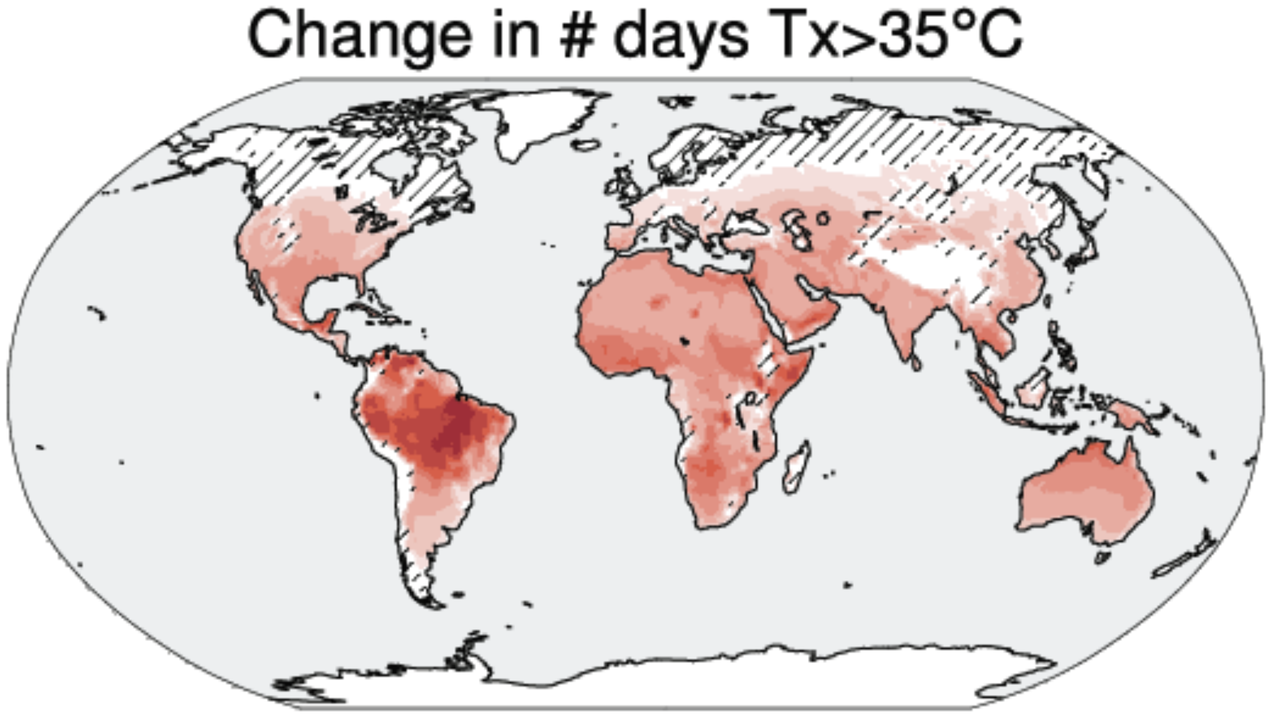


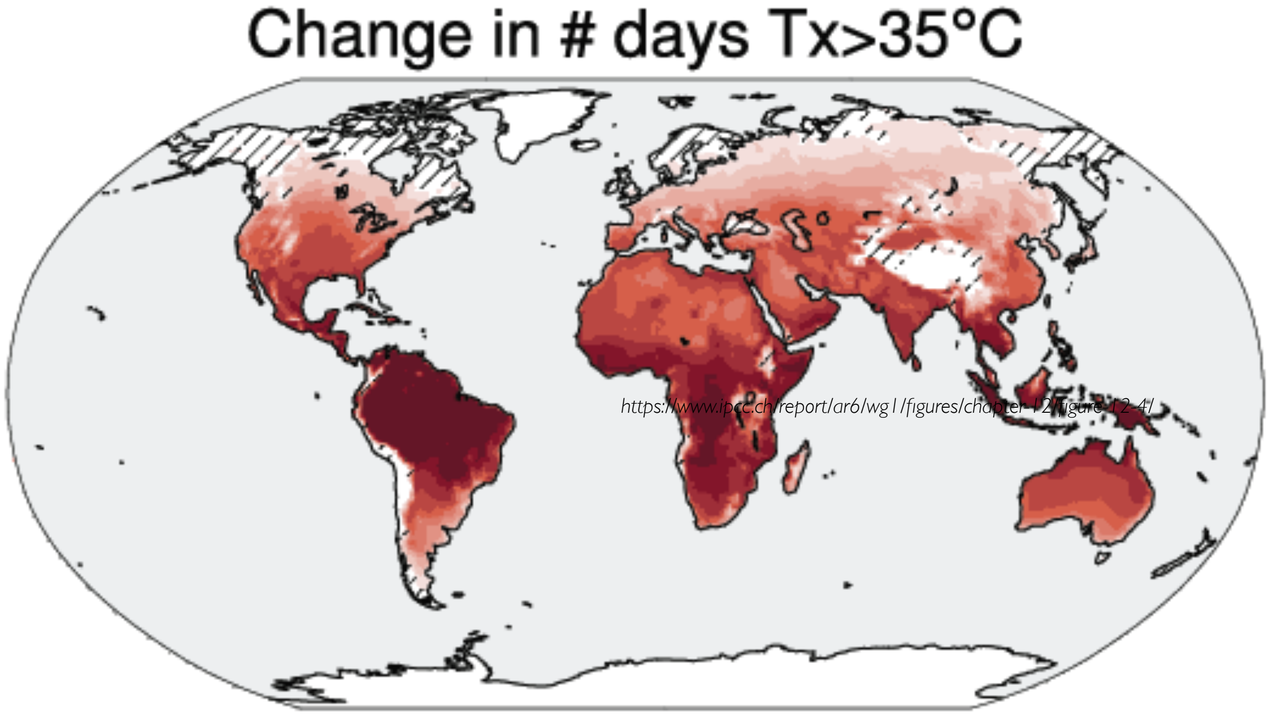
Simulated change at **4°C** global warming





Temperature Extremes

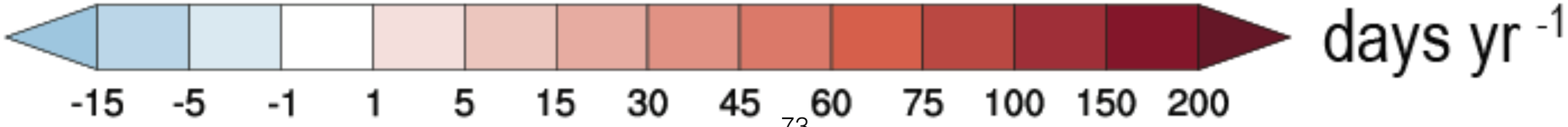




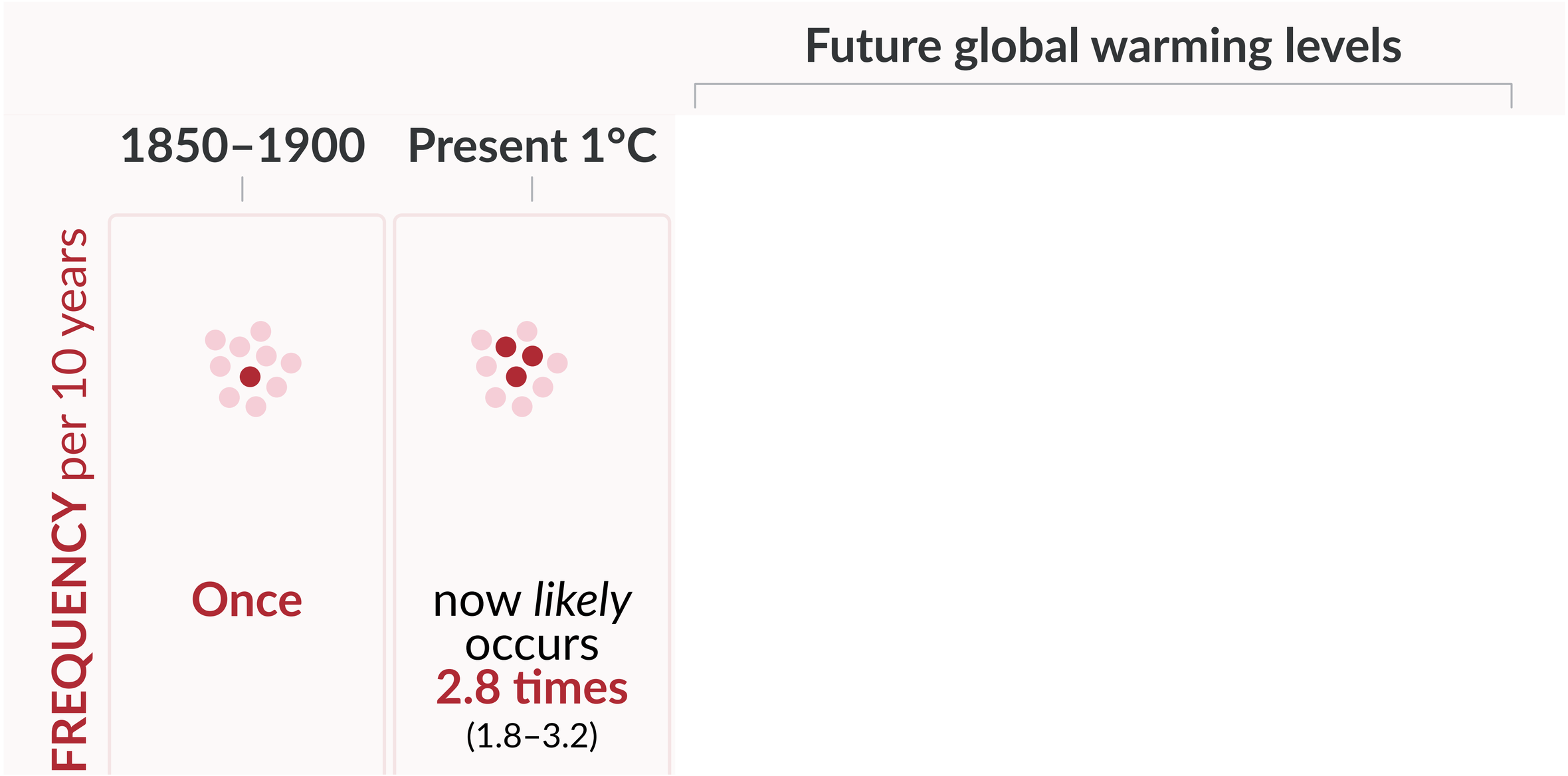
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-12/figure-12-4/

Low Warming Scenario
(2080-2100)

High Warming Scenario
(2080-2100)

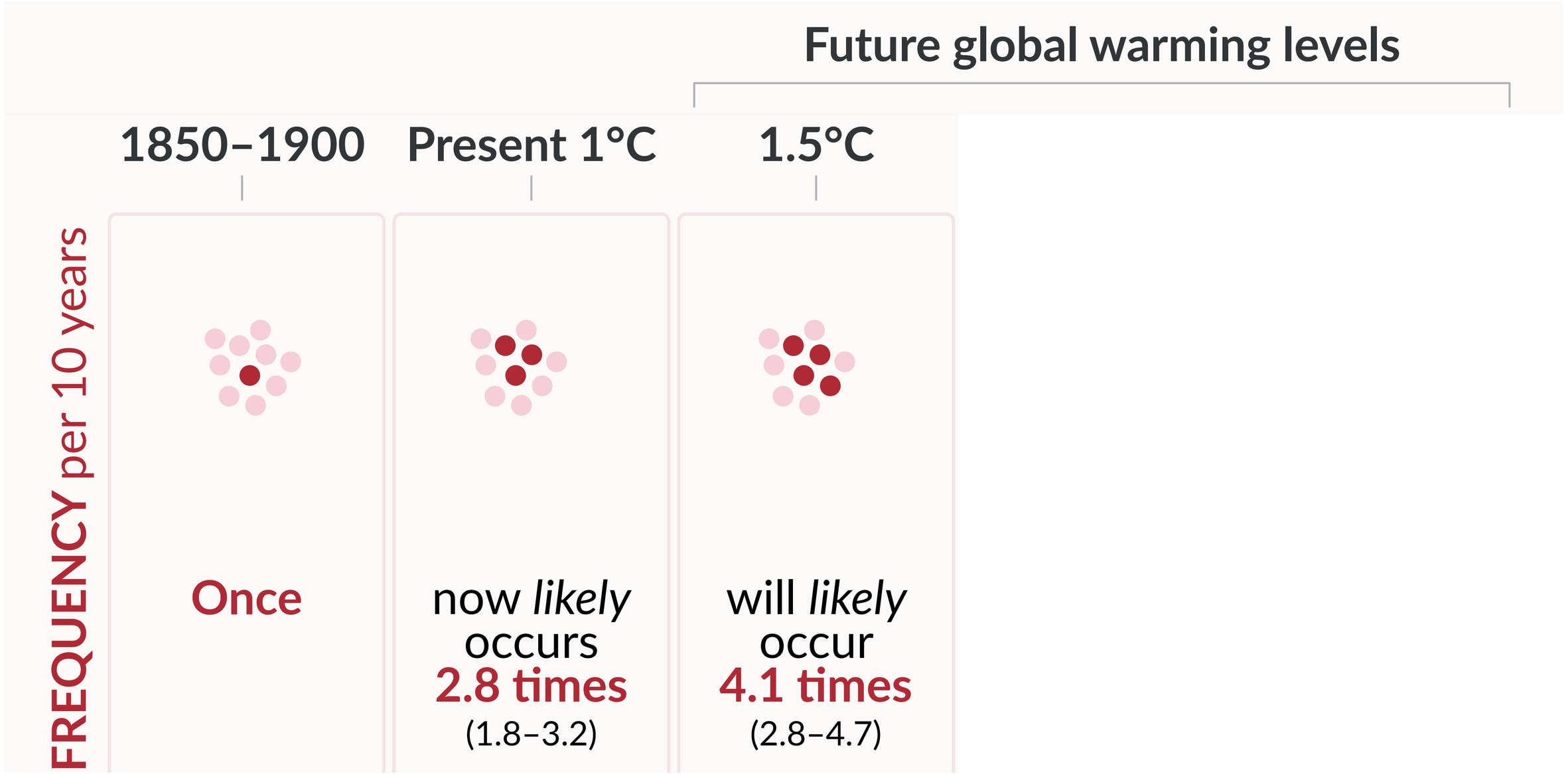


Changes in ***10-year heat extremes***



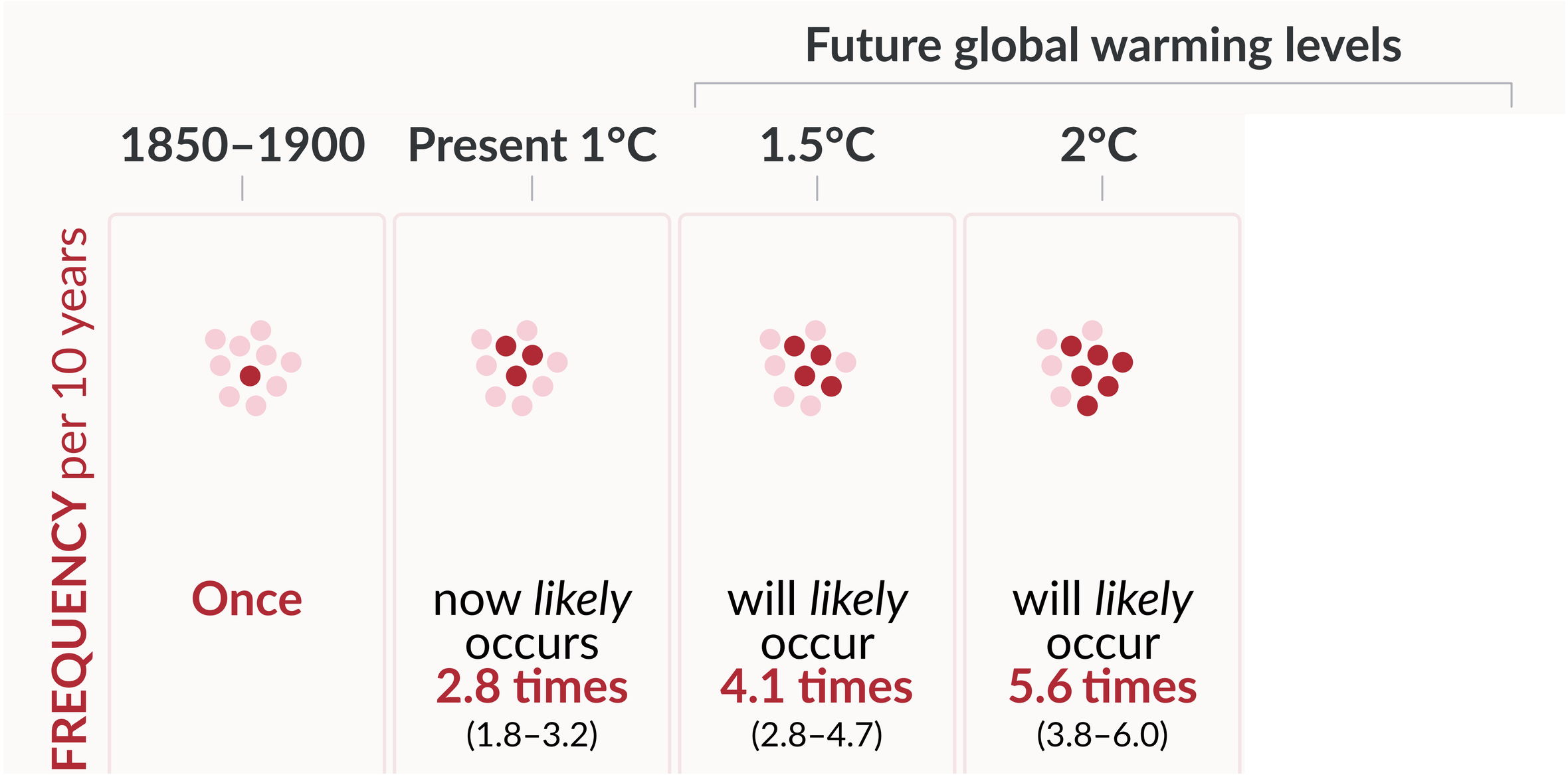
https://www.ipcc.ch/report/ar6/wg1/#SPM

Changes in ***10-year heat extremes***



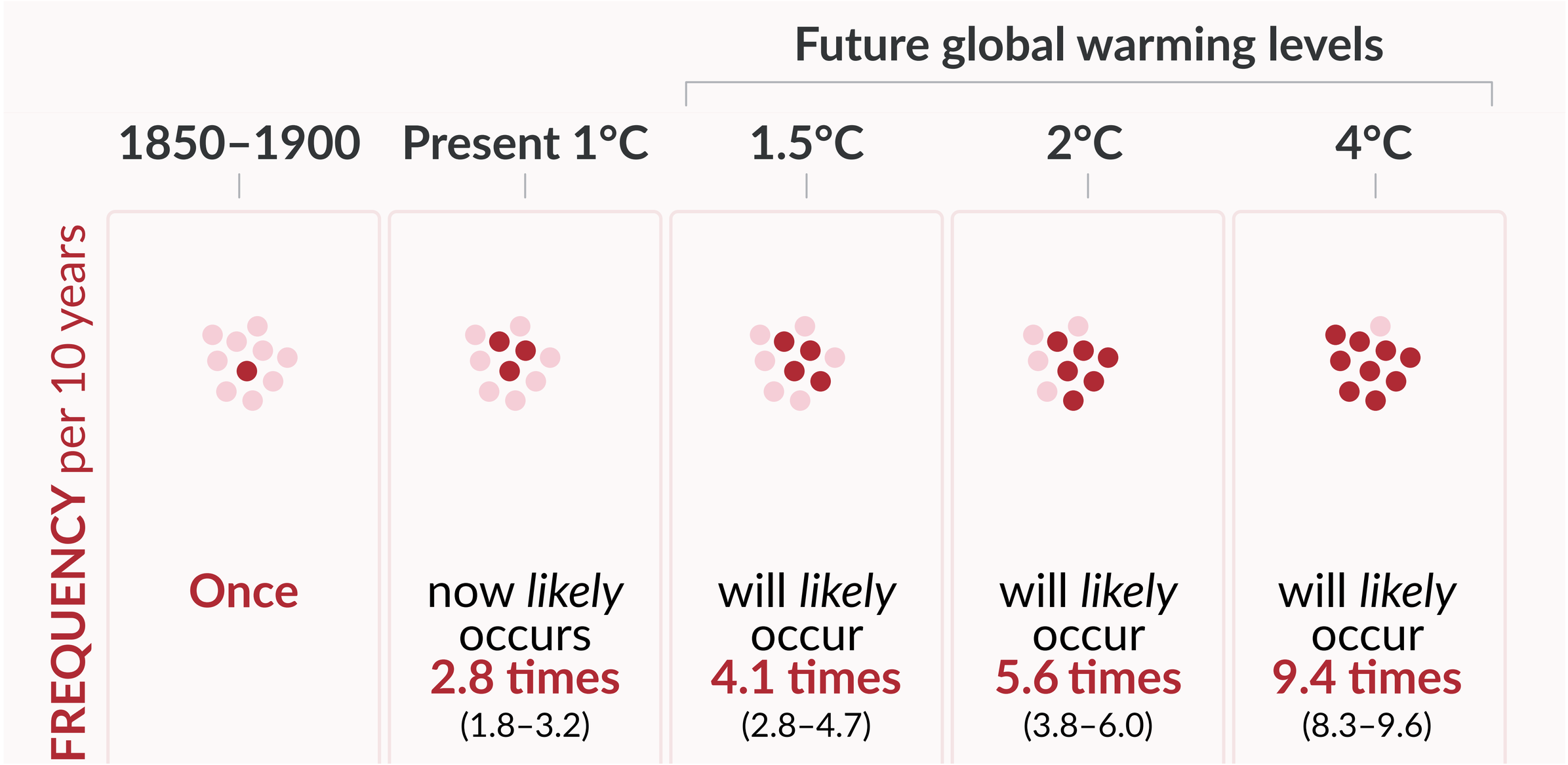
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Changes in ***10-year heat extremes***



https://www.ipcc.ch/report/ar6/wg1/#SPM

Changes in ***10-year heat extremes***



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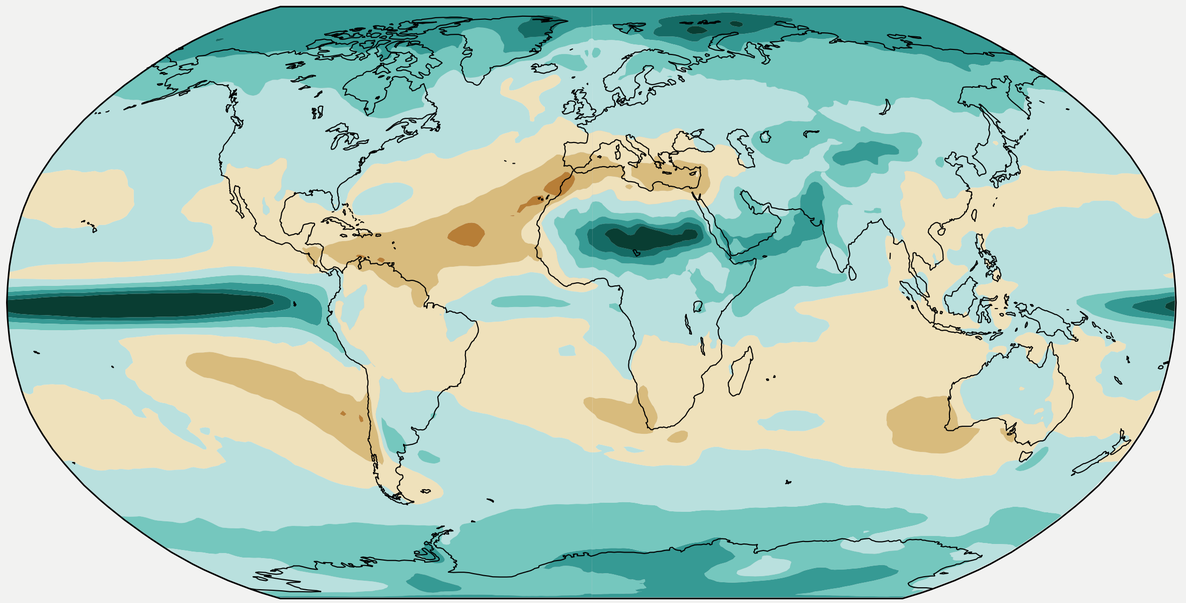
Precipitation (rain+snow)

Robust results for some areas: wetter high latitudes, drier subtropics;

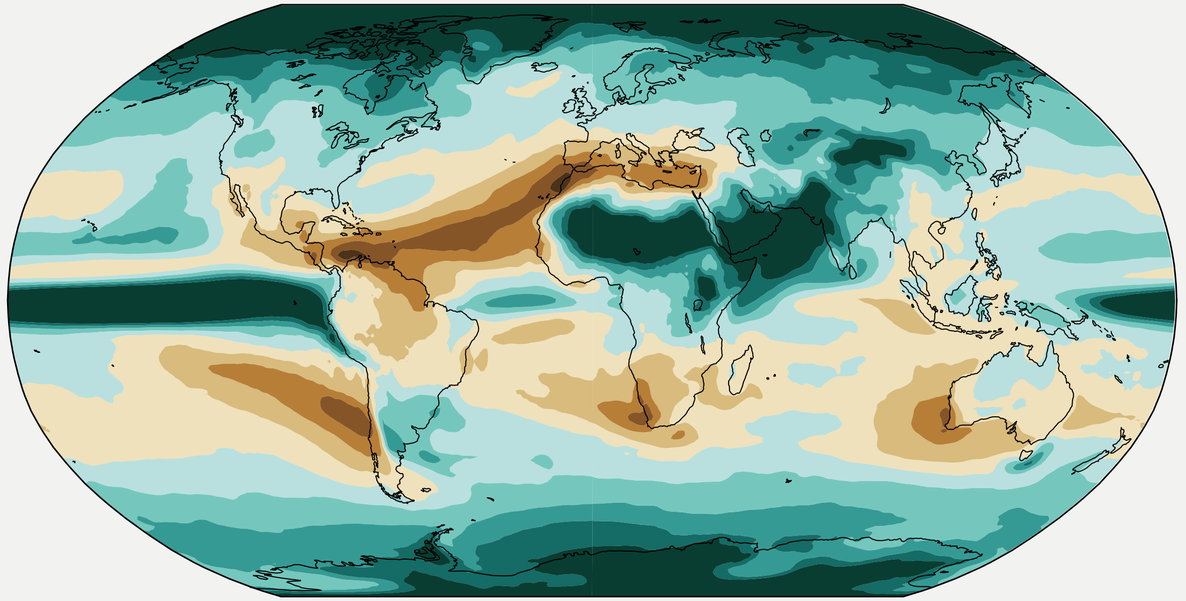
Higher uncertainty b/c more processes (humidity, stability, energy, etc)

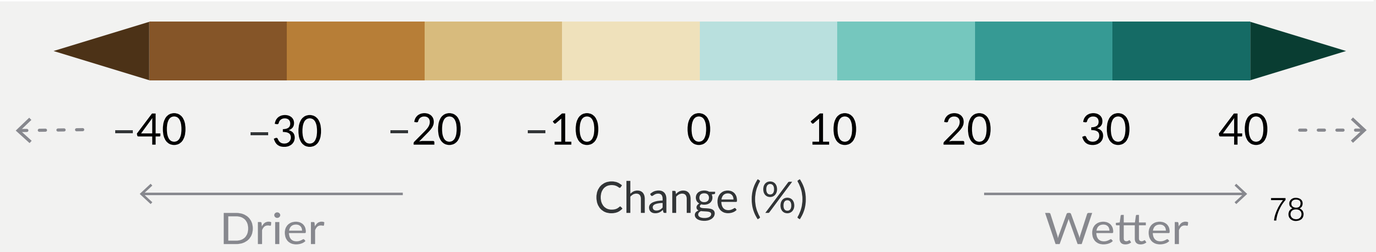
https://www.ipcc.ch/report/ar6/wg1/#SPM

Simulated change at **2°C** global warming

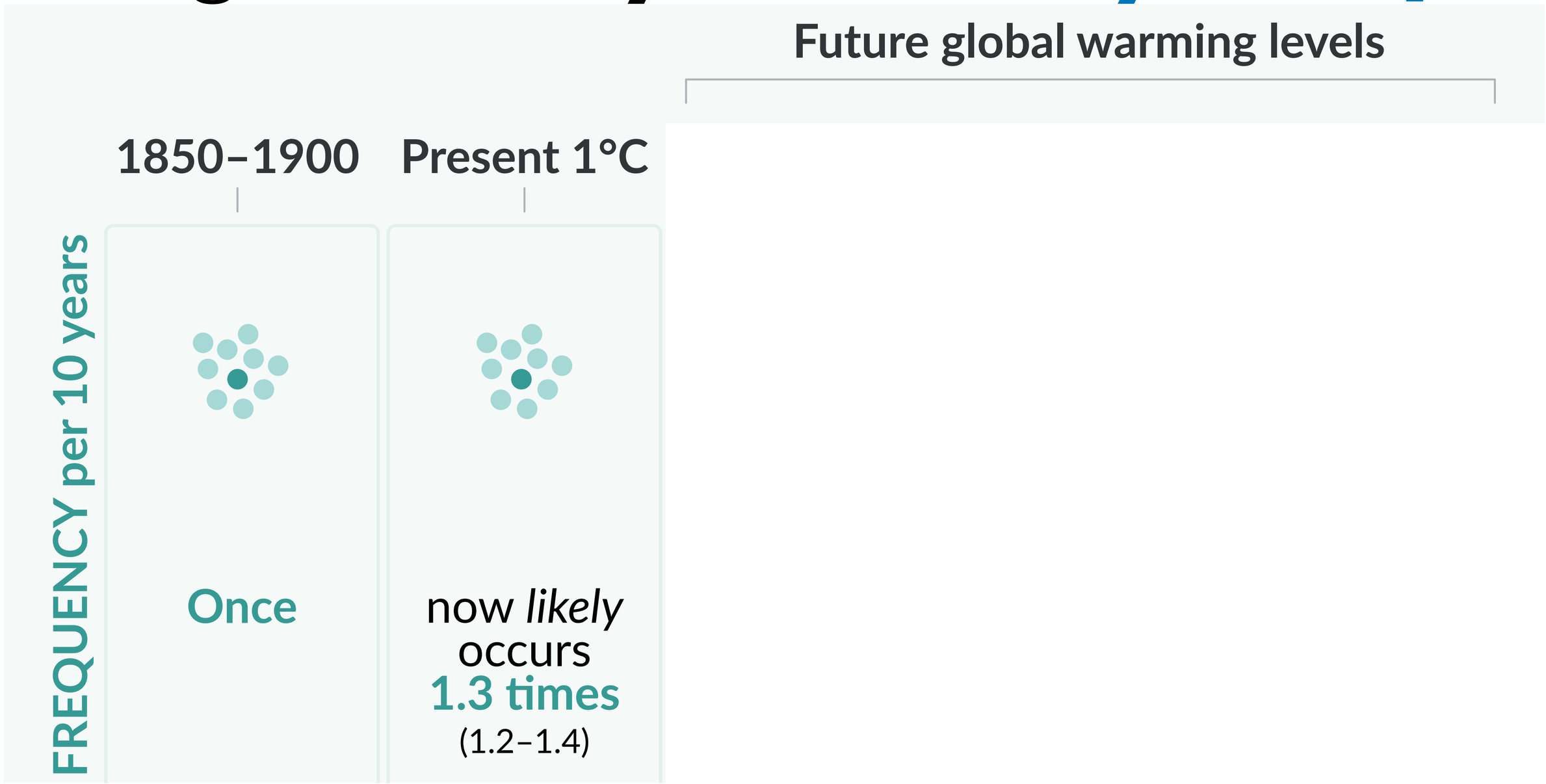


Simulated change at **4°C** global warming



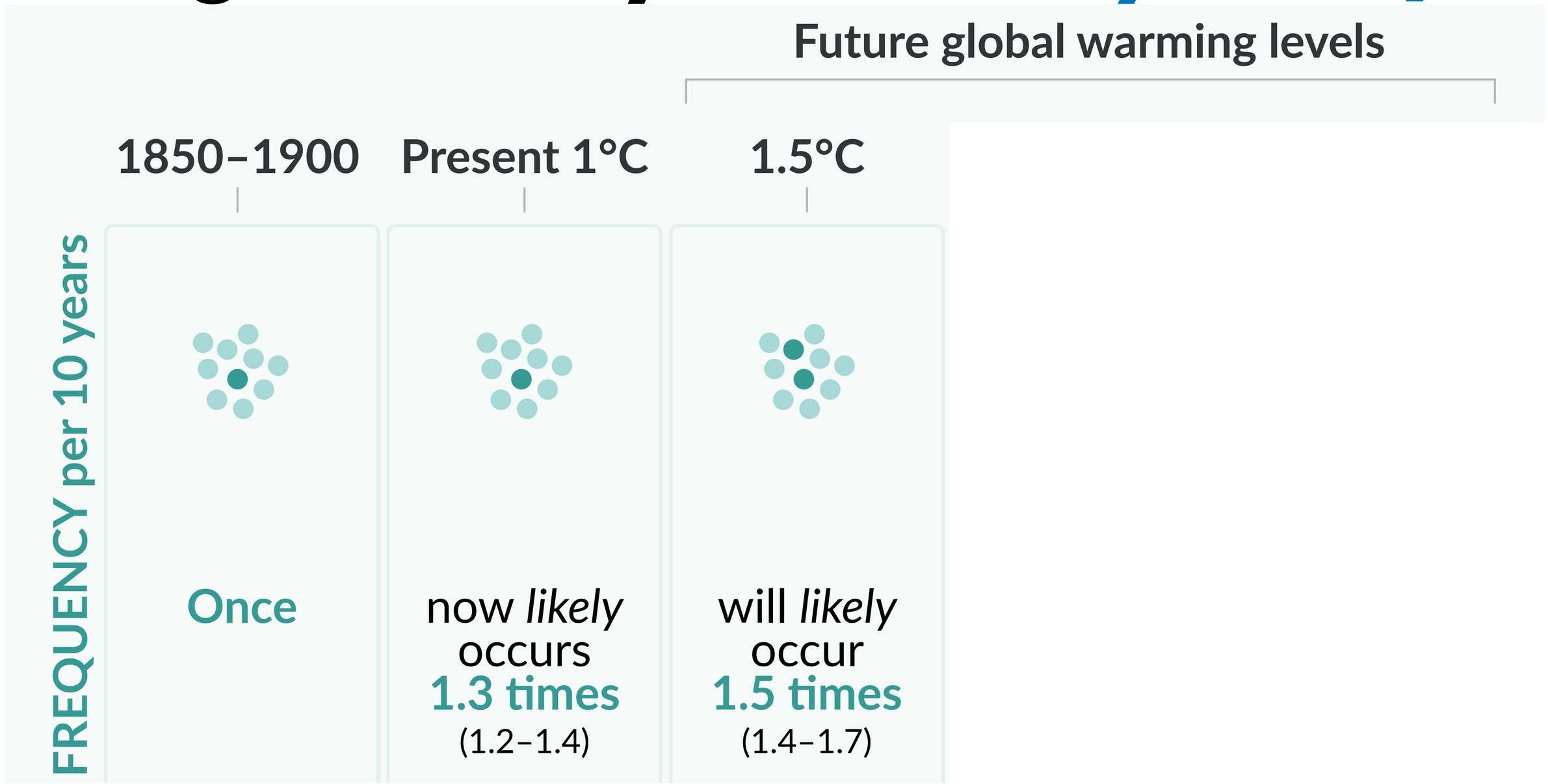


Changes in ***10-year heavy rainfall***



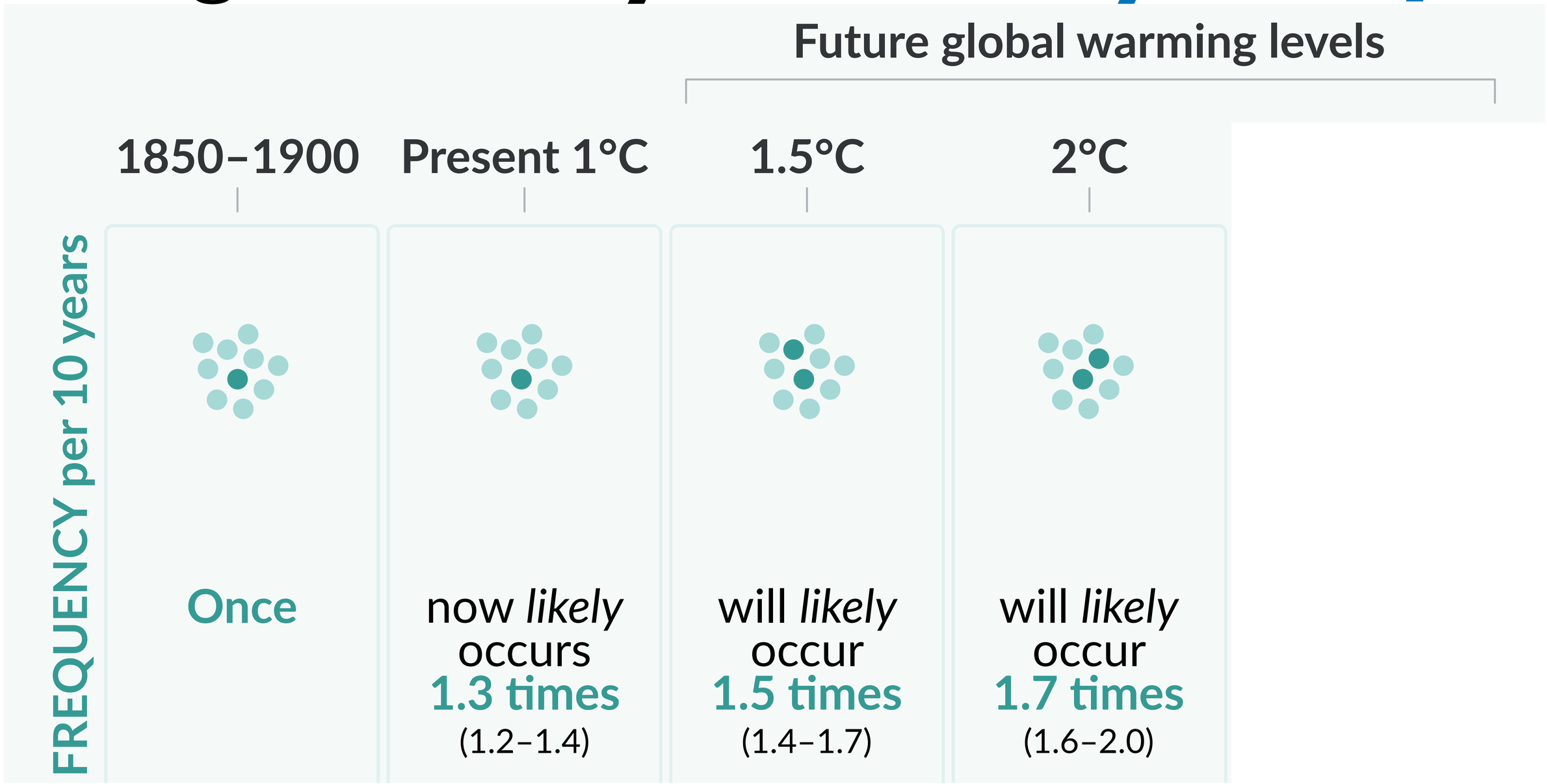
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Changes in ***10-year heavy rainfall***



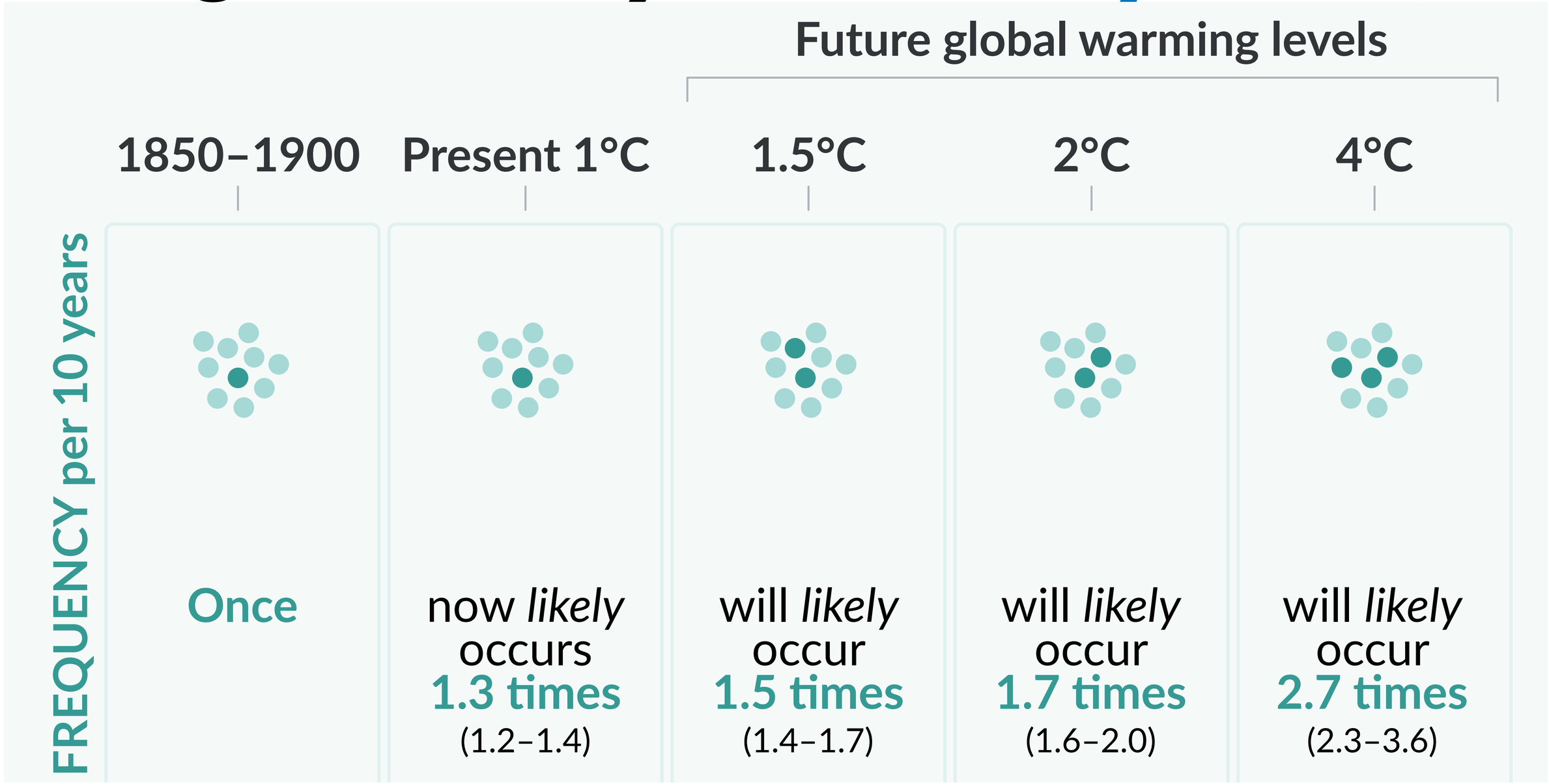
https://www.ipcc.ch/report/ar6/wg1/#SPM

Changes in ***10-year heavy rainfall***



https://www.ipcc.ch/report/ar6/wg1/#SPM

Changes in ***10-year heavy rainfall***



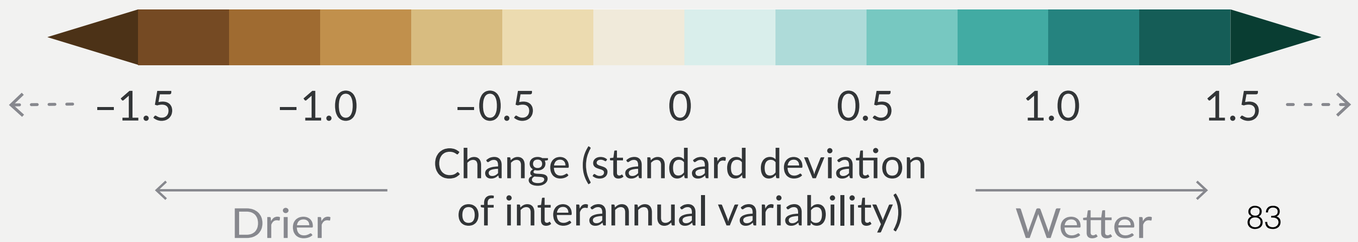
https://www.ipcc.ch/report/ar6/wg1/#SPM

Soil Moisture & Drought

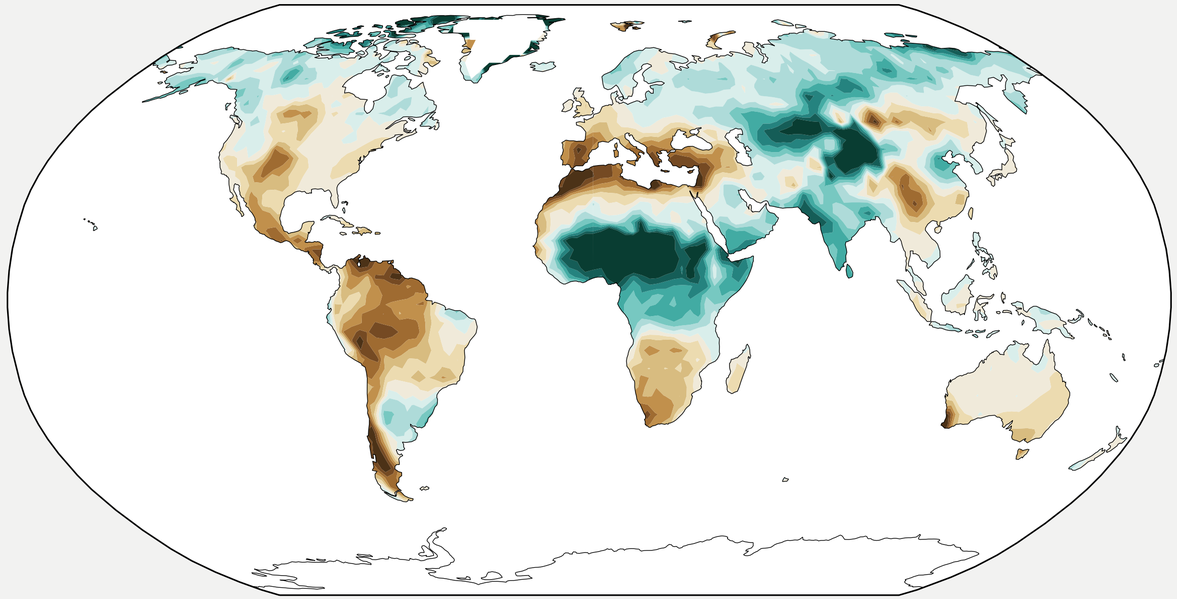
Robust results for some areas: wetter high latitudes, drier subtropics;

Higher uncertainty b/c more processes (humidity, stability, energy, etc)

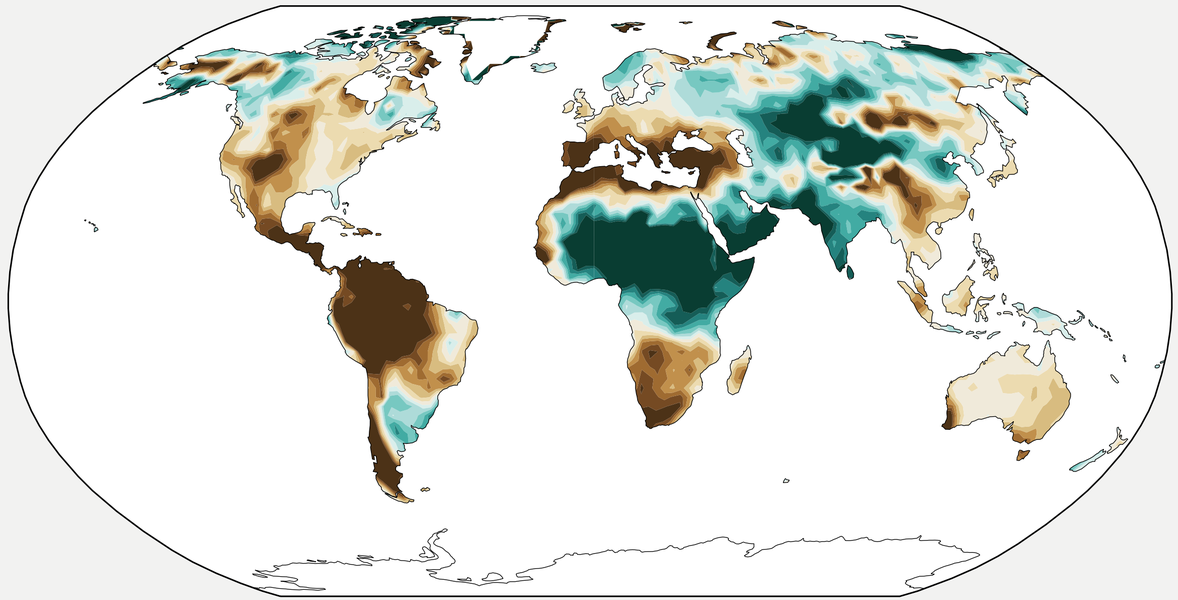
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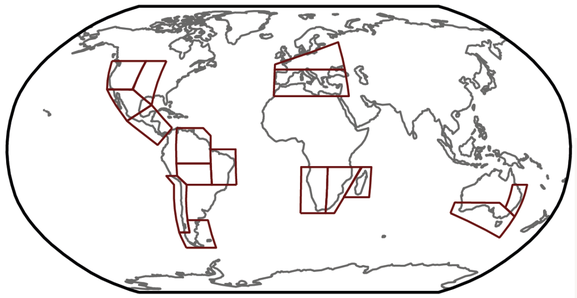


Simulated change at **2°C** global warming



Simulated change at **4°C** global warming





Changes in ***10-year*** ***soil moisture drought***

Future global warming levels

1850–1900 | **Present 1°C**

FREQUENCY per 10 years

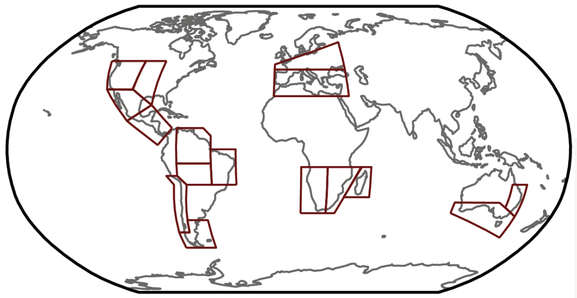


Once



now *likely* occurs **1.7 times** (0.7–4.1)

https://www.ipcc.ch/report/ar6/wg1/#SPM

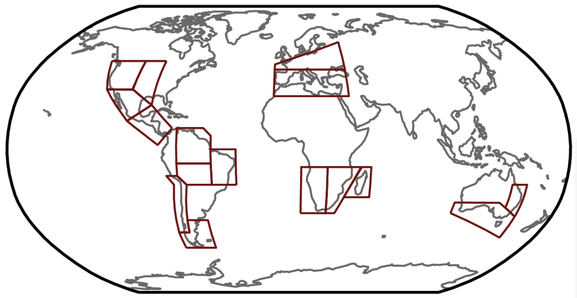


Changes in ***10-year soil moisture drought***

Future global warming levels

1850–1900	Present 1°C	1.5°C
FREQUENCY per 10 years		
Once	now *likely* occurs **1.7 times** (0.7–4.1)	will *likely* occur **2.0 times** (1.0–5.1)

https://www.ipcc.ch/report/ar6/wg1/#SPM

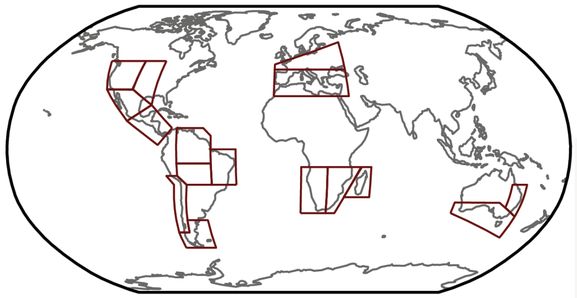


Changes in ***10-year*** ***soil moisture drought***

Future global warming levels

1850–1900	Present 1°C	1.5°C	2°C
FREQUENCY per 10 years			
Once	now *likely* occurs **1.7 times** (0.7–4.1)	will *likely* occur **2.0 times** (1.0–5.1)	will *likely* occur **2.4 times** (1.3–5.8)

https://www.ipcc.ch/report/ar6/wg1/#SPM



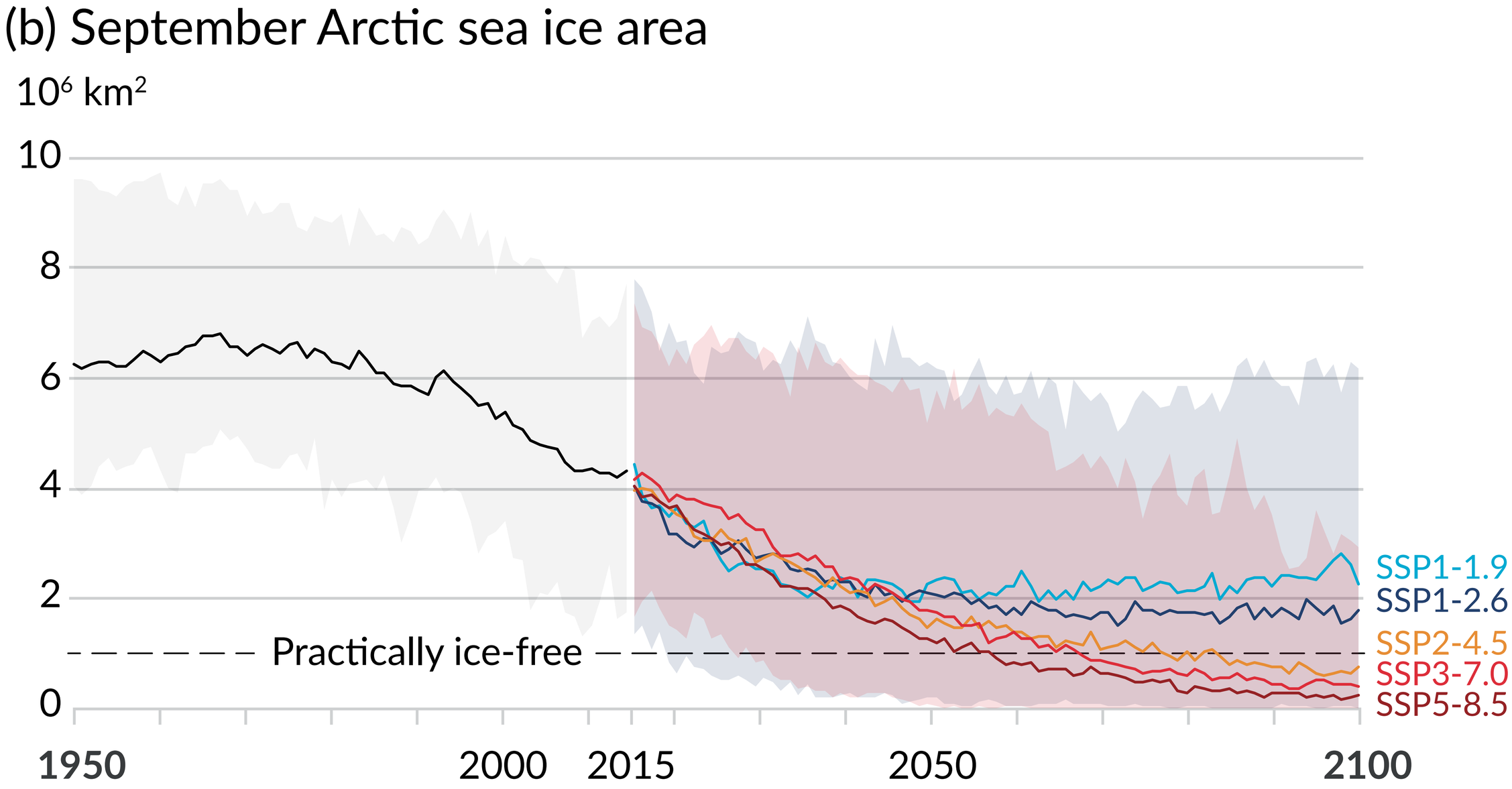
Changes in ***10-year*** ***soil moisture drought***

Future global warming levels

1850–1900	Present 1°C	1.5°C	2°C	4°C
FREQUENCY per 10 years				
Once	now *likely* occurs **1.7 times** (0.7–4.1)	will *likely* occur **2.0 times** (1.0–5.1)	will *likely* occur **2.4 times** (1.3–5.8)	will *likely* occur **4.1 times** (1.7–7.2)

https://www.ipcc.ch/report/ar6/wg1/#SPM

Arctic Sea Ice



https://www.ipcc.ch/report/ar6/wg1/#SPM

Sea Level Rise & Coastal Flooding

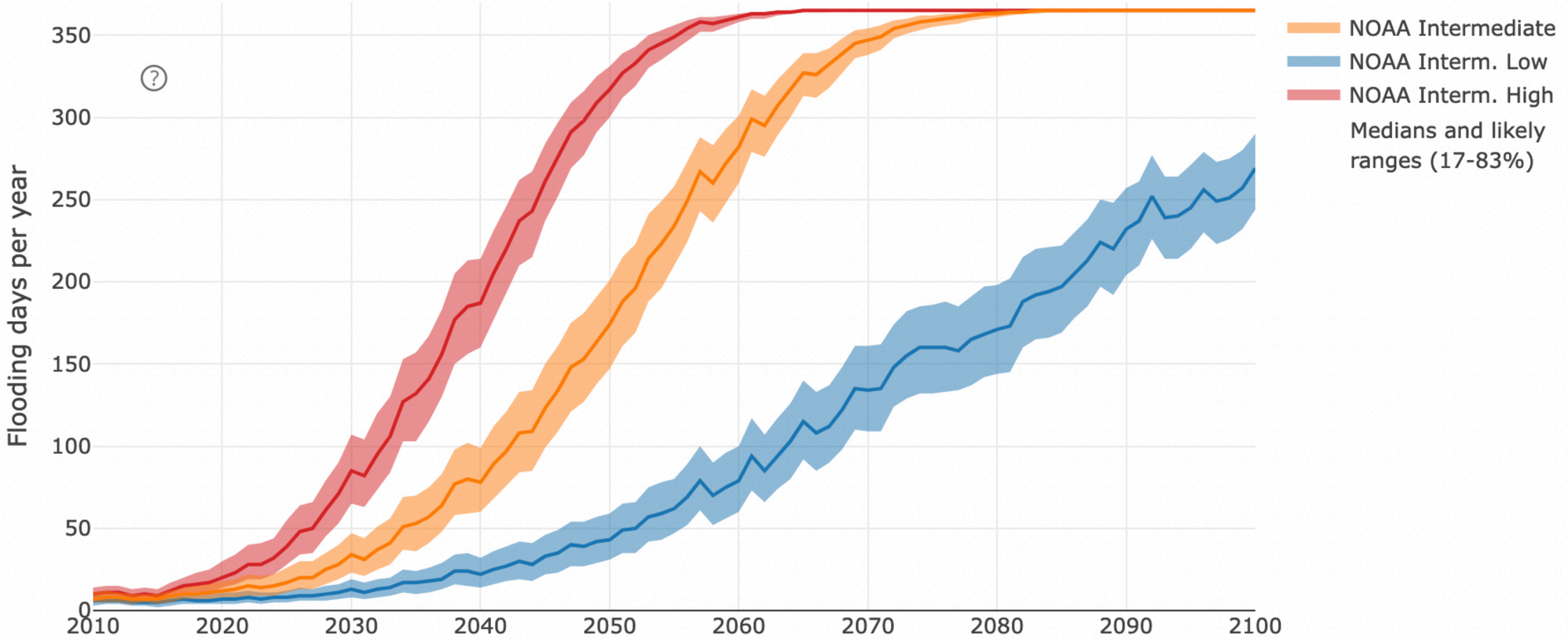
MHHW stands for *Mean Higher High Water*, which is defined as the average of the highest observed water level at the selected location on each tidal day during the period 1983-2001

Flooding days during the 21st century

The graph below shows the number of days per year that sea level in **Montauk, NY** is projected to exceed **53 cm** above MHHW.

▸ **Read more**

Choose the local mean sea level projection(s) to use: NOAA Sea Level Rise Scenarios

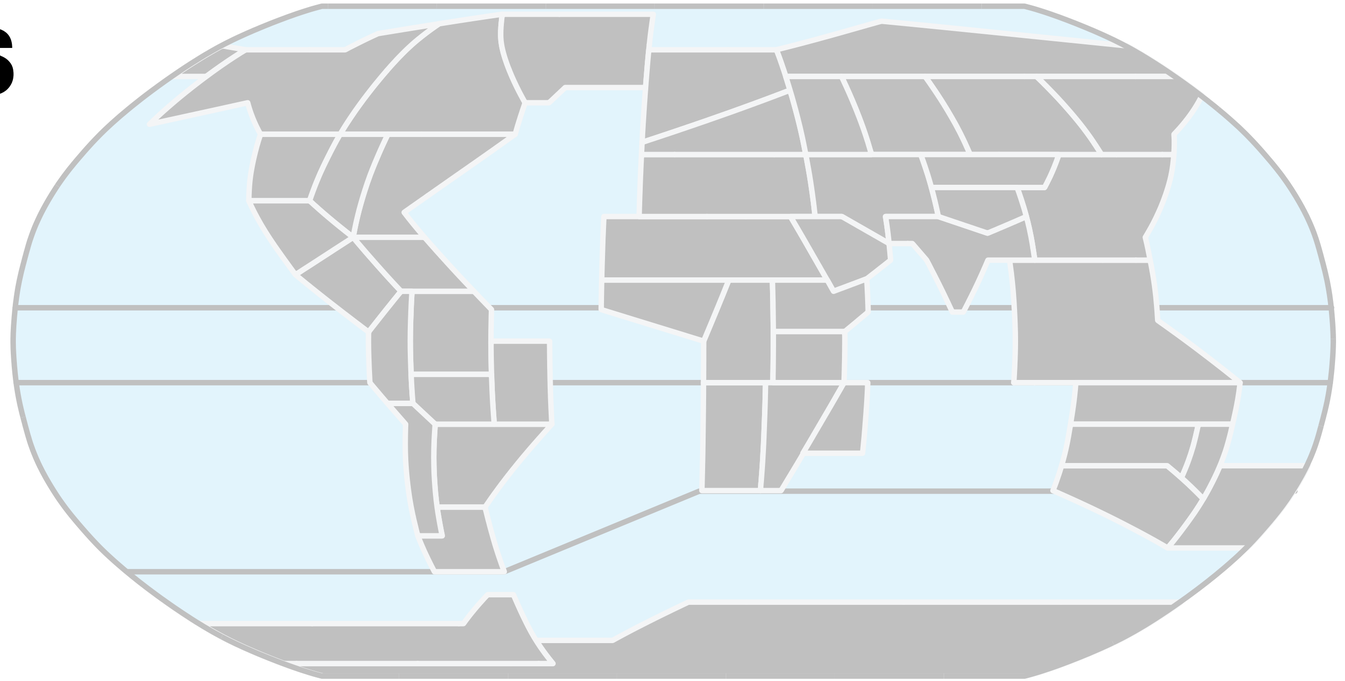


https://sealevel.nasa.gov/flooding-days-projection/

Climate Impact Drivers

BAR CHART LEGEND

- Regions with ***high*** *confidence* **increase**
- Regions with ***medium*** *confidence* **increase**
- Regions with ***high*** *confidence* **decrease**
- Regions with ***medium*** *confidence* **decrease**





Example: Extreme heat

50/55: vulnerable regions

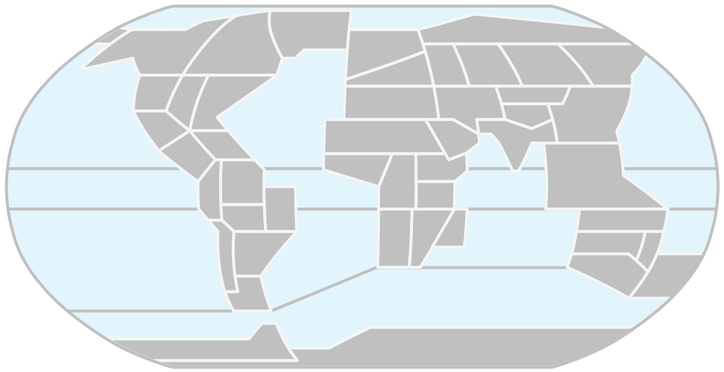
49/50: high confidence for increased risk

1/50: medium confidence for increased risk

https://www.ipcc.ch/report/ar6/wg1/#SPM

https://interactive-atlas.ipcc.ch/

Climate Impact Drivers



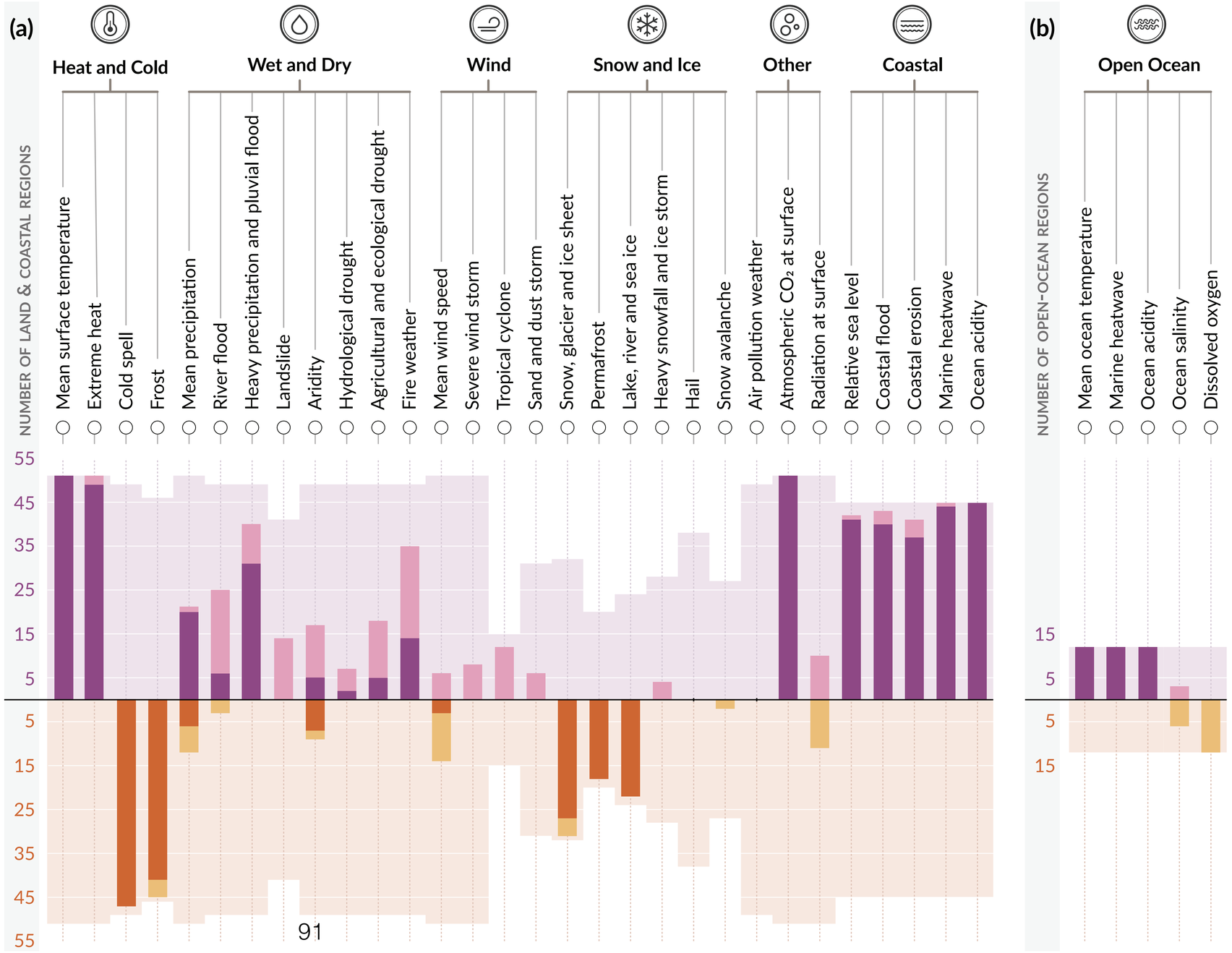
https://interactive-atlas.ipcc.ch/

BAR CHART LEGEND

- Regions with ***high*** *confidence* **increase**
- Regions with ***medium*** *confidence* **increase**
- Regions with ***high*** *confidence* **decrease**
- Regions with ***medium*** *confidence* **decrease**

https://www.ipcc.ch/report/ar6/wg1/#SPM

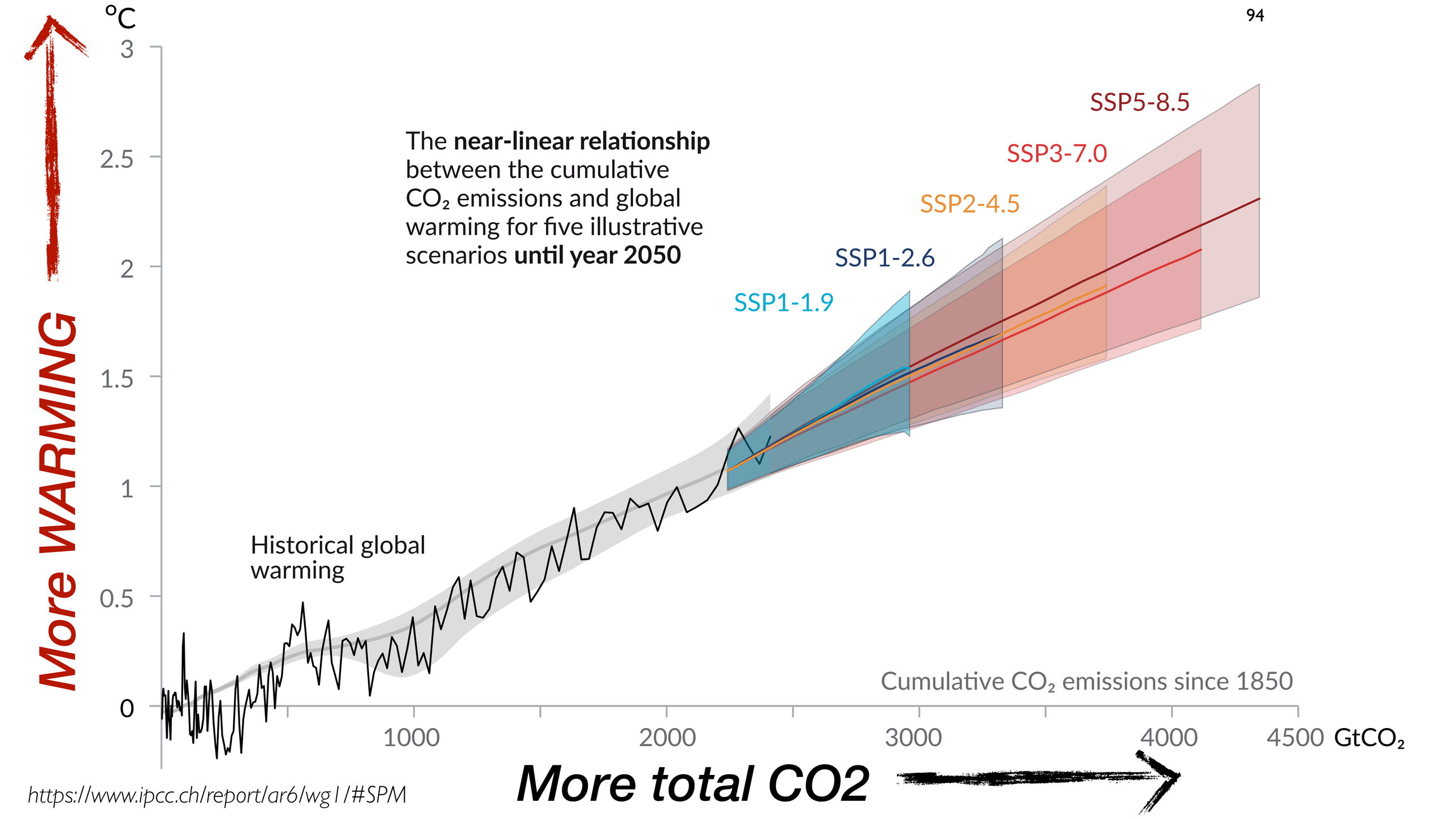
Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to increase or decrease with ***high*** *confidence* (dark shade) or ***medium*** *confidence* (light shade)



REFLECTION

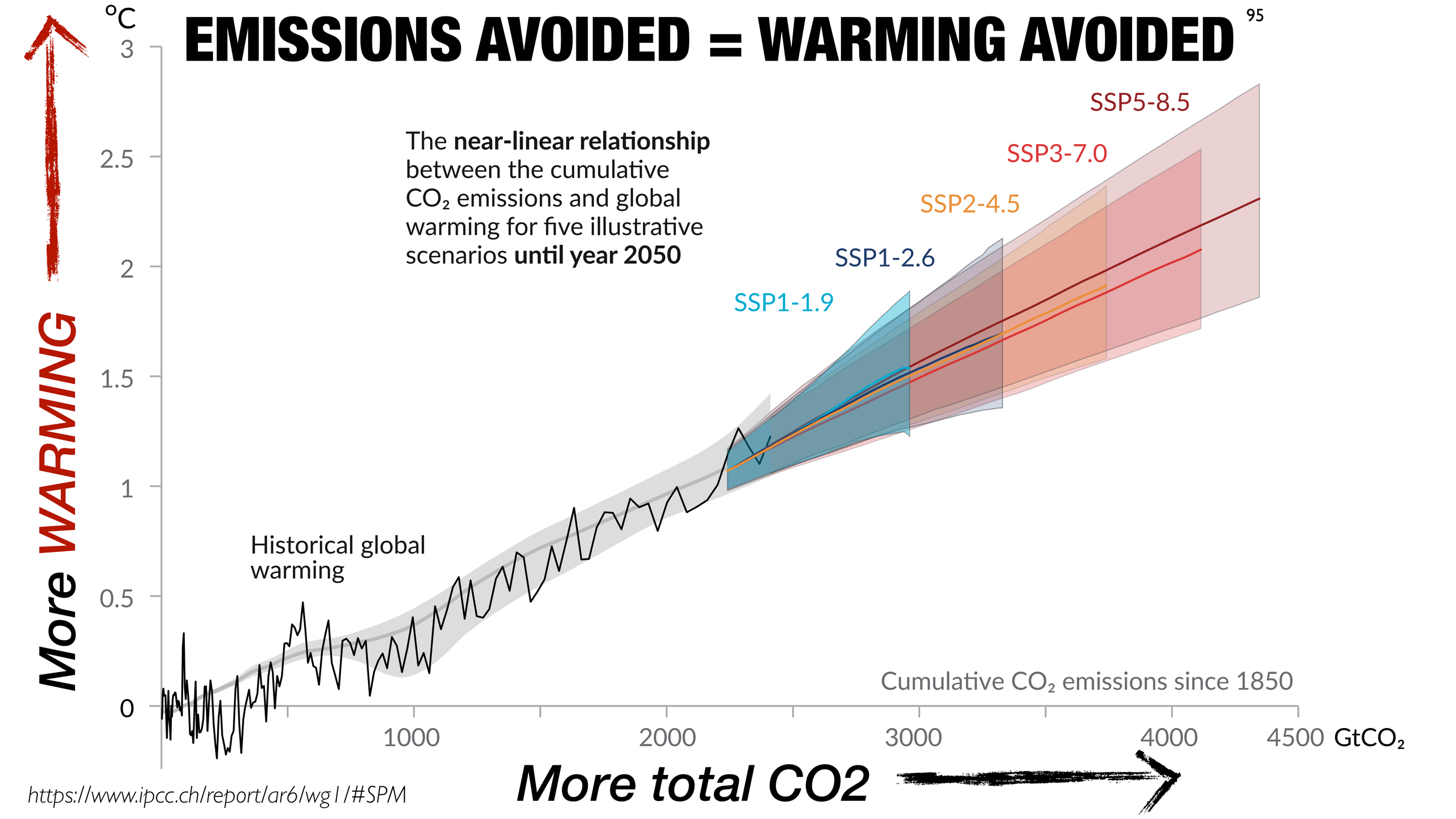
WHAT IS THE MUDDIEST POINT SO FAR? THAT IS, THE THING LEAST CLEAR TO YOU?

CLIMATE MITIGATION

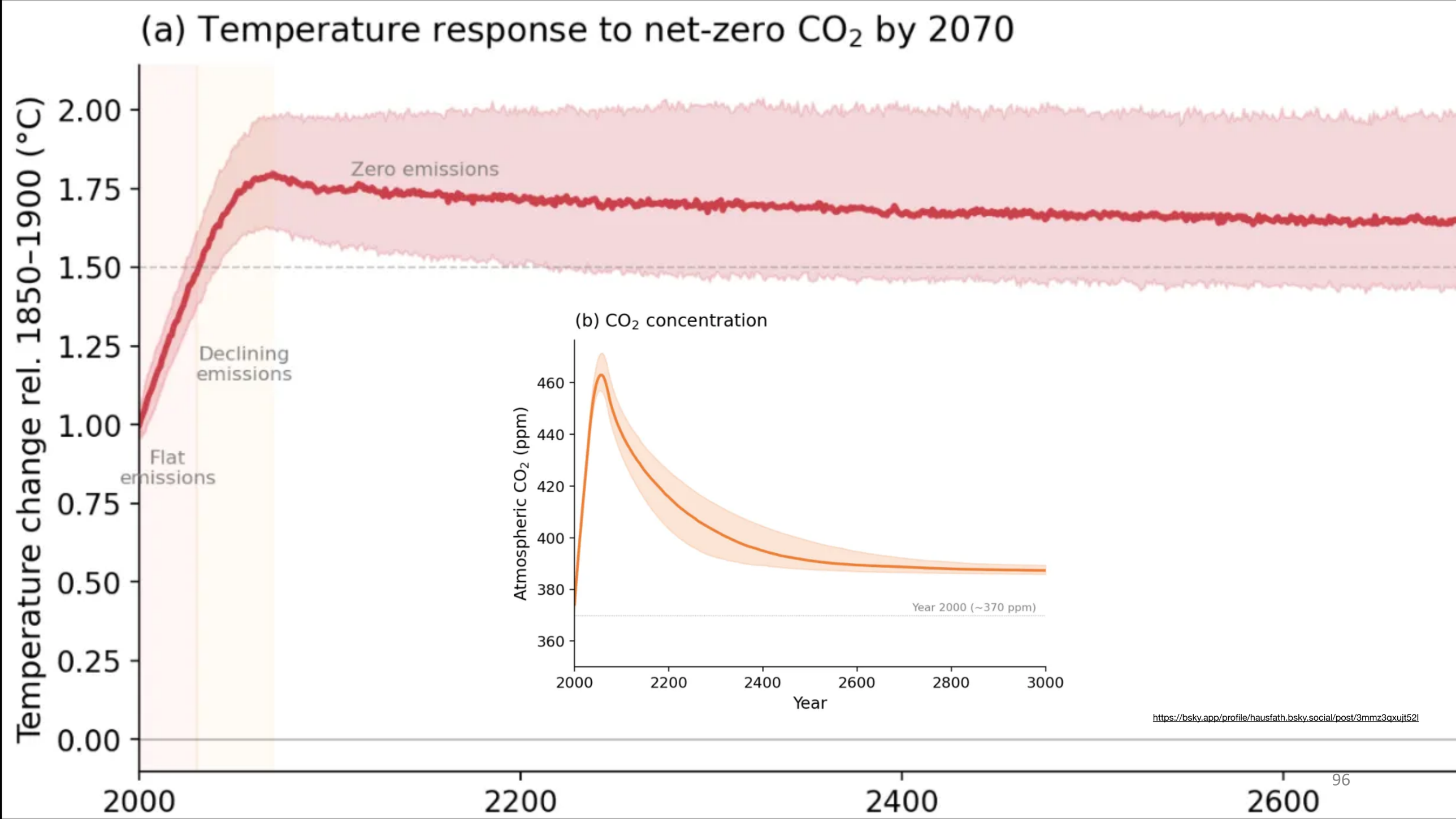


https://www.ipcc.ch/report/ar6/wg1/#SPM

EMISSIONS AVOIDED = WARMING AVOIDED



https://www.ipcc.ch/report/ar6/wg1/#SPM



https://bsky.app/profile/hausfath.bsky.social/post/3mmz3qxujt52l

KAYA IDENTITY

$$GHG_{emissions} = P * \frac{G}{P} * \frac{E}{G} * \frac{F}{E}$$

P = global population

G = world GDP

E = global energy consumption

F = GHG emissions from human sources (fossil fuels)

KAYA IDENTITY

$$GHG_{emissions} = P * \frac{G}{P} * \frac{E}{G} * \frac{F}{E}$$

GDP per capita

(economic consumption)

KAYA IDENTITY

$$GHG_{emissions} = P * \frac{G}{P} * \frac{E}{G} * \frac{F}{E}$$

energy intensity

(How much energy for a unit of economic productivity)

KAYA IDENTITY

$$GHG_{emissions} = P * \frac{G}{P} * \frac{E}{G} * \boxed{\frac{F}{E}}$$

emissions intensity of energy

(fossil fuel use)

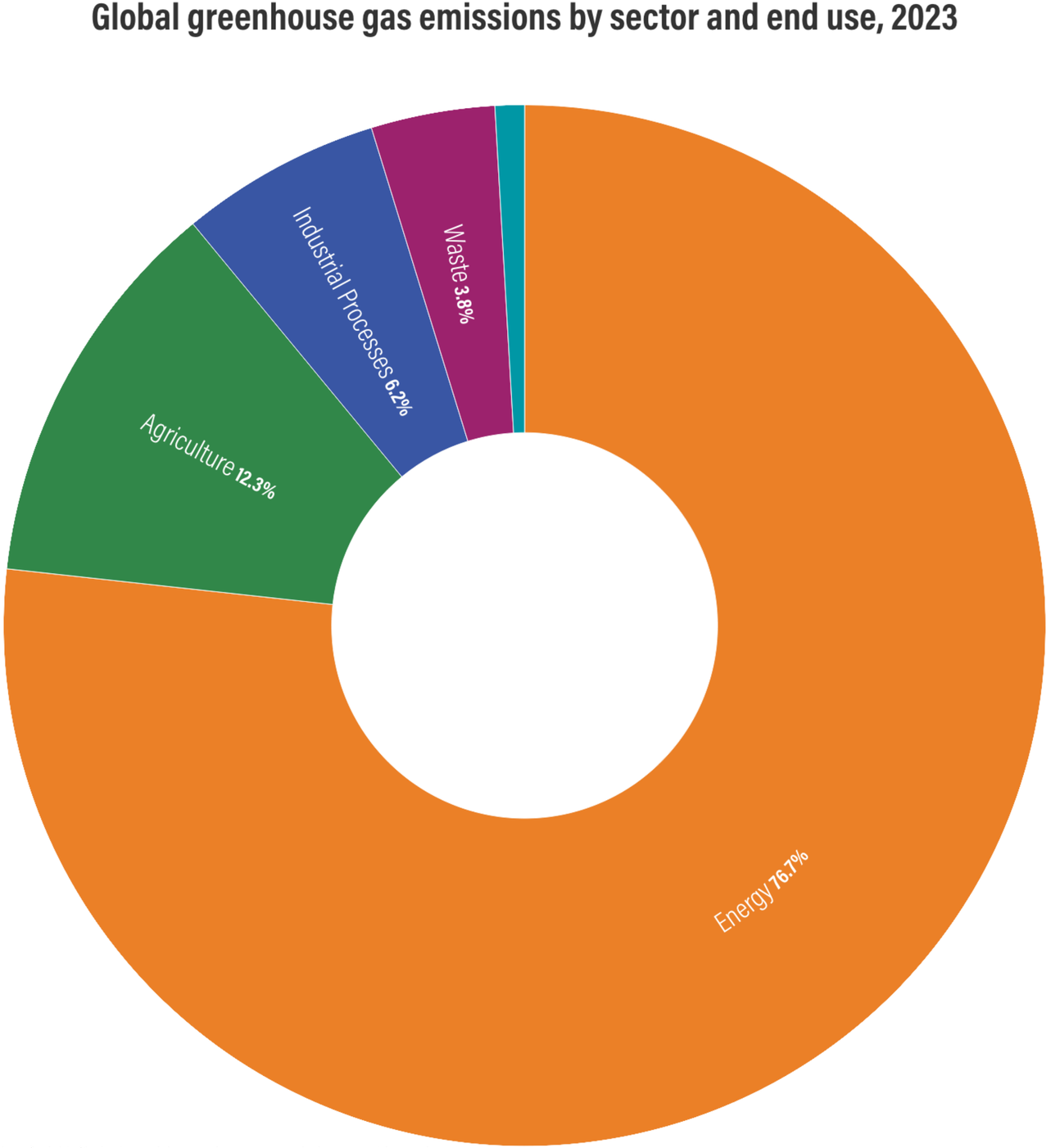
KAYA IDENTITY

$$GHG_{emissions} = P * \frac{G}{P} * \frac{E}{G} * \frac{F}{E}$$

reduce consumption

improve efficiency

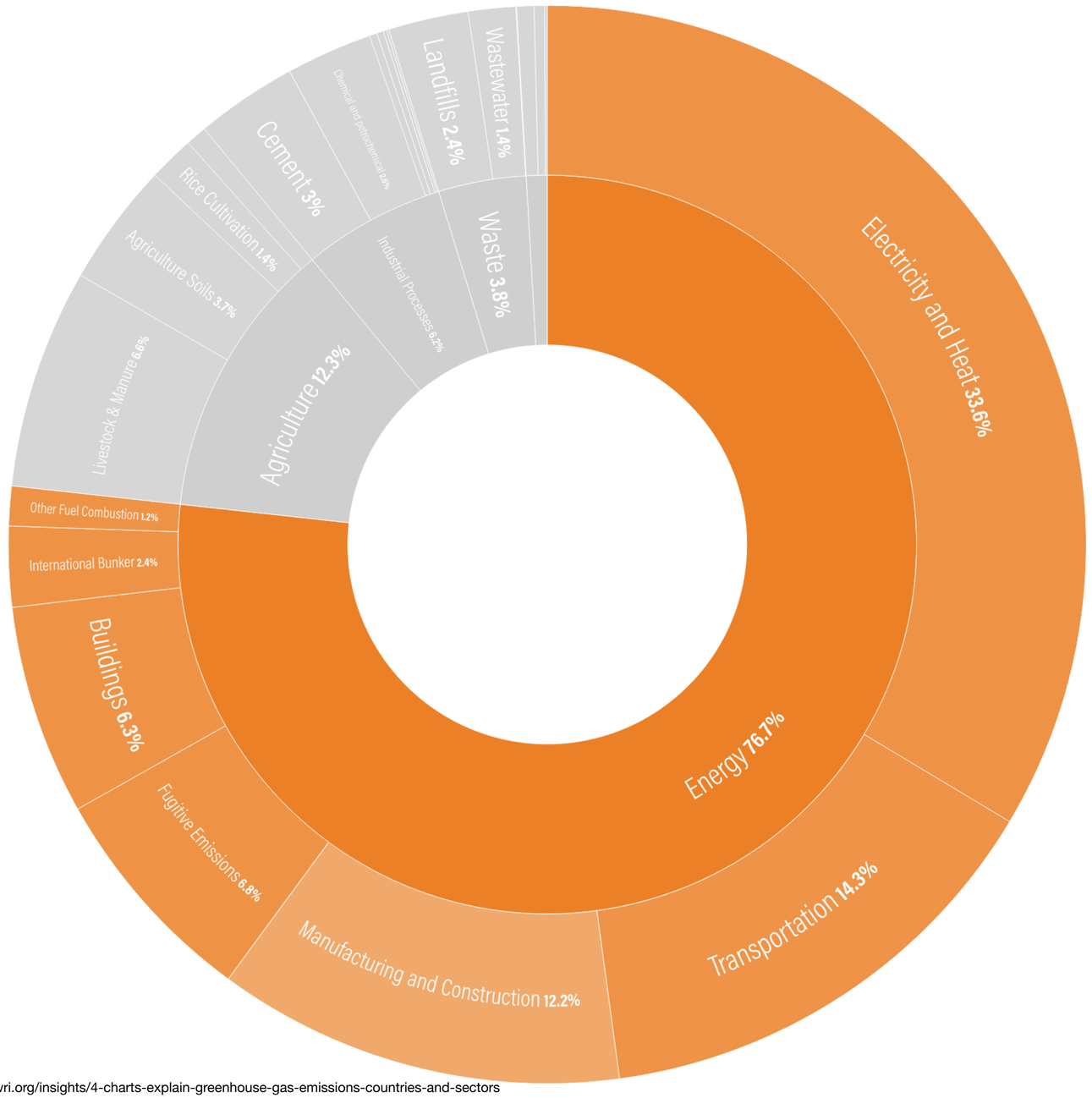
switch to renewables



>76% of GHG Emissions from Energy Final Use

WORLD RESOURCES INSTITUTE

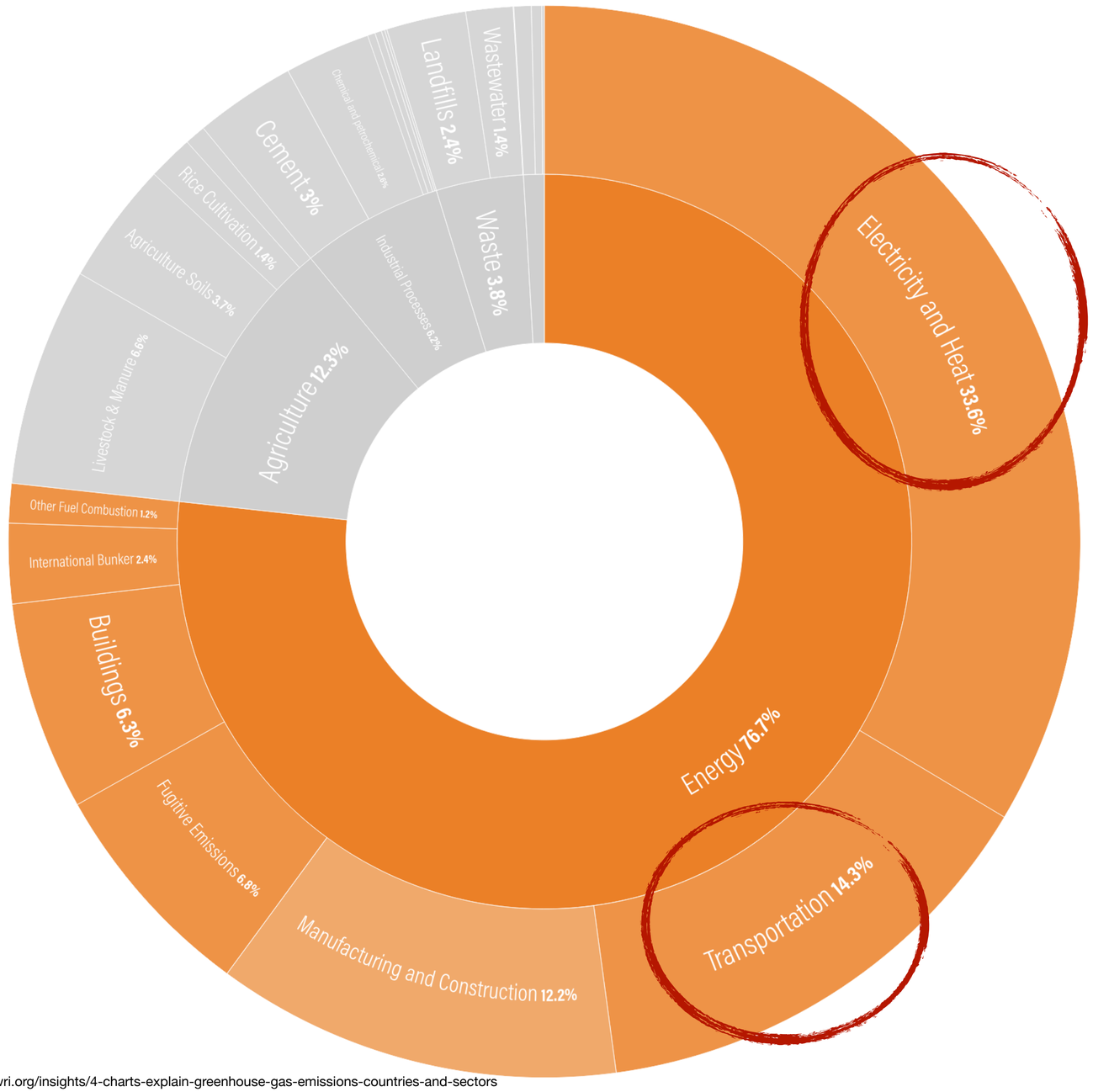
https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors



>76% of GHG Emissions from Energy

WORLD RESOURCES INSTITUTE

https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors



Electricity+Heat & *Transportation*

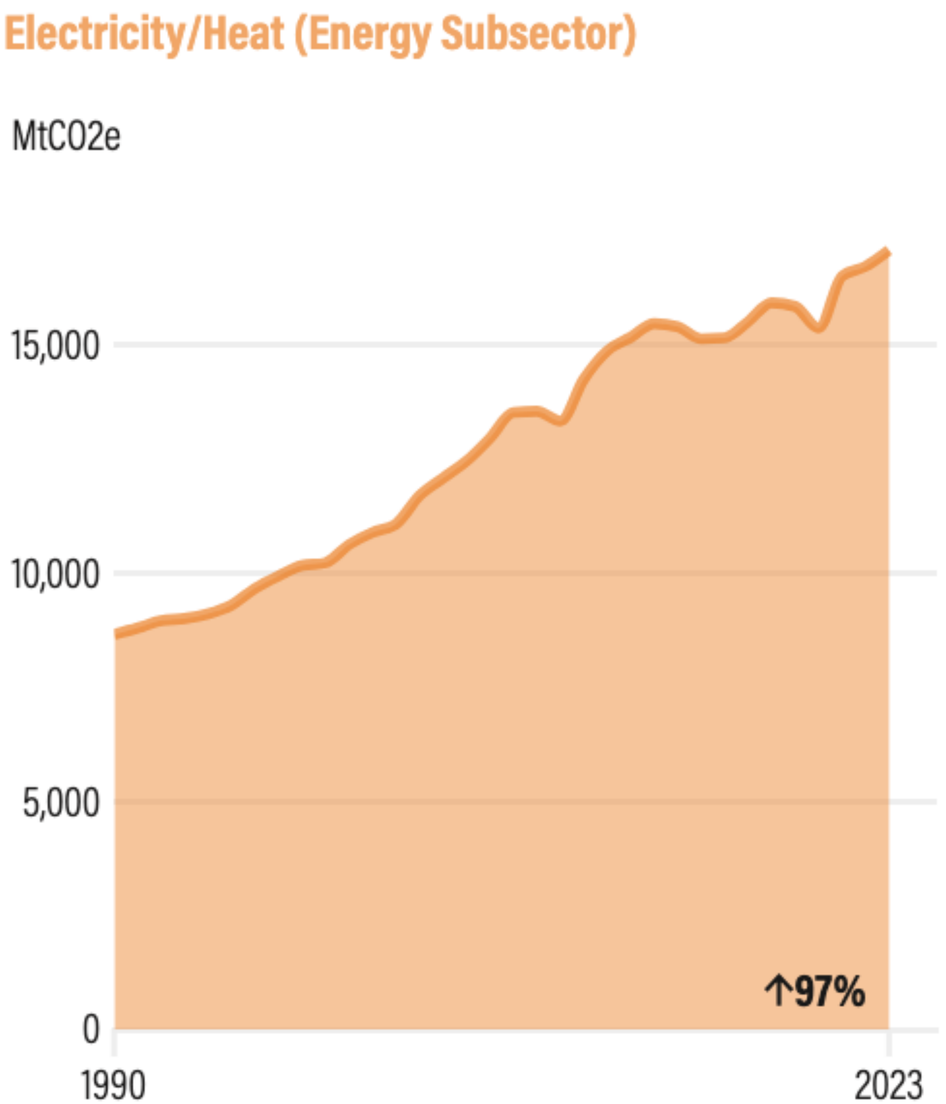
Largest component of Energy related emissions

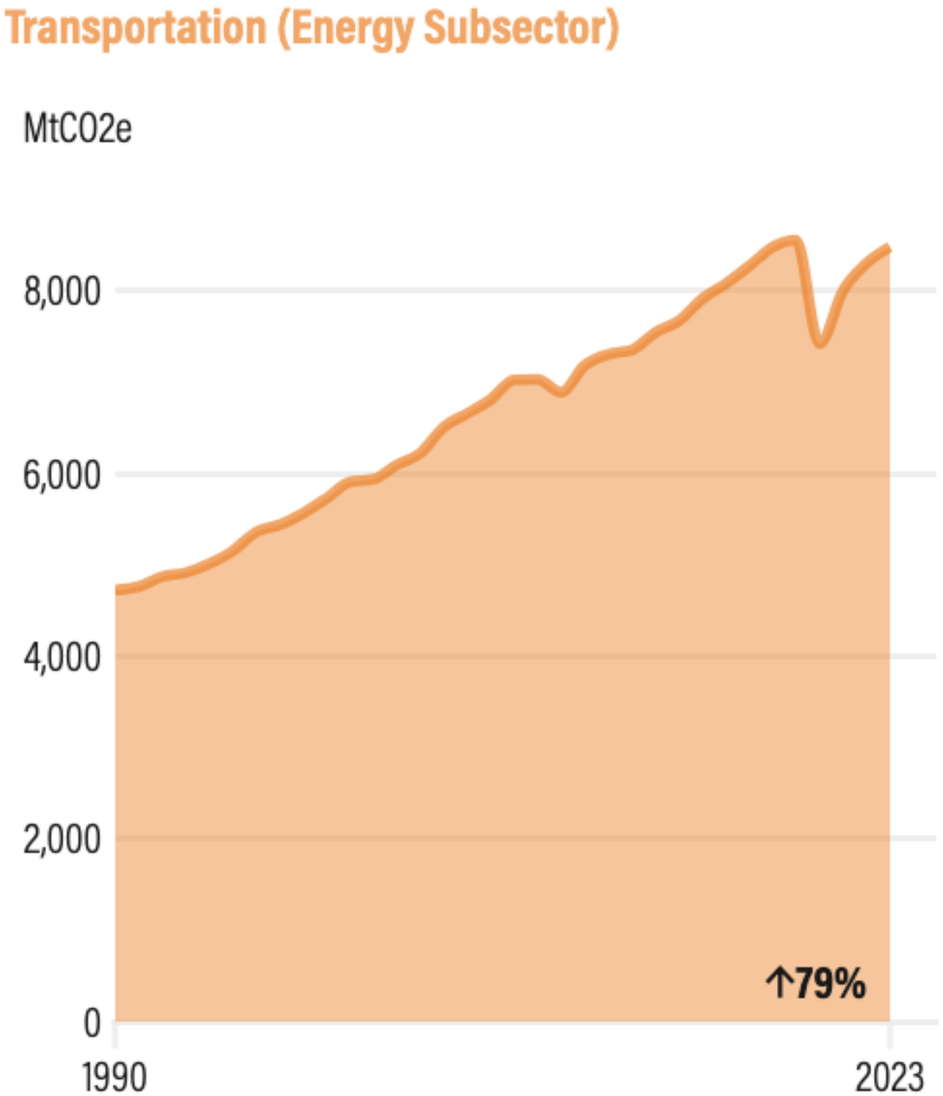
WORLD RESOURCES INSTITUTE

https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

Trends in sectoral emissions, 1990-2023

Emissions for industrial processes, electricity/heat and transportation sectors are growing fastest



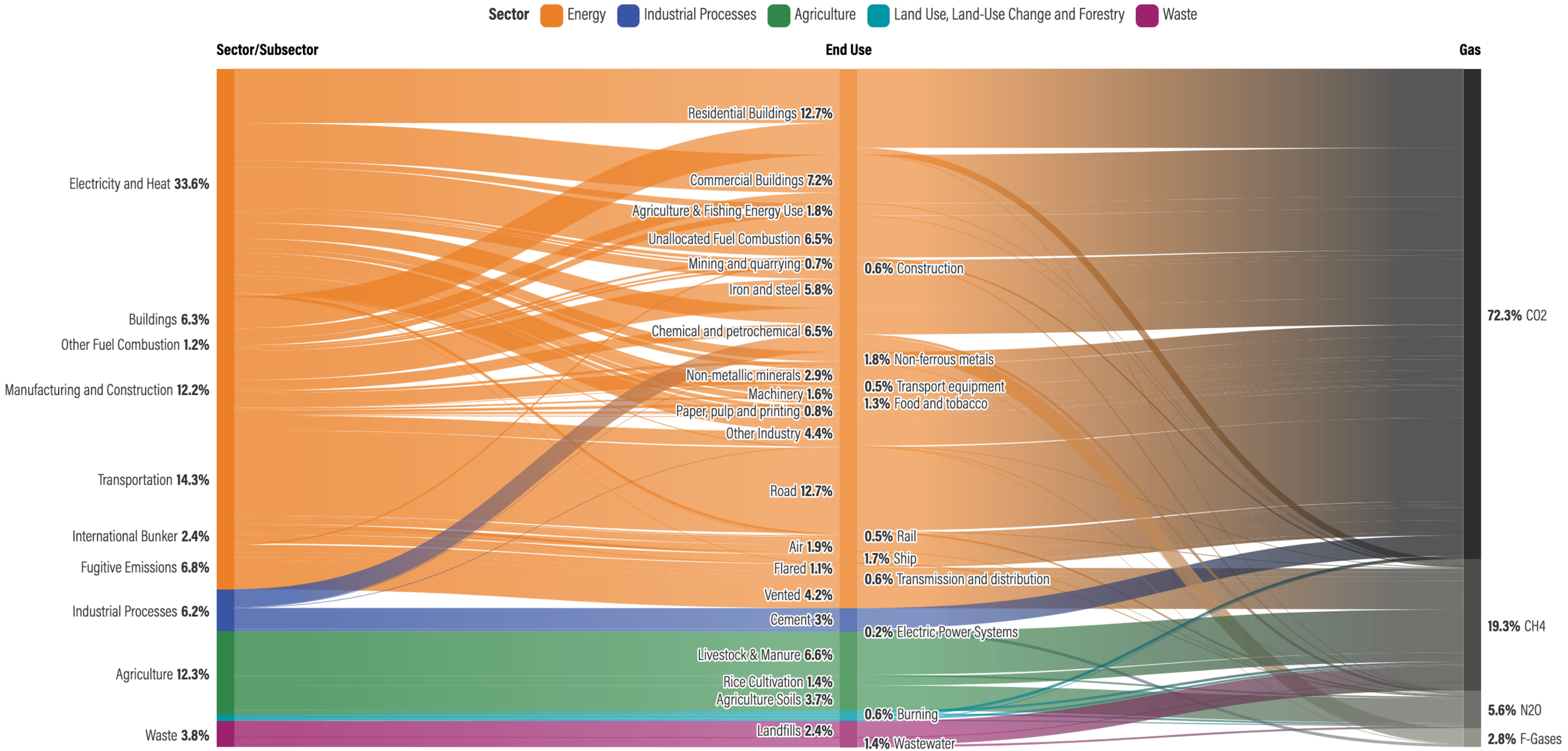


WORLD RESOURCES INSTITUTE

https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

WORLD RESOURCES INSTITUTE

Flow of global greenhouse gas emissions in 2023



https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

Agriculture, Forestry and Other Land Use **(AFOLU)**

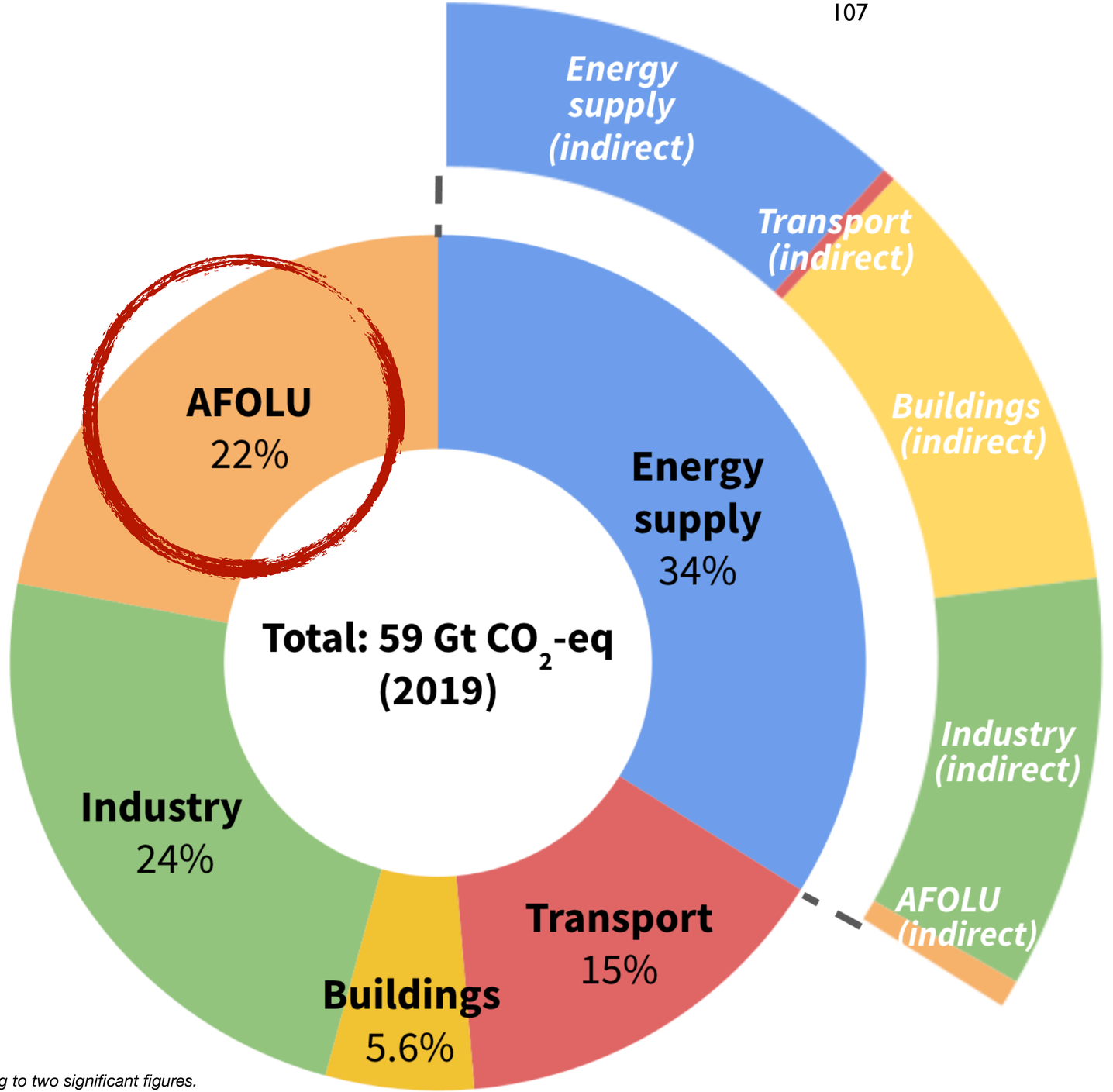
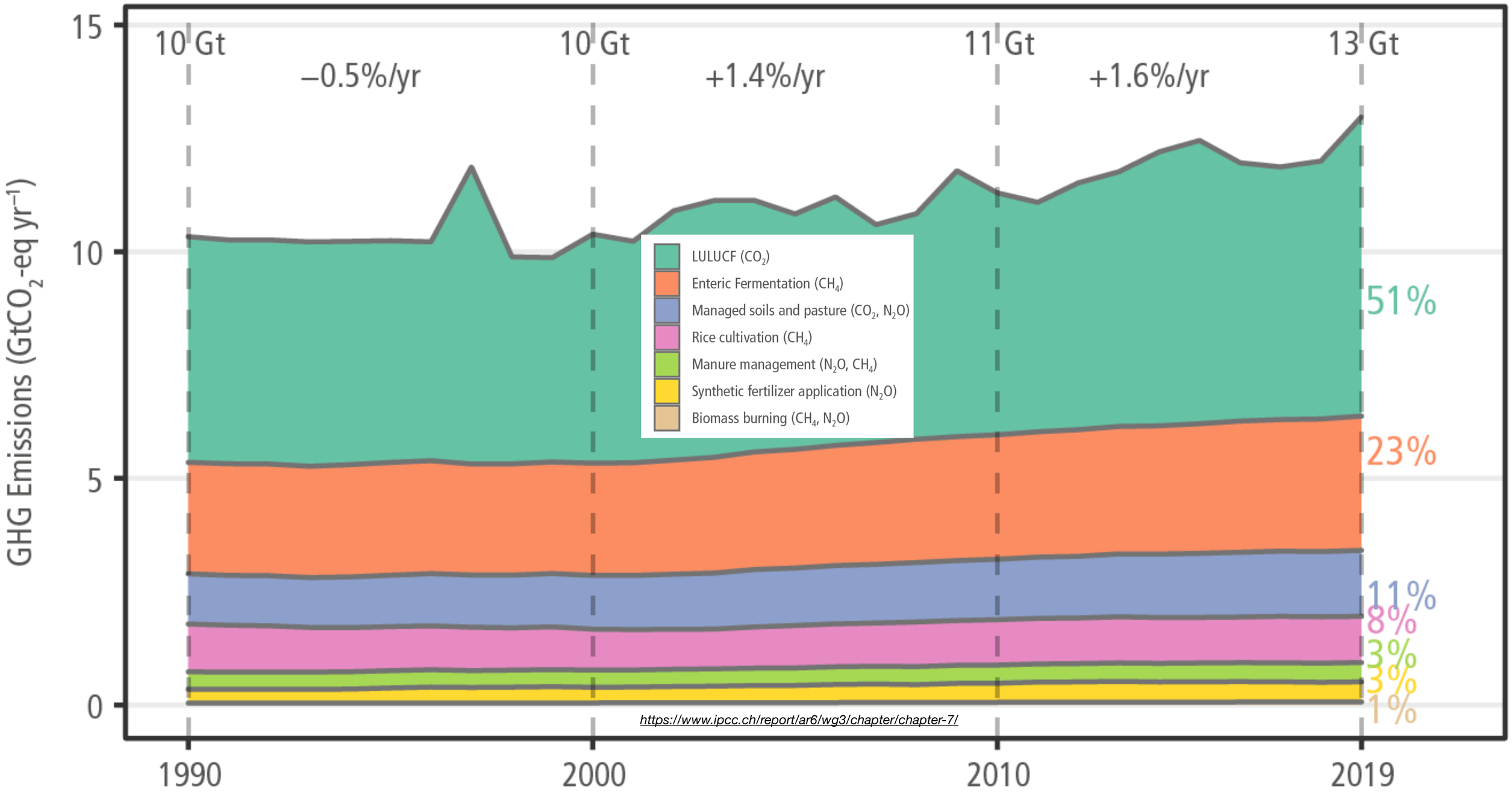


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.
Credit: Dr. Priya Donti

a. AFOLU global trends in GHG emissions and removals

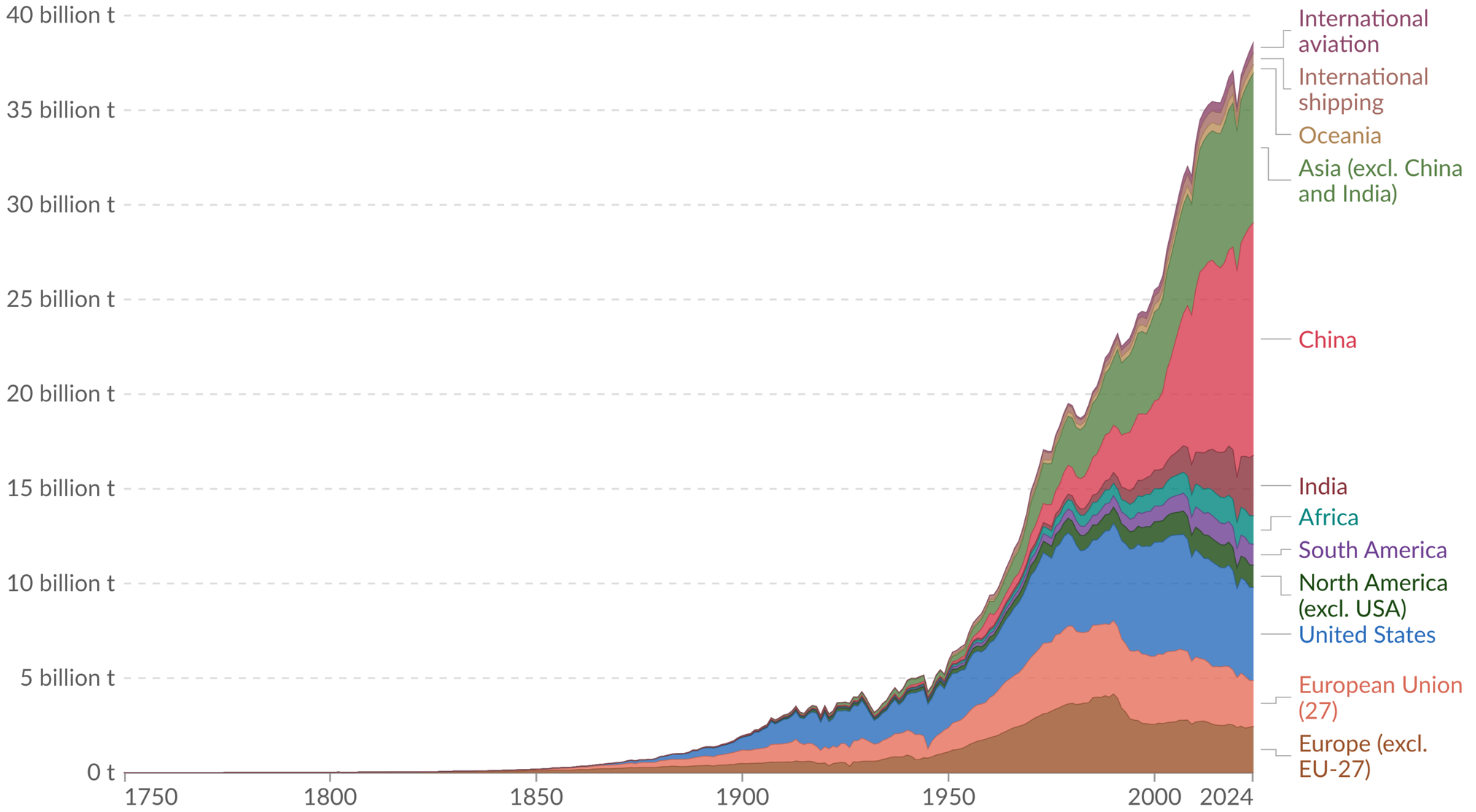


https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-7/

Annual CO_2 emissions by world region

Our World in Data

Emissions from fossil fuels and industry[1] are included, but not land-use change emissions[2]. International aviation and shipping are included as separate entities, as they are not included in any country's emissions.



Data source: Global Carbon Budget (2025)

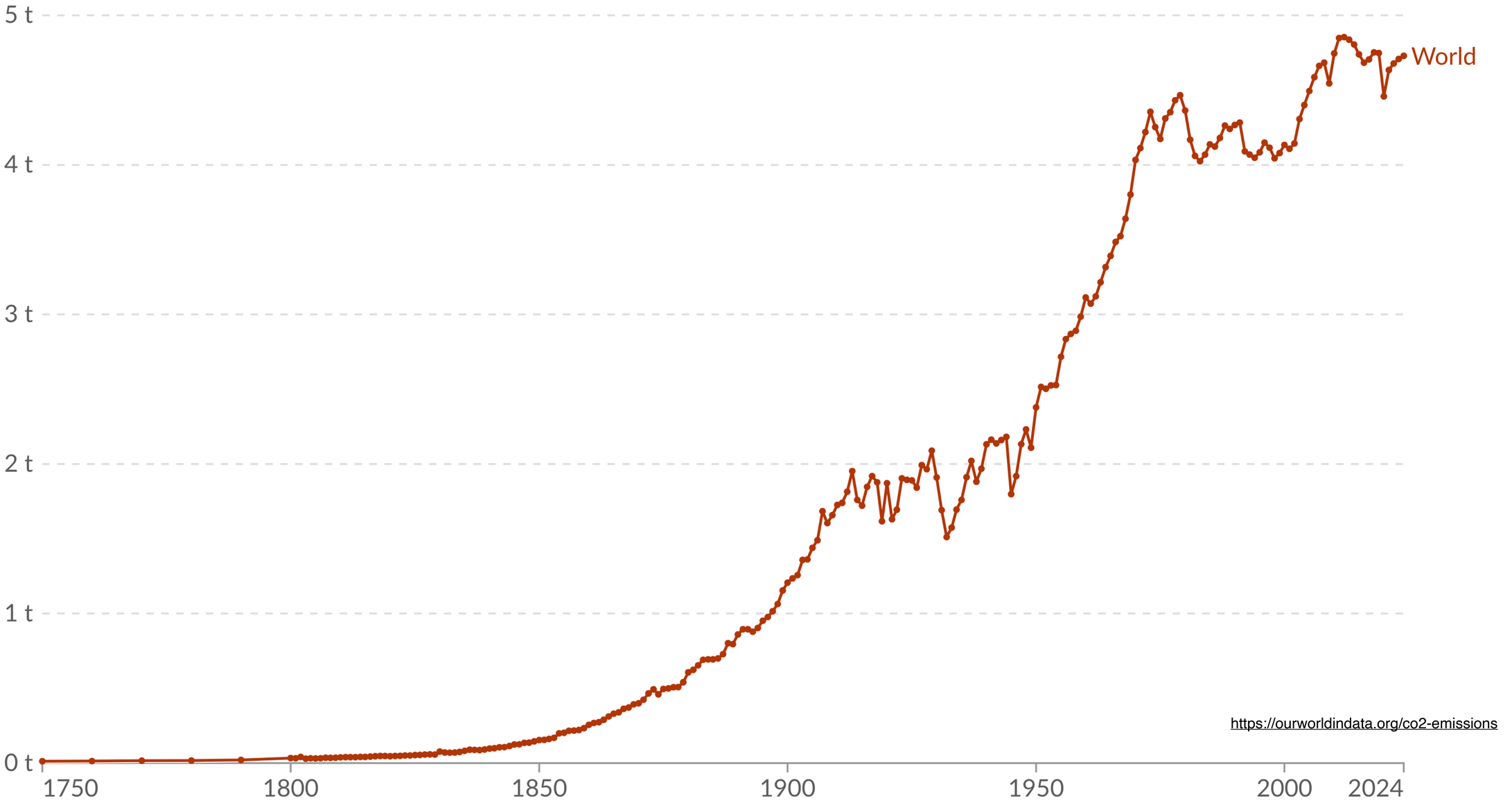
https://ourworldindata.org/co2-emissions

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

Our World in Data

CO_2 emissions per capita

Carbon dioxide (CO_2) emissions from burning fossil fuels and industrial processes[1]. This includes emissions from transport, electricity generation, and heating, but not land-use change[2].

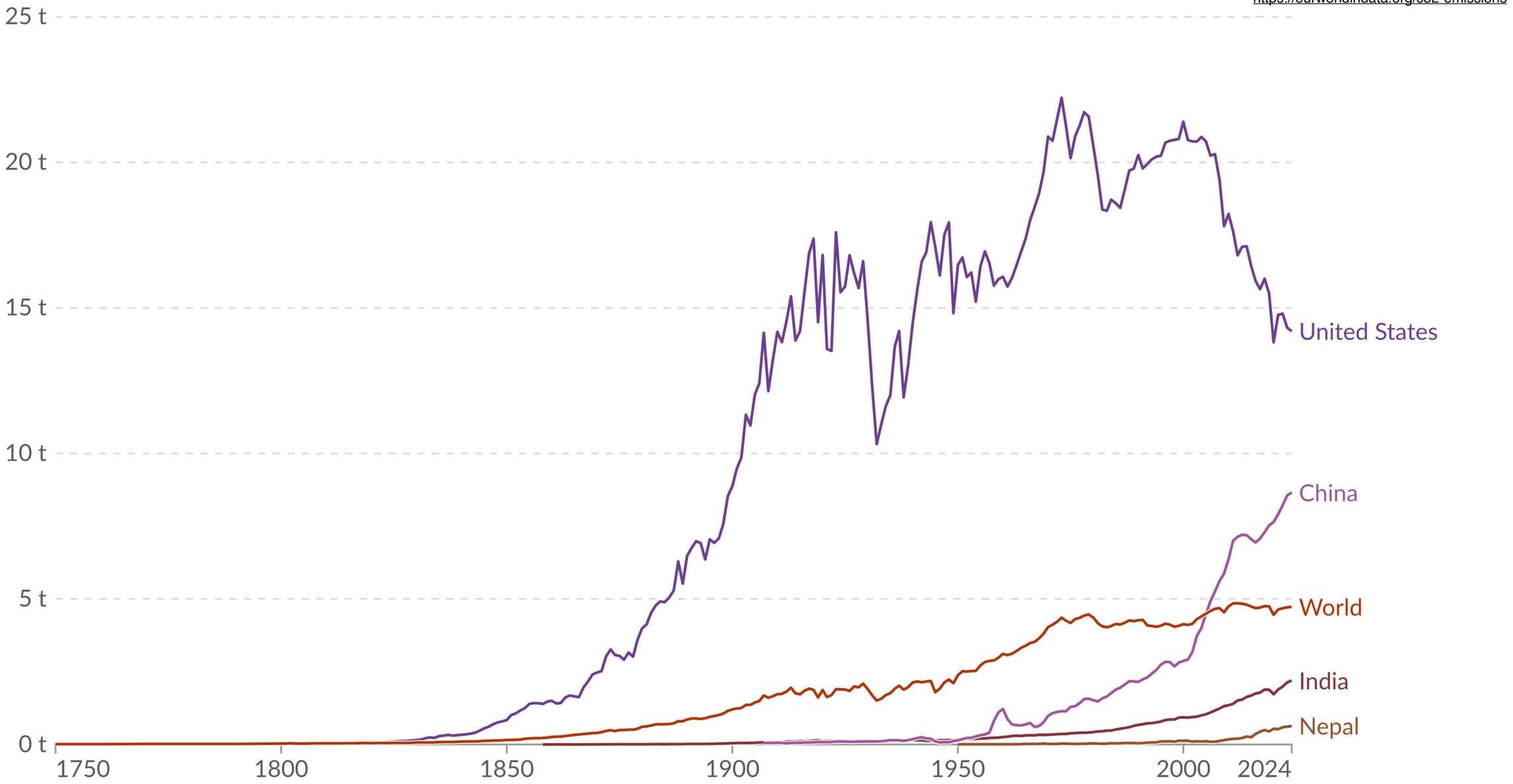


CO_2 emissions per capita

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Our World in Data

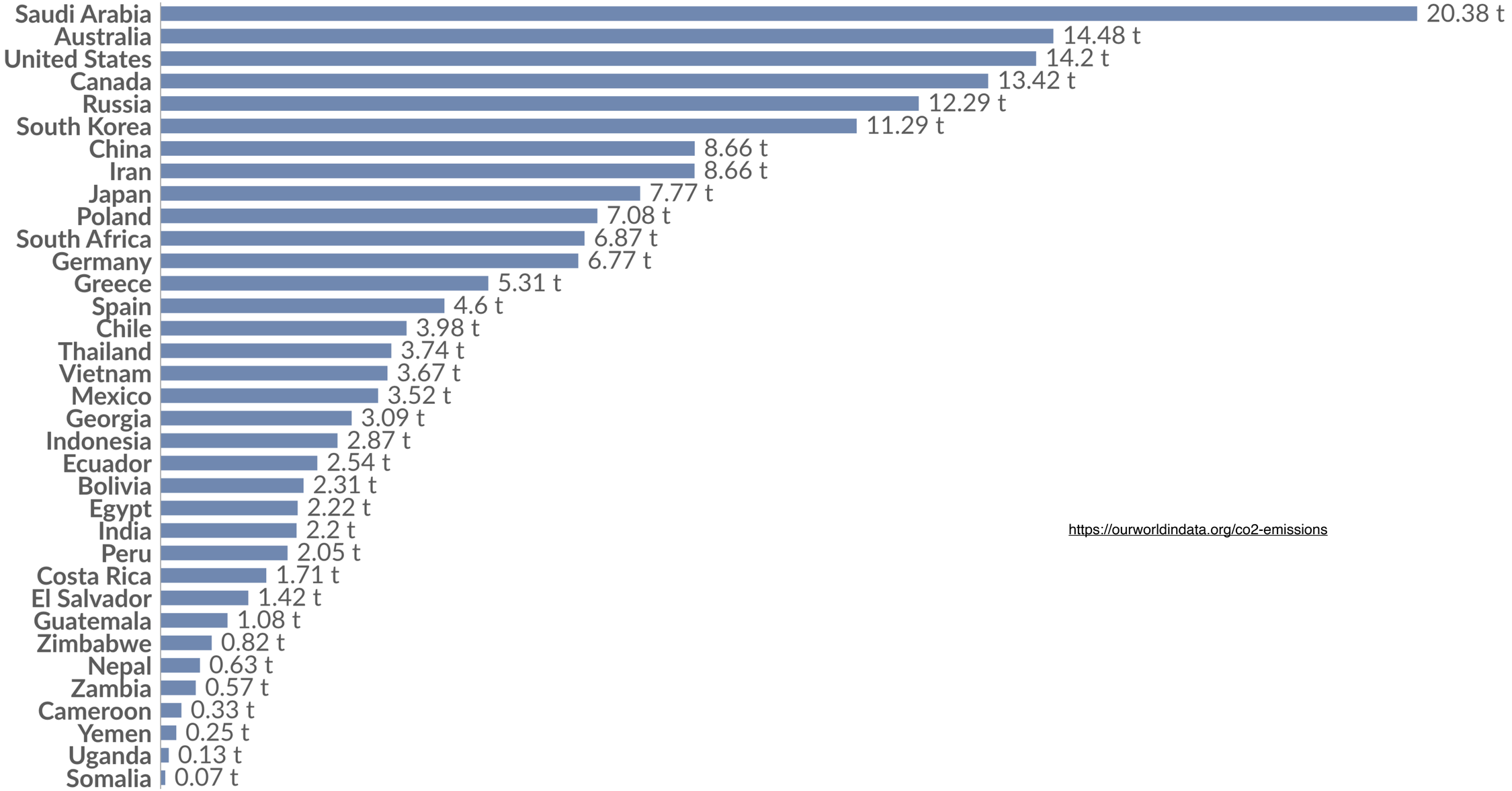
https://ourworldindata.org/co2-emissions



CO_2 emissions per capita, 2024

Our World in Data

Carbon dioxide (CO_2) emissions from burning fossil fuels and industrial processes[1]. This includes emissions from transport, electricity generation, and heating, but not land-use change[2].

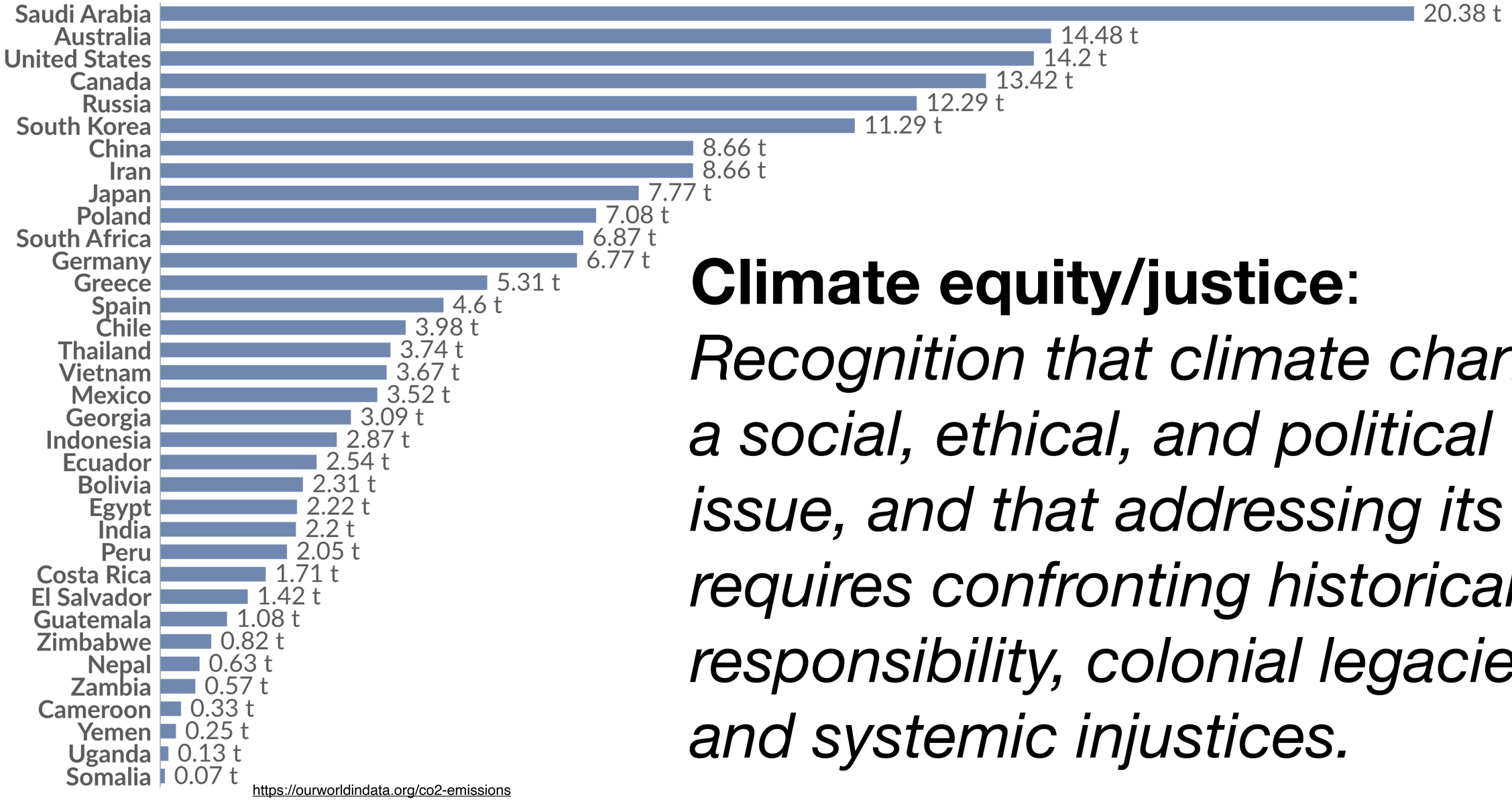


https://ourworldindata.org/co2-emissions

CO_2 emissions per capita, 2024

Our World in Data

Carbon dioxide (CO_2) emissions from burning fossil fuels and industrial processes[1]. This includes emissions from transport, electricity generation, and heating, but not land-use change[2].



https://ourworldindata.org/co2-emissions

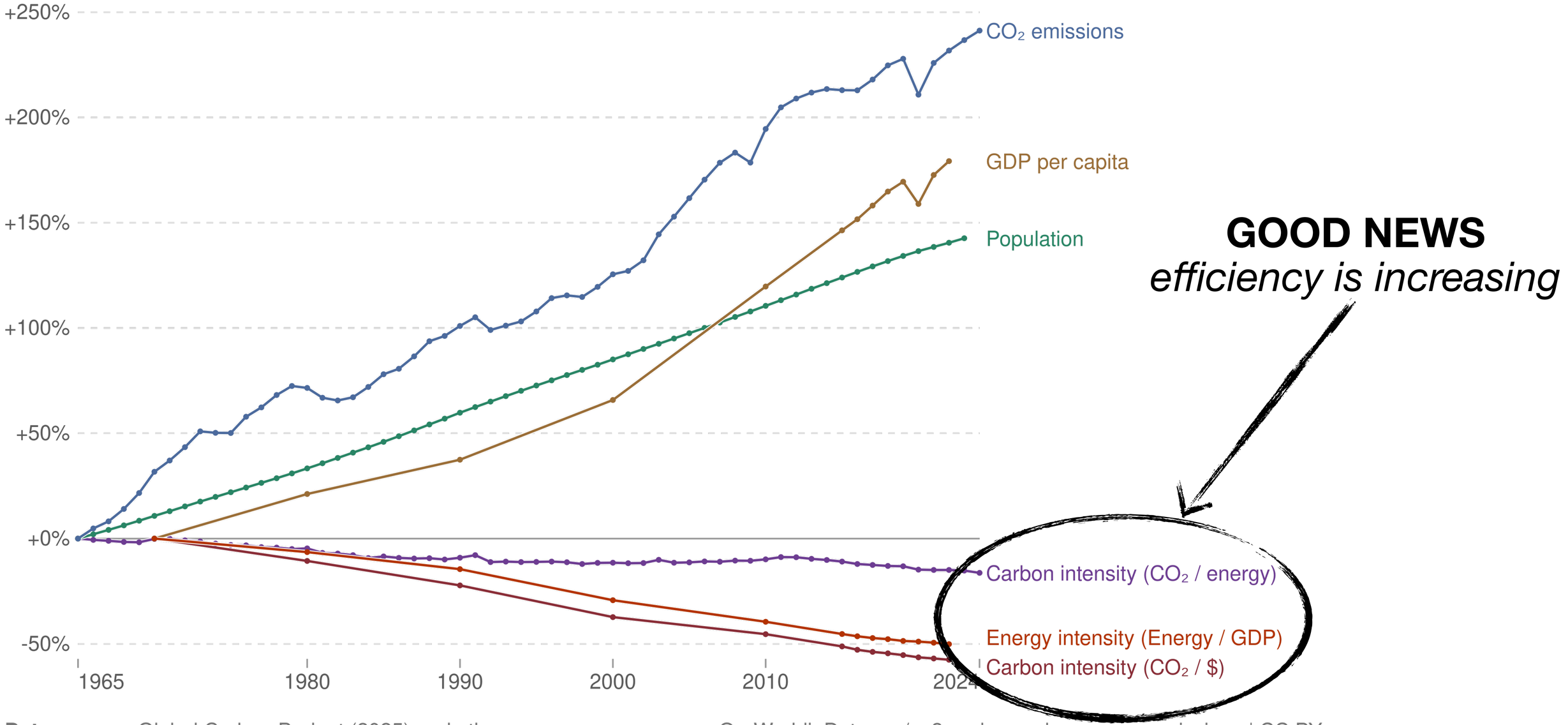
Climate equity/justice:

Recognition that climate change is a social, ethical, and political issue, and that addressing its root requires confronting historical responsibility, colonial legacies, and systemic injustices.

Kaya identity: drivers of CO_2 emissions, World

Our World in Data

Percentage change in the four parameters of the Kaya Identity, which determine total CO_2 emissions. Emissions from fossil fuels and industry are included. Land-use change emissions are not included.



Data source: Global Carbon Budget (2025) and other sources

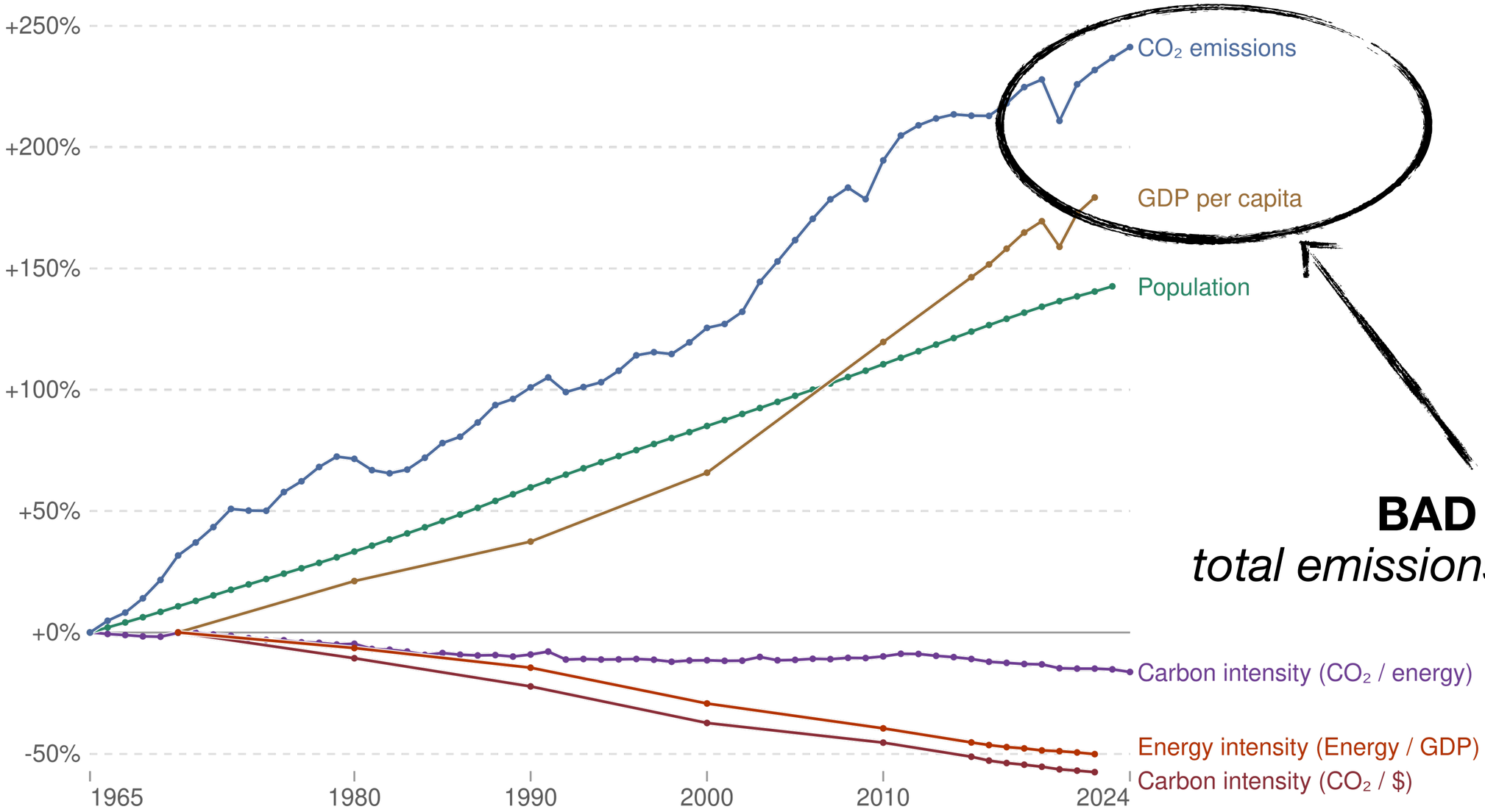
OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

Note: GDP per capita is measured in 2011 international-$ (PPP). This adjusts for inflation and cross-country price differences.

Kaya identity: drivers of CO_2 emissions, World

Our World in Data

Percentage change in the four parameters of the Kaya Identity, which determine total CO_2 emissions. Emissions from fossil fuels and industry are included. Land-use change emissions are not included.



BAD NEWS

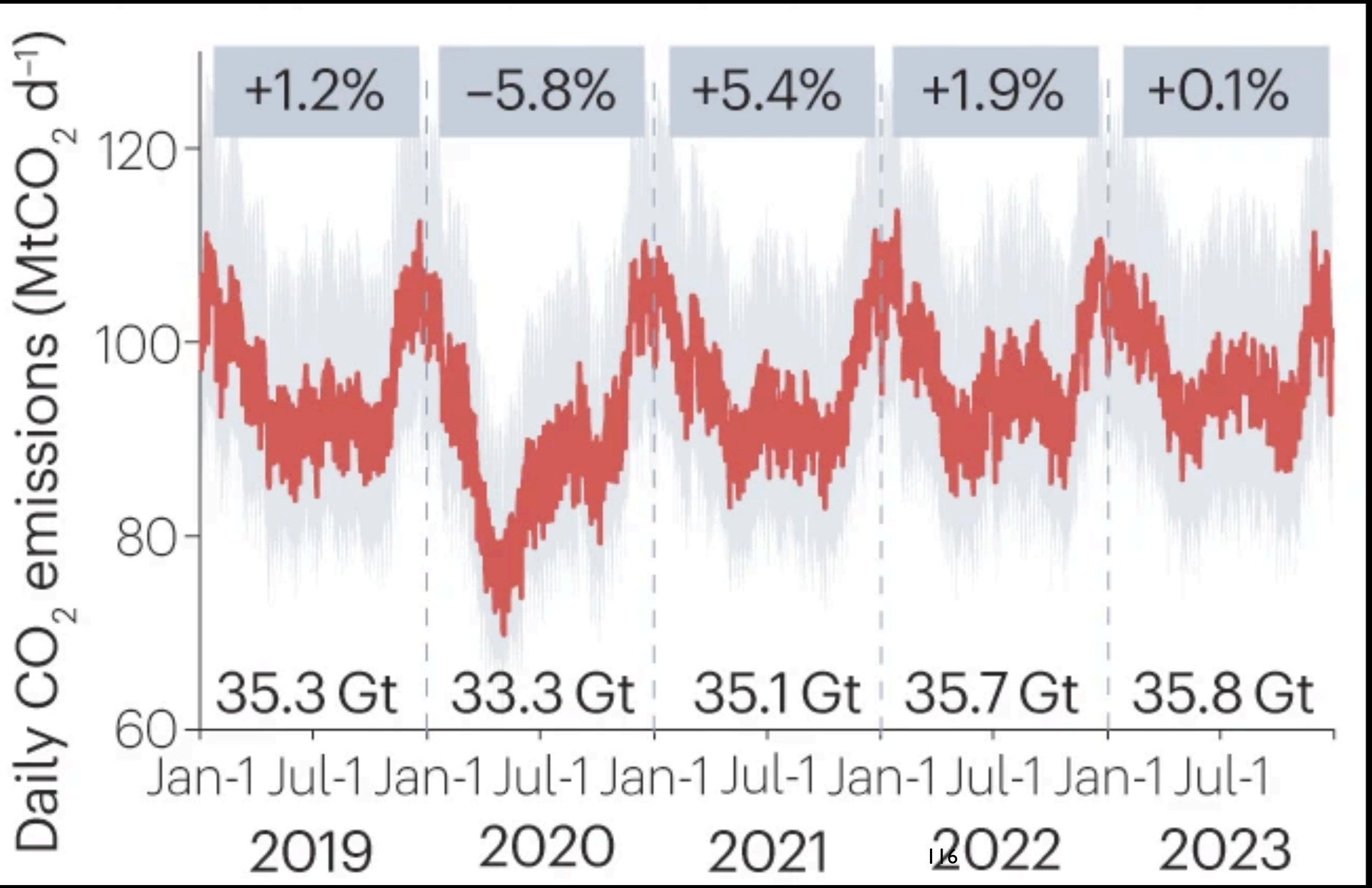
total emissions still increasing

Data source: Global Carbon Budget (2025) and other sources

OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

Note: GDP per capita is measured in 2011 international-$ (PPP). This adjusts for inflation and cross-country price differences.

The Scale of the Challenge



COVID

Only **5.8%** year on year decline in emissions

https://www.nature.com/articles/s43017-024-00532-2#Sec3

The Paris Agreement (COP 21, Dec 2015)

"The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century ***well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.****"*

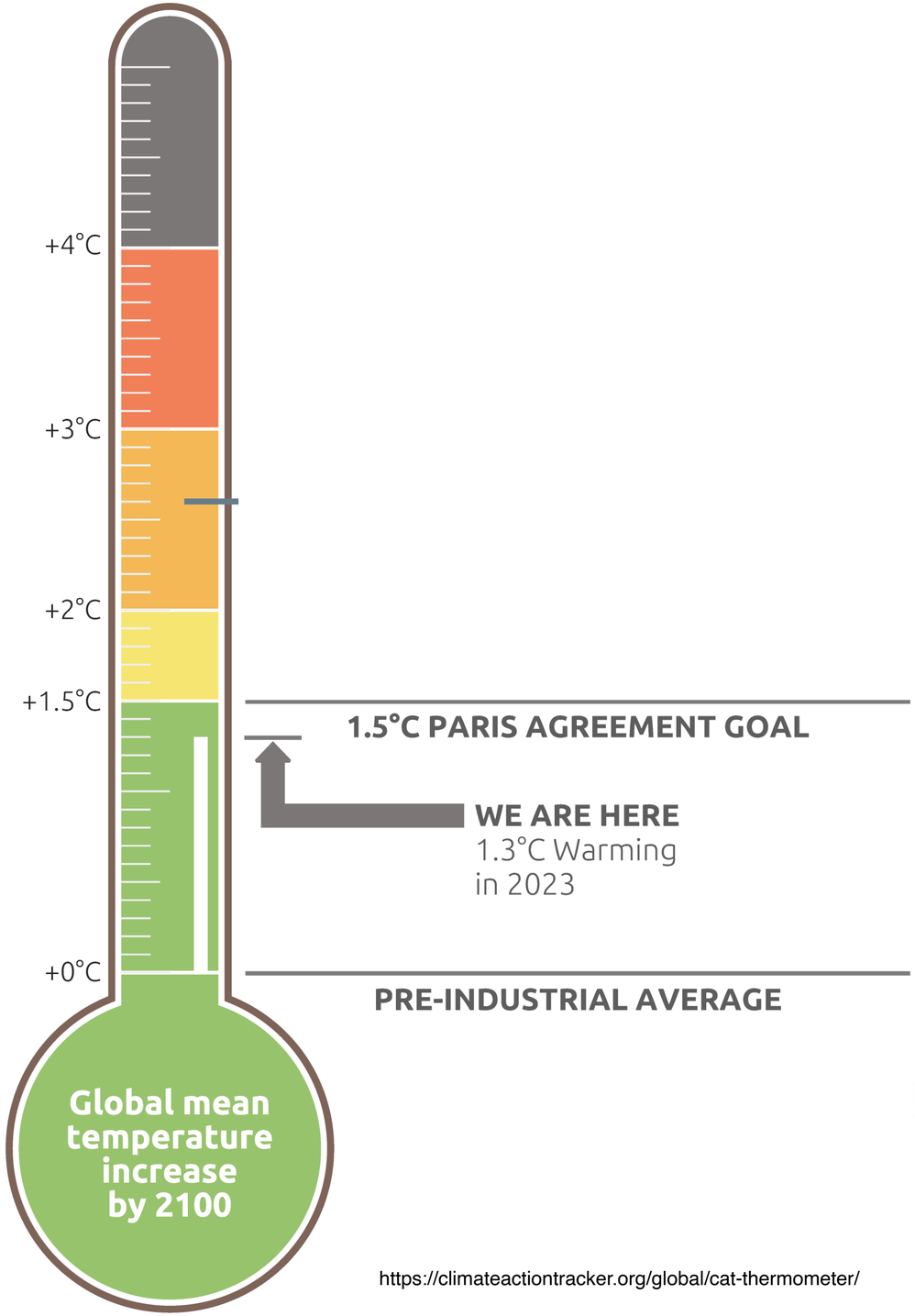
2º limit comes from Yale Economist William Nordhaus in his 1975 paper: "Can We Control Carbon Dioxide?"

Based on idea that it would be reasonable to try to keep climate change within limits of "normal variation"

Nordhaus stressed that his thought process was "deeply unsatisfactory"

http://unfccc.int/paris_agreement/items/9485.php

http://theconversation.com/why-is-climate-changes-2-degrees-celsius-of-warming-limit-so-important-82058



CAT warming projections

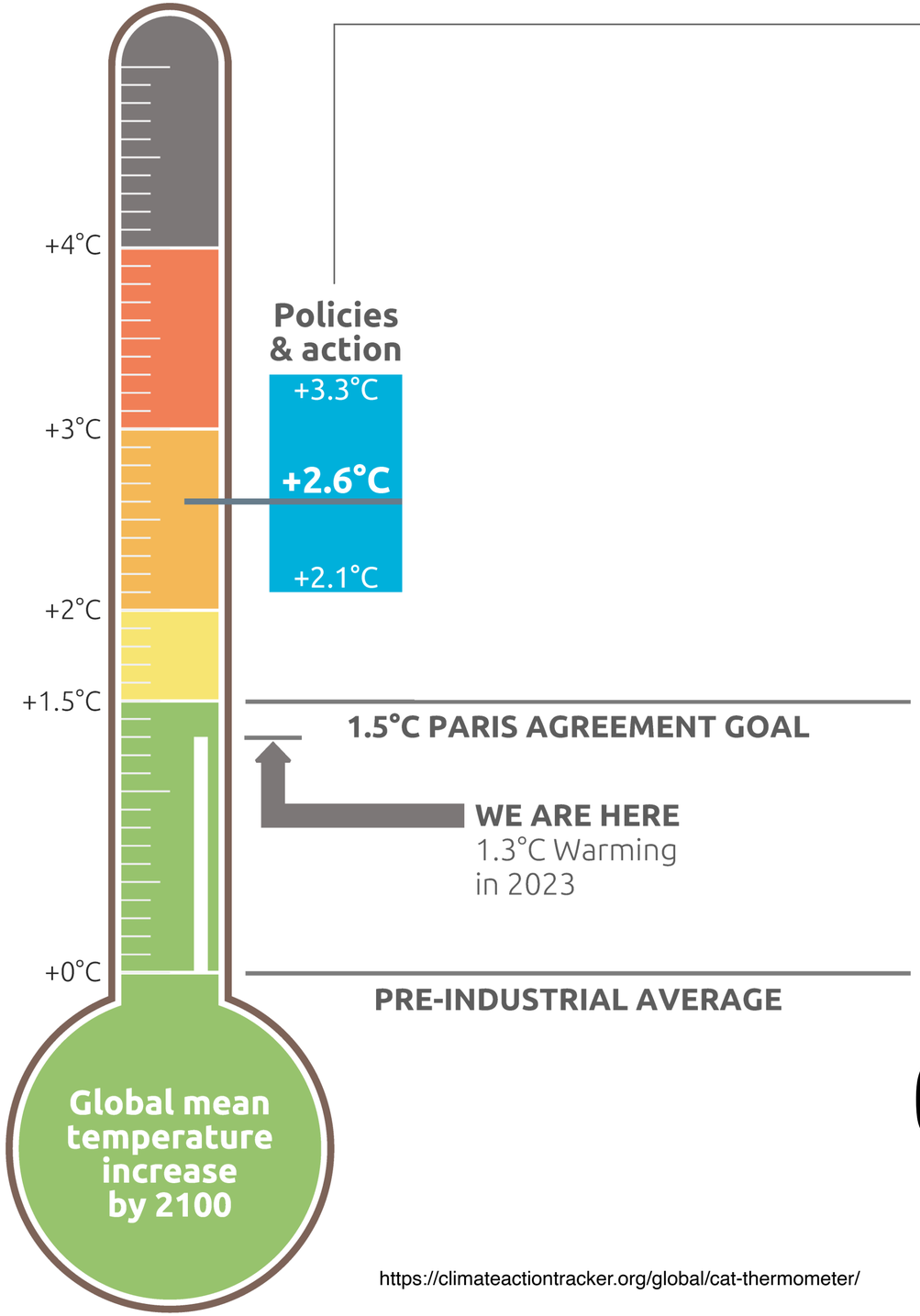
Global temperature increase by 2100

November 2025 Update

Climate Outcomes for Current and Committed Scenarios

https://climateactiontracker.org/global/cat-thermometer/

Policies & action
Real world action based on current policies †

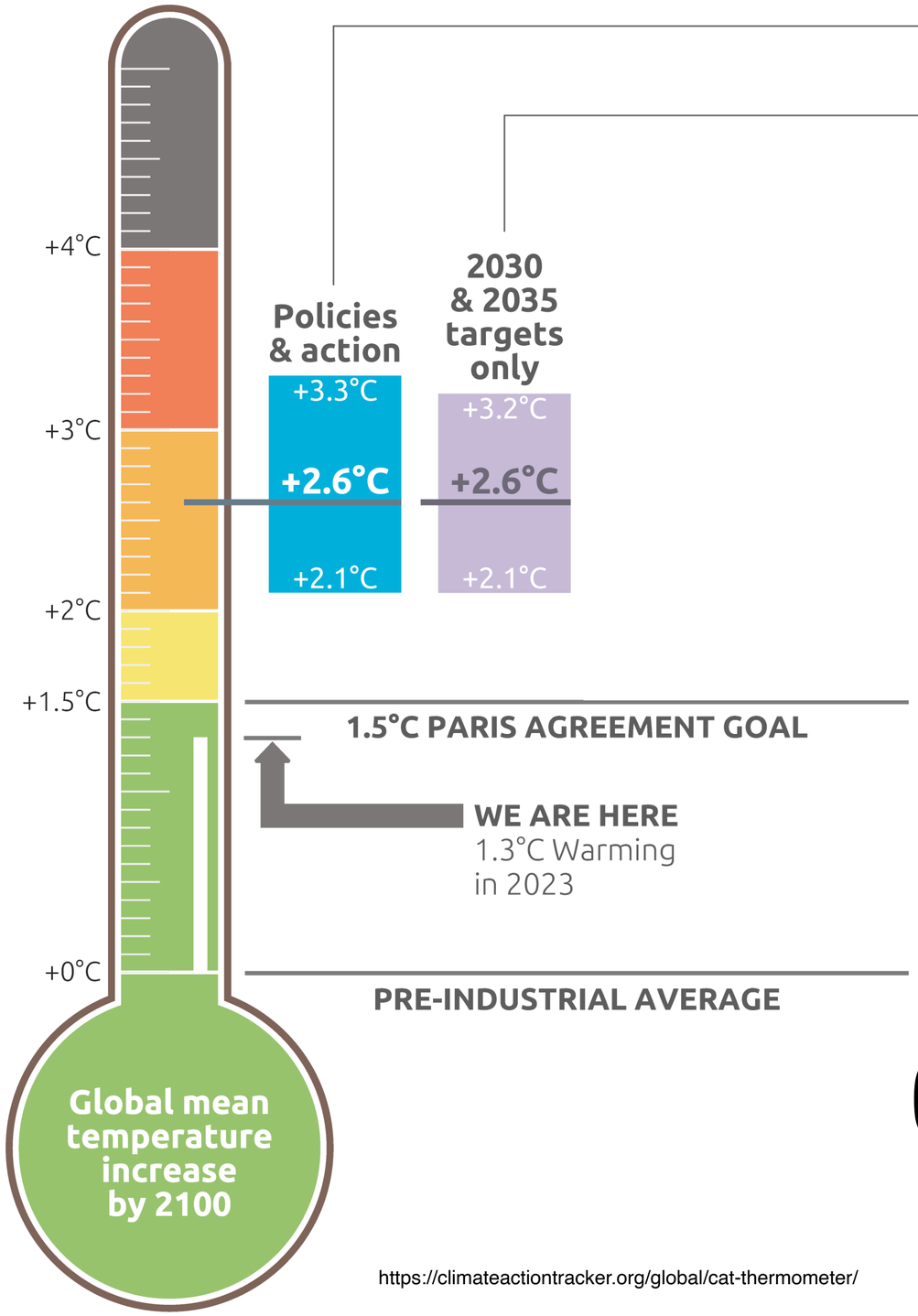


CAT warming projections
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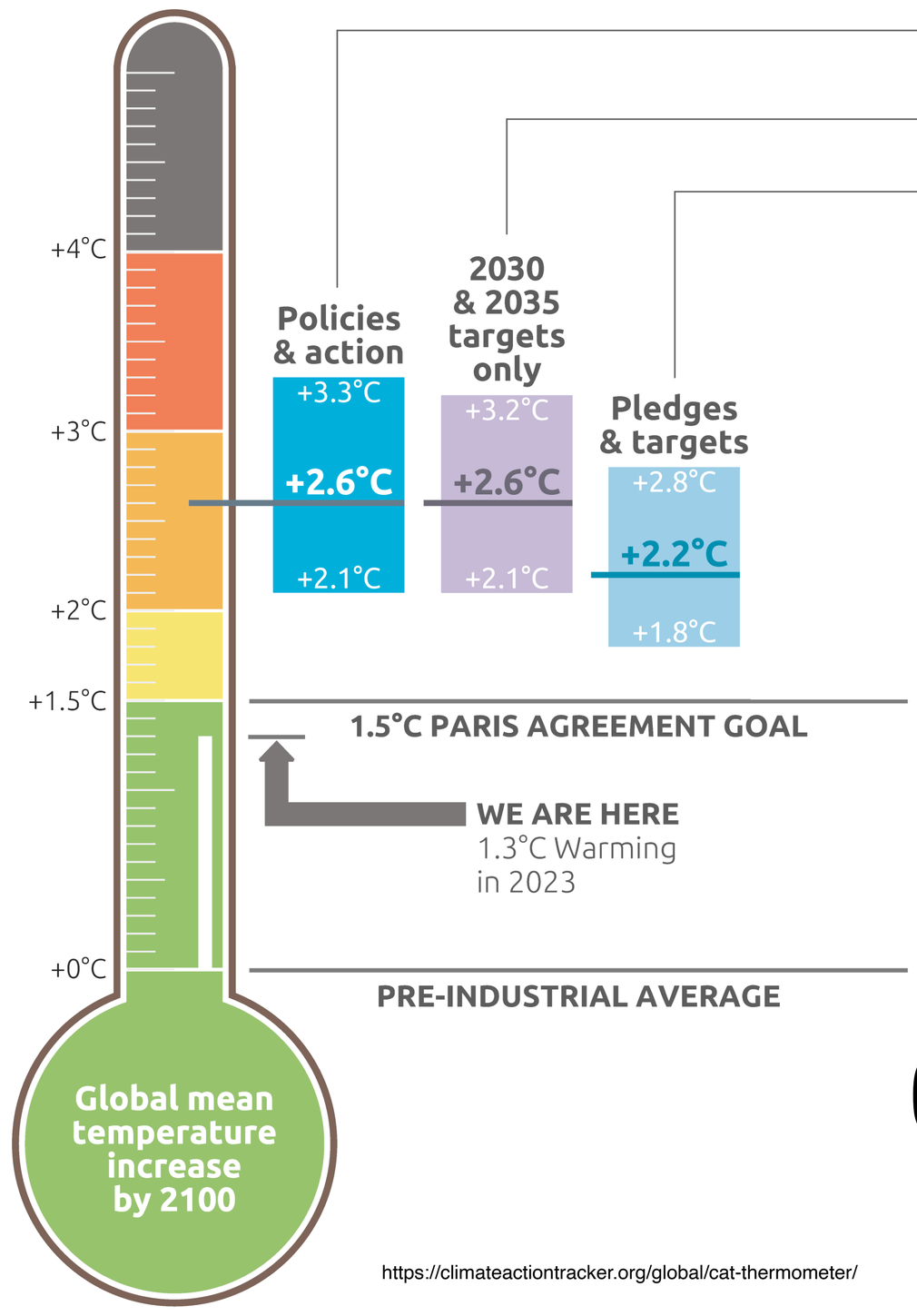
CAT warming projections

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https://climateactiontracker.org/global/cat-thermometer/



Policies & action
Real world action based on current policies †

2030 & 2035 targets only
Based on submitted NDC targets* †

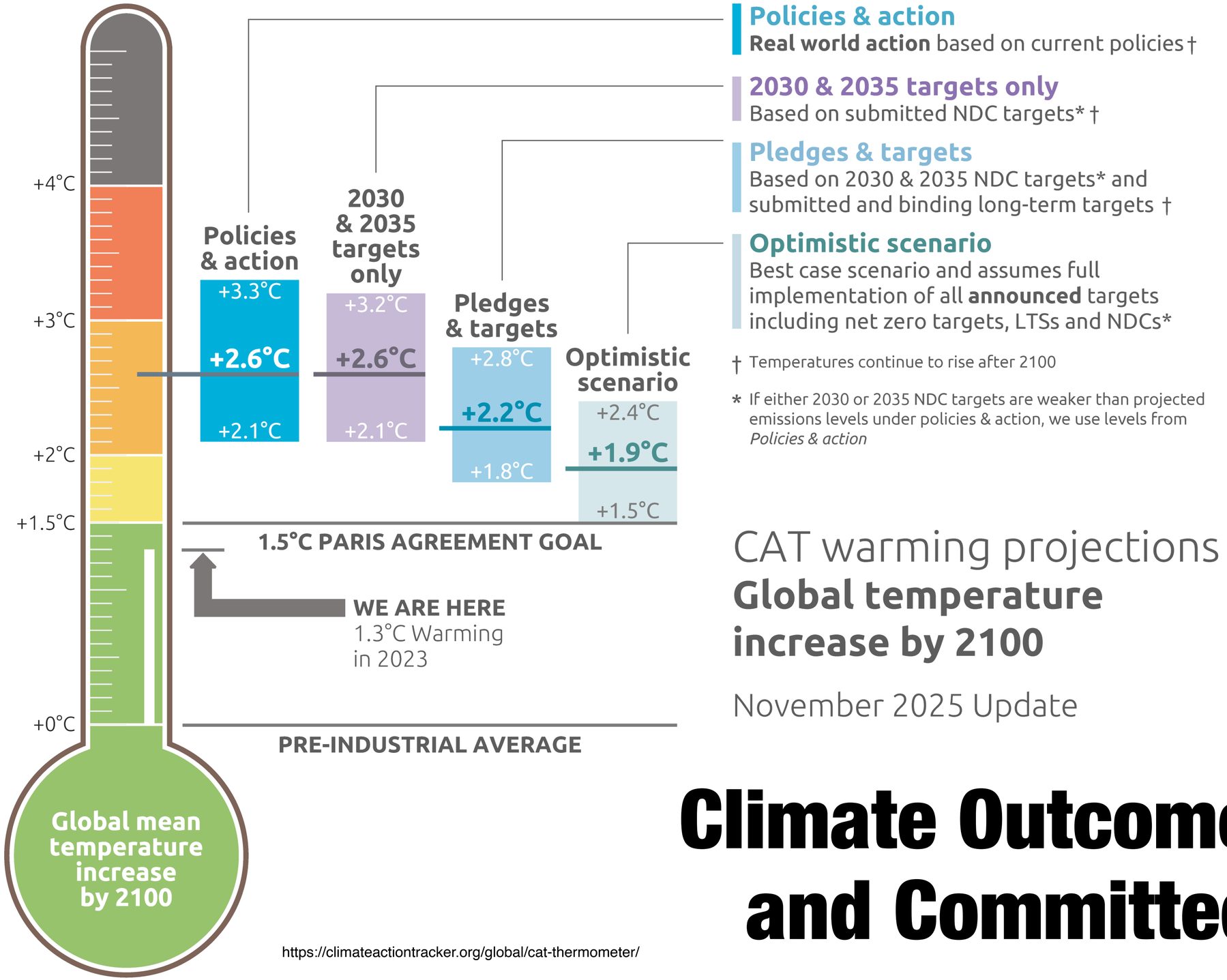
Pledges & targets
Based on 2030 & 2035 NDC targets* and submitted and binding long-term targets †

CAT warming projections
Global temperature increase by 2100

November 2025 Update

Climate Outcomes for Current and Committed Scenarios

https://climateactiontracker.org/global/cat-thermometer/



Policies & action
Real world action based on current policies †

2030 & 2035 targets only
Based on submitted NDC targets* †

Pledges & targets
Based on 2030 & 2035 NDC targets* and submitted and binding long-term targets †

Optimistic scenario
Best case scenario and assumes full implementation of all **announced** targets including net zero targets, LTSs and NDCs*

† Temperatures continue to rise after 2100

* If either 2030 or 2035 NDC targets are weaker than projected emissions levels under policies & action, we use levels from *Policies & action*

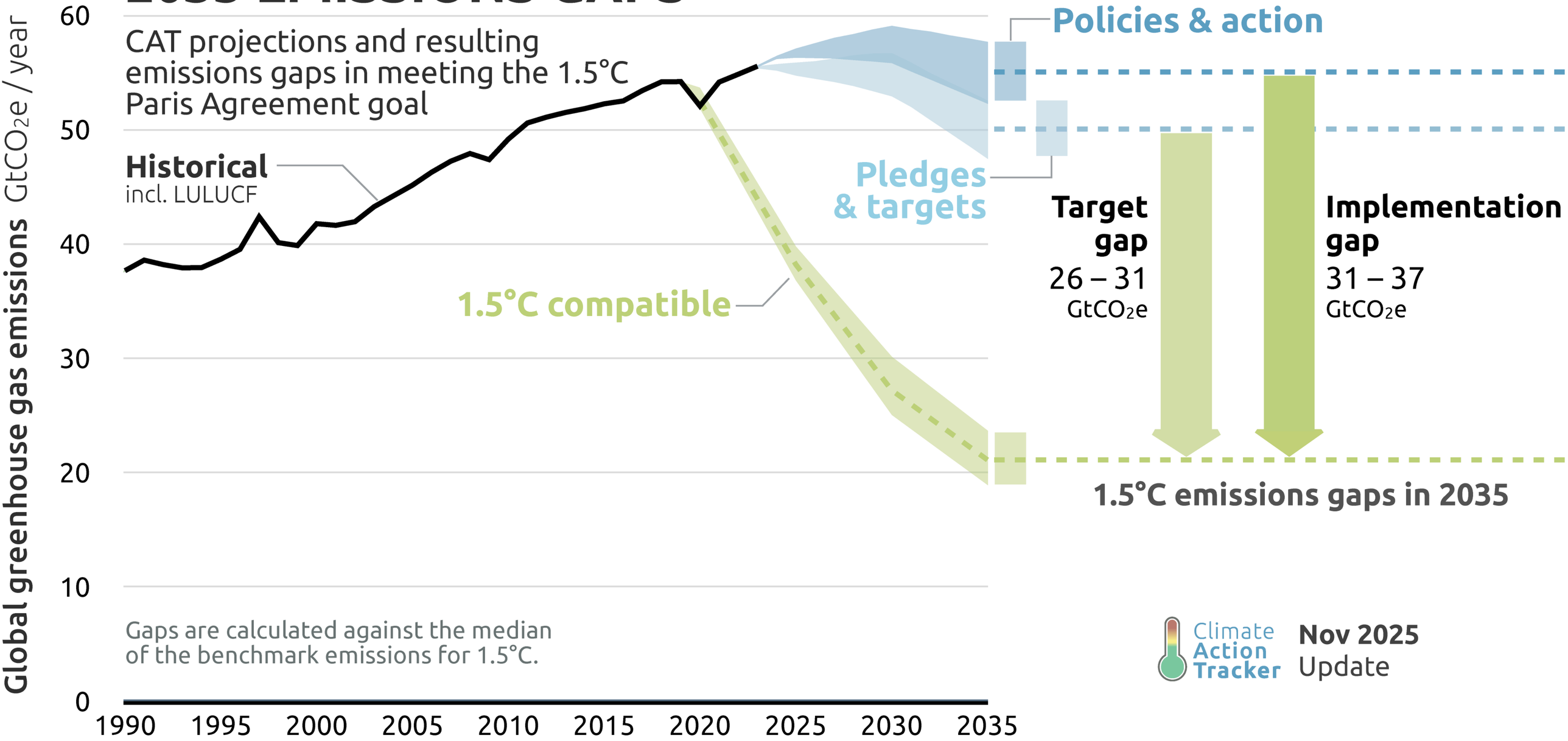
CAT warming projections
Global temperature increase by 2100

November 2025 Update

Climate Outcomes for Current and Committed Scenarios

https://climateactiontracker.org/global/cat-thermometer/

2035 EMISSIONS GAPS

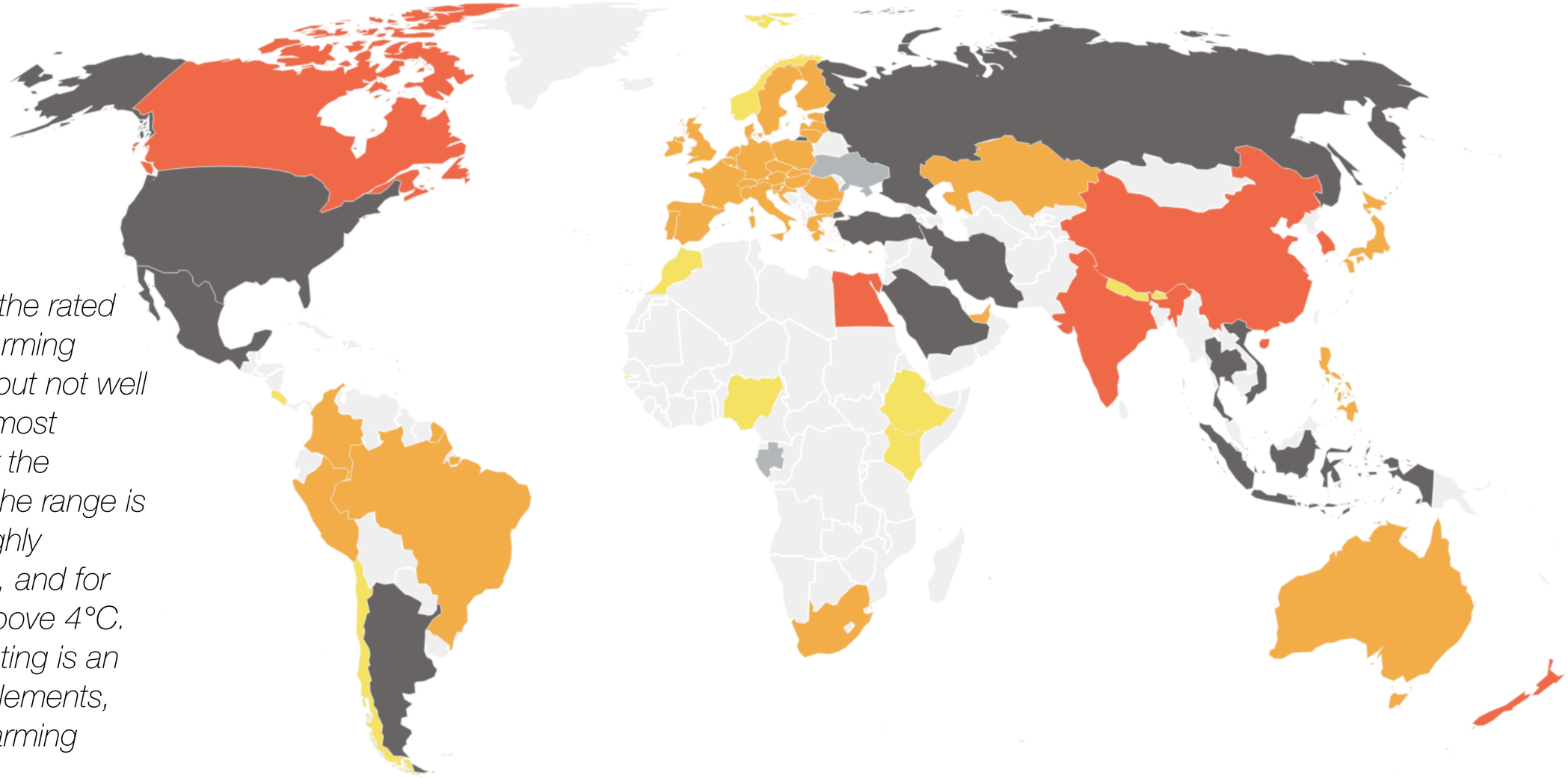


Climate Action Tracker **Nov 2025** Update

https://climateactiontracker.org/global/cat-emissions-gaps/

Countries: Proposed Contributions

If all countries followed the rated country's approach, warming could be held below—but not well below—2°C for the "Almost sufficient" category. For the "Insufficient" category, the range is 2°C to 3°C, for the "Highly Insufficient" 3°C to 4°C, and for "Critically insufficient" above 4°C. Given that the overall rating is an aggregate of different elements, we do not provide a warming range for it.



CRITICALLY INSUFFICIENT | HIGHLY INSUFFICIENT | INSUFFICIENT | ALMOST SUFFICIENT | 1.5°C PARIS AGREEMENT COMPATIBLE

http://climateactiontracker.org/countries.html

CLIMATE ADAPTATION

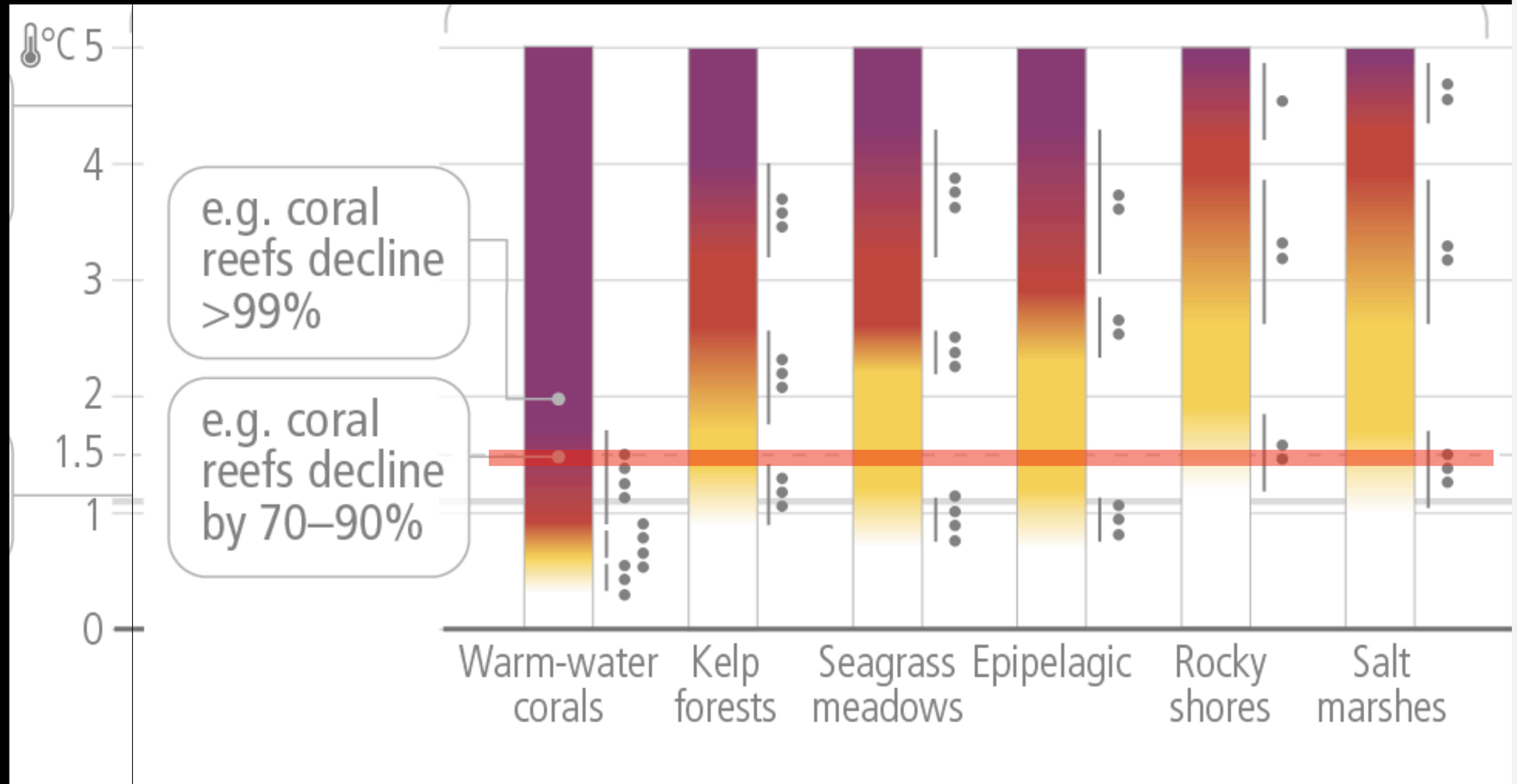
CLIMATE ADAPTATION

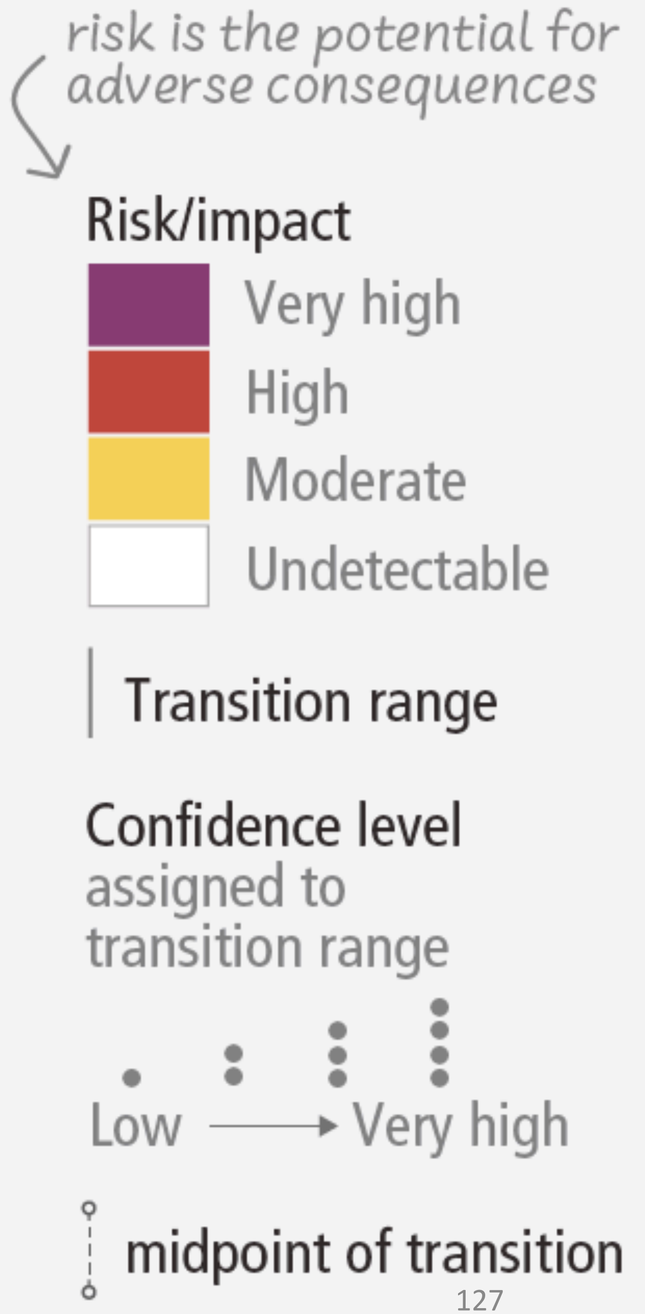
Robustness: Withstanding a range of outcomes with no/minimal impact

Resilience: Recovering quickly after impact

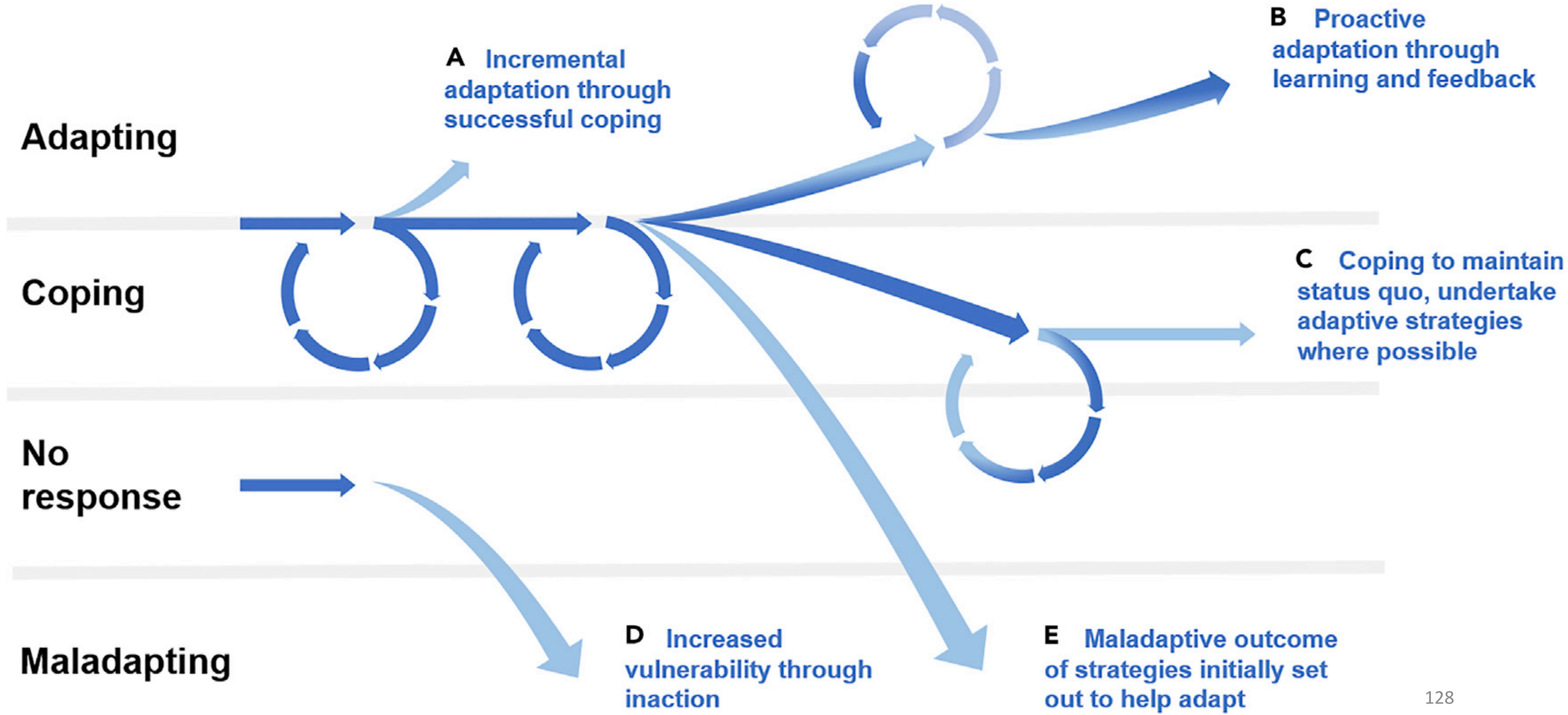
ANY warming avoided is warming we don't have to adapt to

(even if we don't meet Paris Goals)

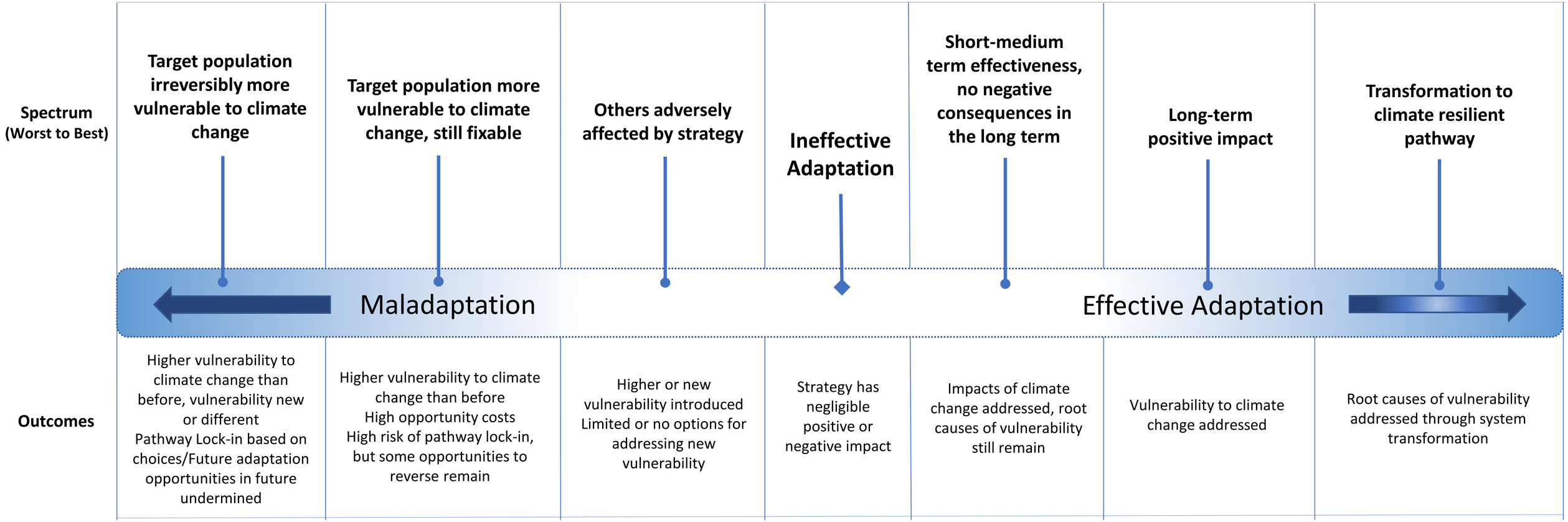




ADAPTATION

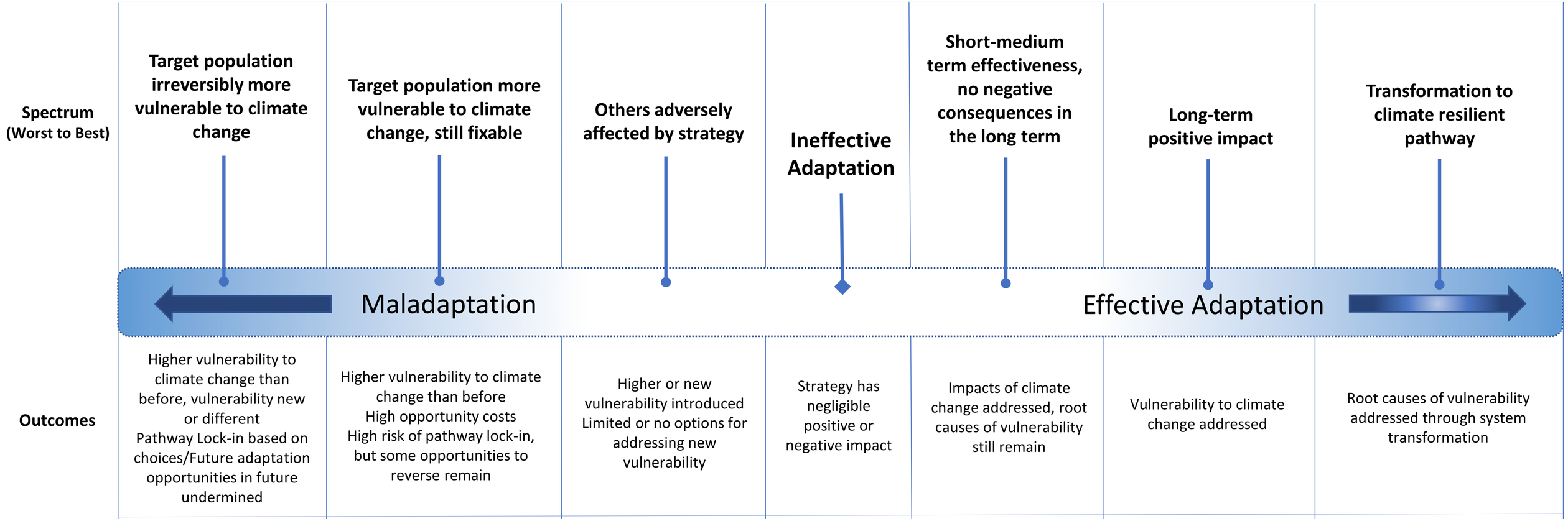


https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2



Continuum of possible outcomes from (mal)adaptation strategies

https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2



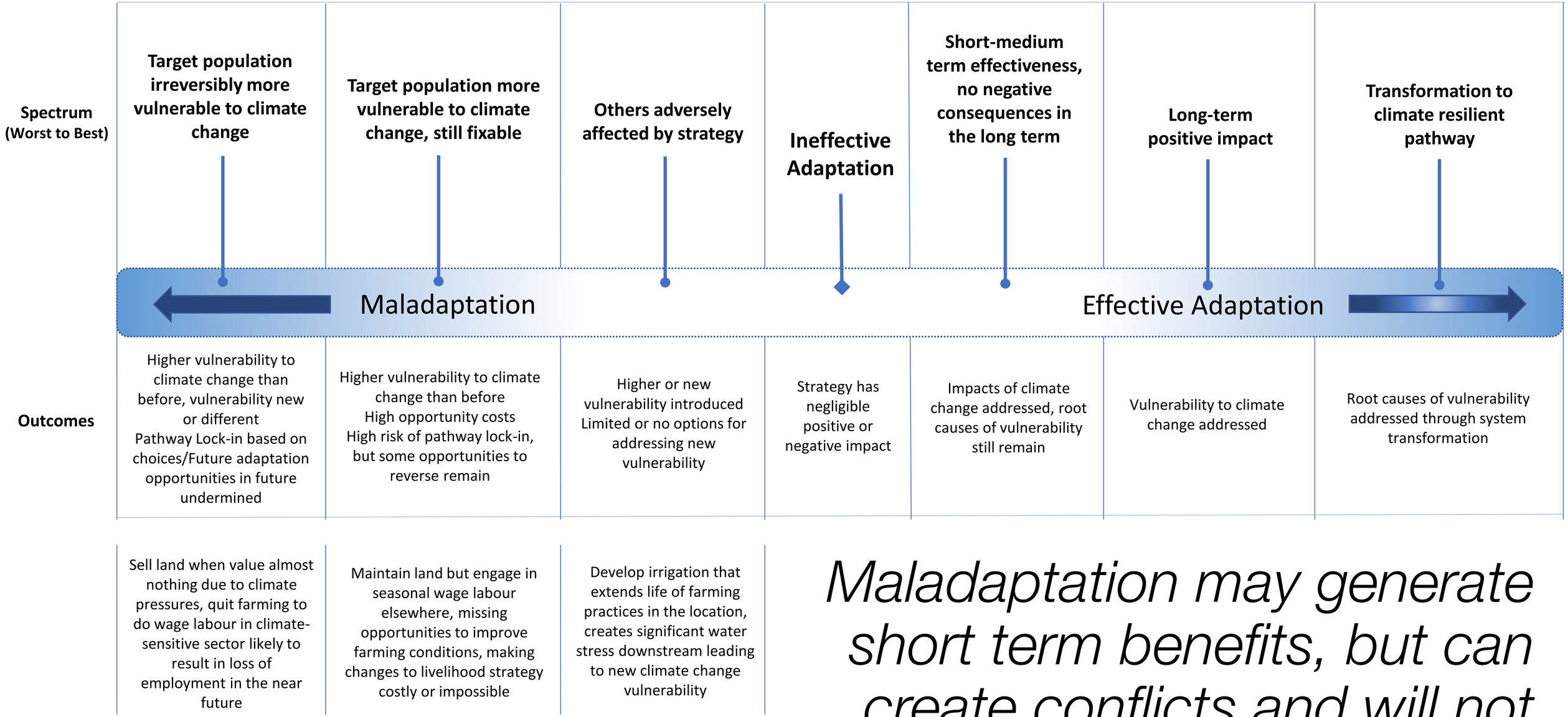
*Effective adaptation increases short and long-term **resilience**; generates **co-benefits**, and requires **cooperation***

Small-scale irrigation is developed for farmers, but climate change continues to pose challenge for agriculture

Mediation groups with upstream/downstream users are established to help create sustainable quotas for water use, making everyone happy, building social capital

Few or no real-world examples exist – this is an ideal outcome

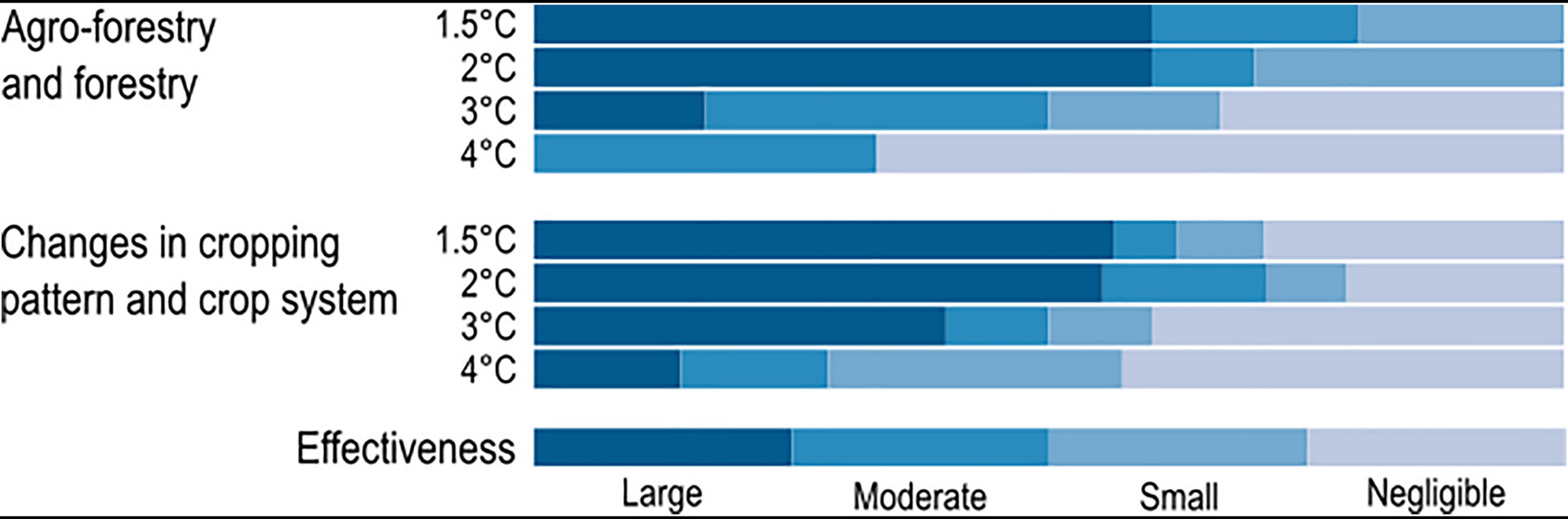
https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2



Maladaptation may generate short term benefits, but can create conflicts and will not lead to long-term sustainability

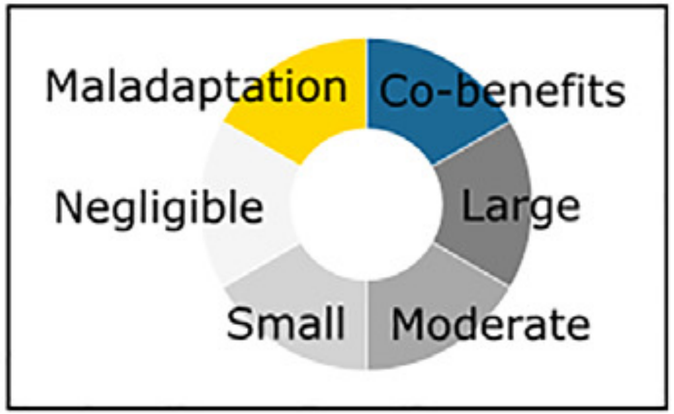
https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2

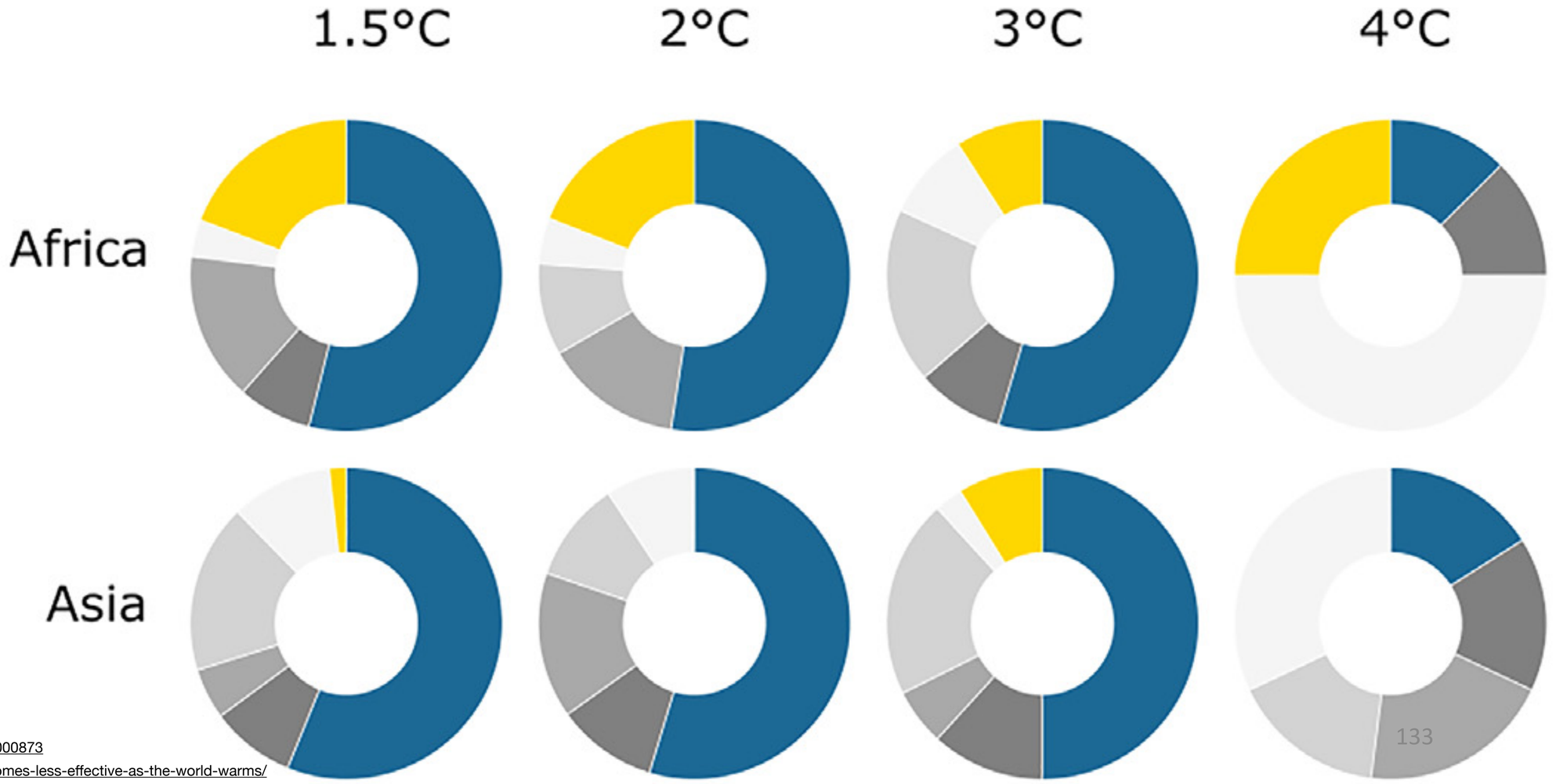
ALSO, adaptation easier and more effective a lower warming levels



https://www.sciencedirect.com/science/article/pii/S2590332224000873
https://www.carbonbrief.org/guest-post-climate-adaptation-becomes-less-effective-as-the-world-warms/

Co-benefts, Maladaptation, & Effectiveness





https://www.sciencedirect.com/science/article/pii/S2590332224000873
https://www.carbonbrief.org/guest-post-climate-adaptation-becomes-less-effective-as-the-world-warms/

Cobenefits & Tradeoffs to Climate Action

Biodiversity measures (& corresponding sections in the main text)	Climate change mitigation
Avoiding deforestation (2.1)	+
Avoiding degradation of permafrost areas (2.1)	+
Reforestation, avoiding forests degradation (2.1)	+
Coastal restoration (2.1)	+
Restoring degraded semi-arid ecosystems (2.1)	?
Restoring inland wetlands (2.1)	?

Contribution to climate change mitigation

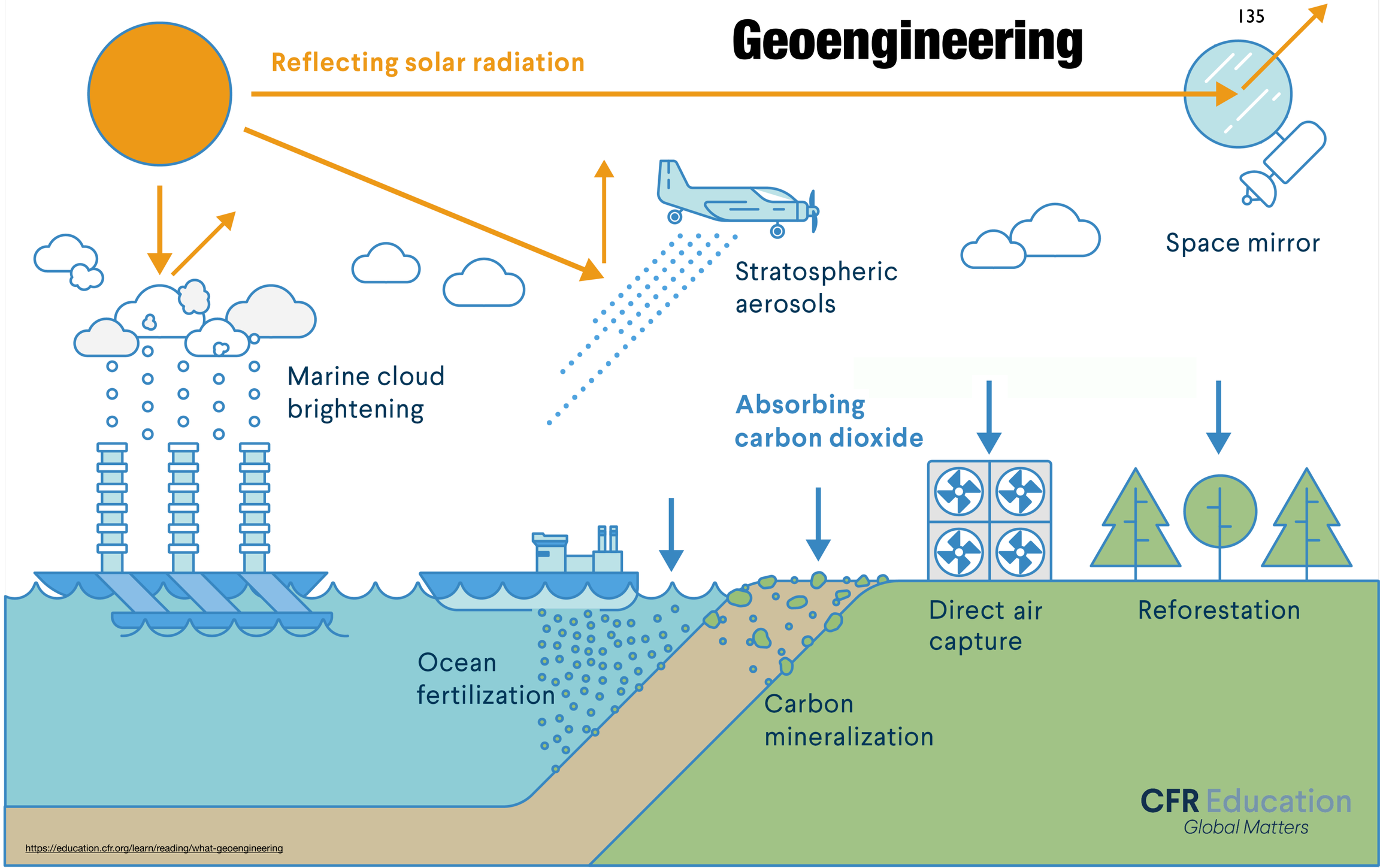
- Significantly positive, strong scientific evidence
- Potentially positive, incomplete evidence & quantification
- Unresolved, lack of evidence, system-dependent, tradeoffs
- Indirect positive
- Loose or non-existent link
- Negative, strong scientific evidence

Reliability of the mitigation outcome

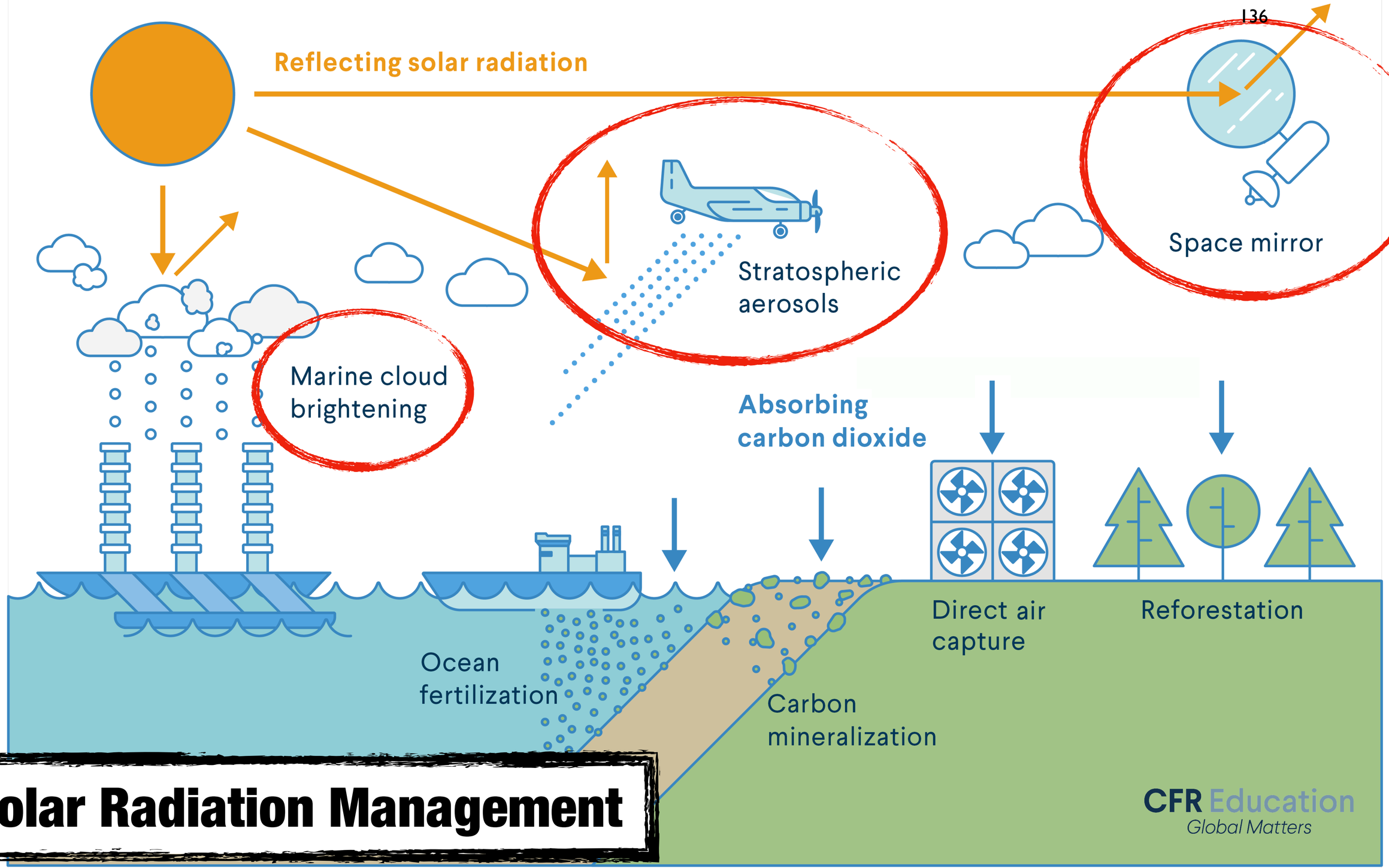
- ++ High
- + Medium
- ? Unresolved, lack of evidence

https://onlinelibrary.wiley.com/doi/pdfdirect/10.1111/gcb.16109

Geoengineering

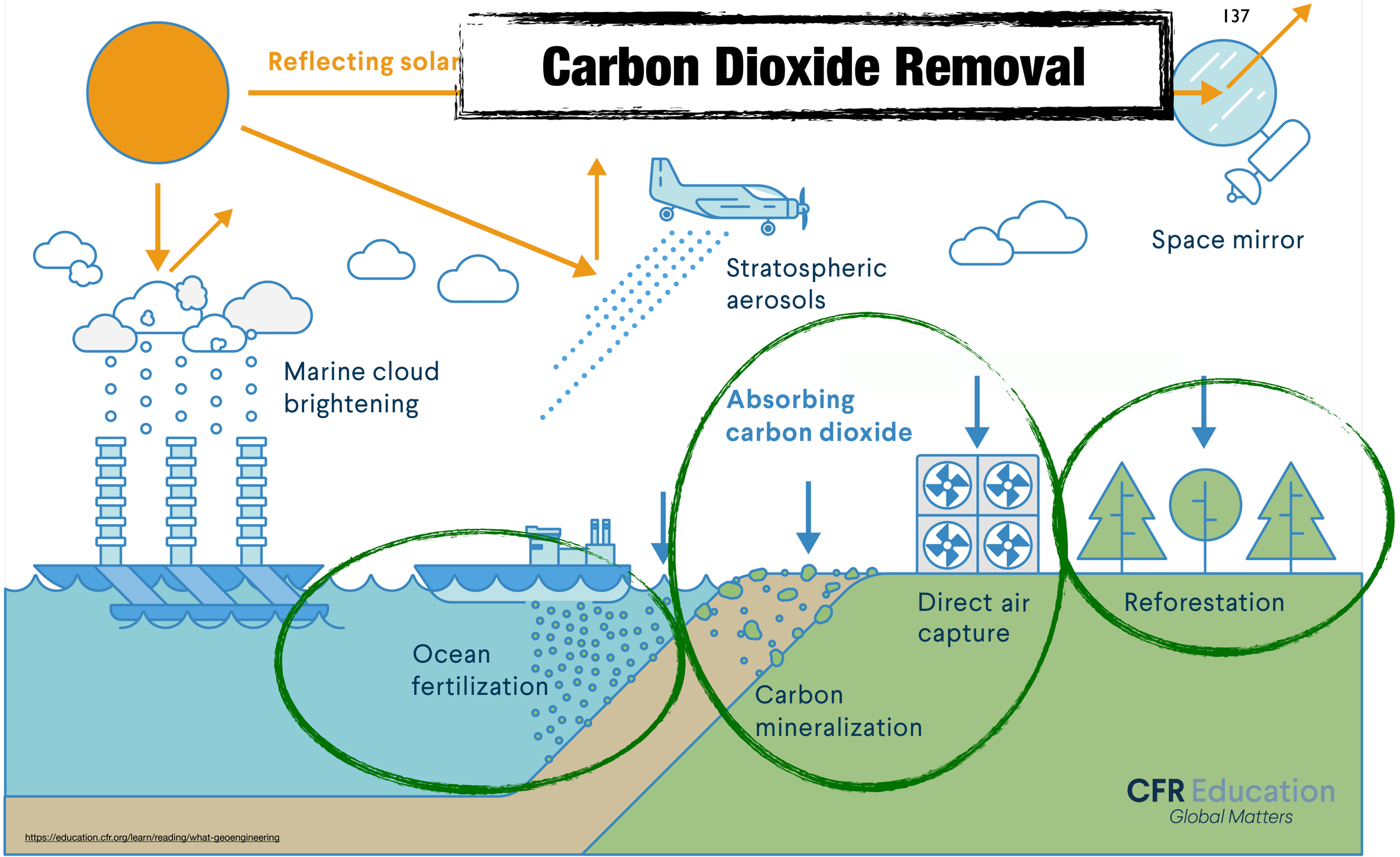


https://education.cfr.org/learn/reading/what-geoengineering



Solar Radiation Management

Carbon Dioxide Removal



https://education.cfr.org/learn/reading/what-geoengineering

Not Theoretical...

Inside Climate News

Pulitzer Prize-winning, nonpartisan r
biggest crisis facing our planet.

Justice & Health

An Indigenous Group's Objection to Geoengineering Spurs a Debate About Social Justice in Climate Science

The Sámi people of Northern Sweden say blocking out the sun with reflective particles to cool the earth is the kind of thinking that produced the climate crisis in the first place.



By Haley Dunleavy
July 7, 2021

PLANET

A Private Company Wants to Block the Sun, Responsibly

Stardust sold geoengineering to investors. Now it needs to sell it to the public.

By Alexander C. Kaufman

Insight: How two weather balloons led Mexico to ban solar geoengineering

By **Cassandra Garrison**

March 27, 2023 4:02 PM EDT · Updated March 27, 2023



Climeworks signs first AI carbon removal deal



By **Molly Burgess**
8 hours ago · 2 min read

Bookmark

Mammoth: our newest facility

Located in Iceland, Mammoth is about ten times bigger than its predecessor plant, Orca.

- Company: ClimeWorks, Location: Iceland
- Powered 100% renewable (geothermal) energy; target peak capacity of **36,000 tons of CO2** per year (actual will be slightly lower)
- Annual Global Human CO2 Emissions: **~38.6 BILLION tons** (2024)
- To nullify these CO2 emissions, we would need **~1,072,222 these plants** operating in equivalent capacity (e.g., powered fully by renewable energy).



https://climeworks.com/news/the-carbon-removal-production-waterfall

Disadvantages of CDR

May be costly to implement at large scales

May take a long time to see climate benefits

May have other, unintended consequences for ecosystems (e.g., ocean fertilization)

Disadvantages of SRM

Must be continuously maintained, which can be expensive

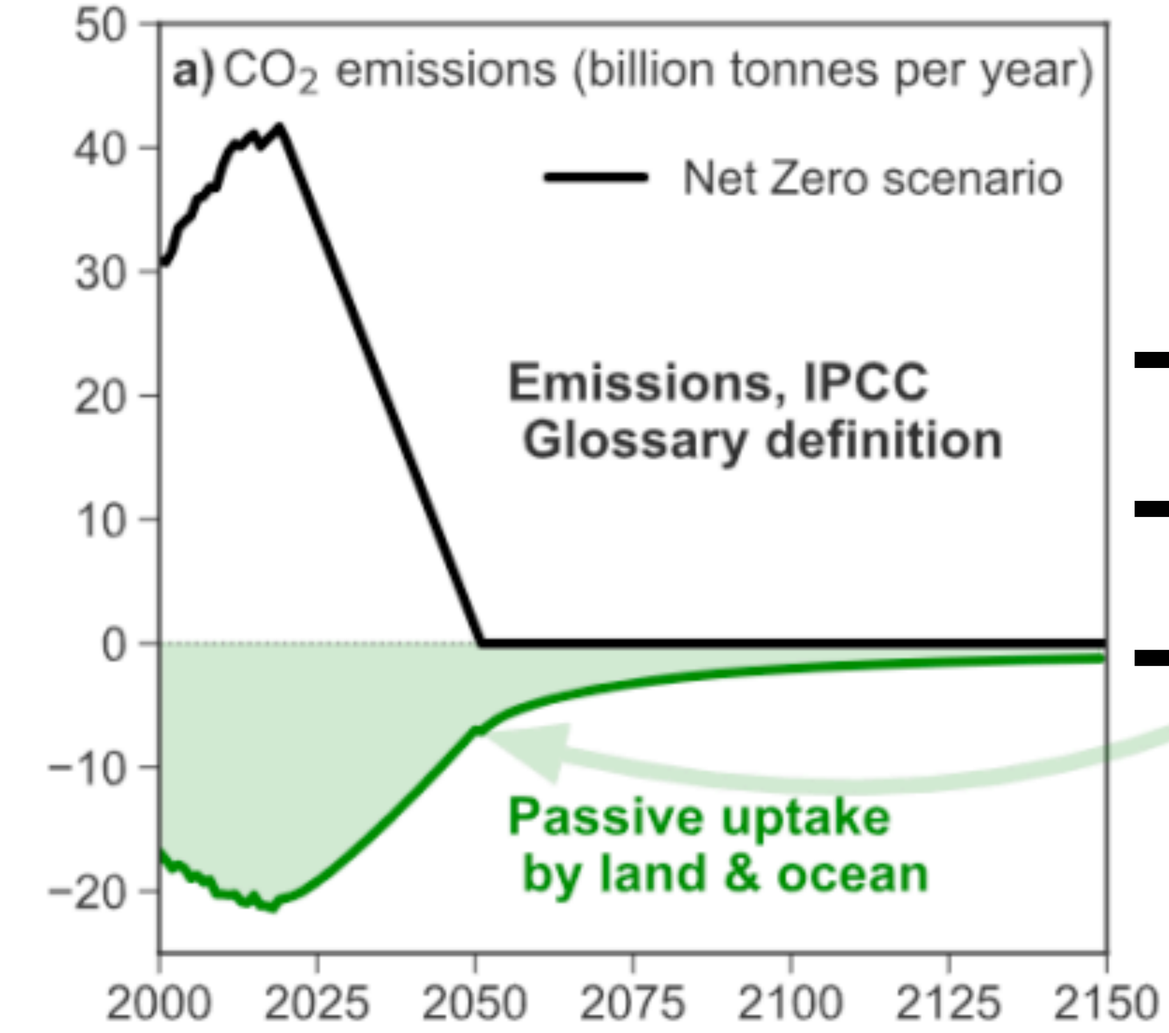
Does not address the issue of ocean acidification at all

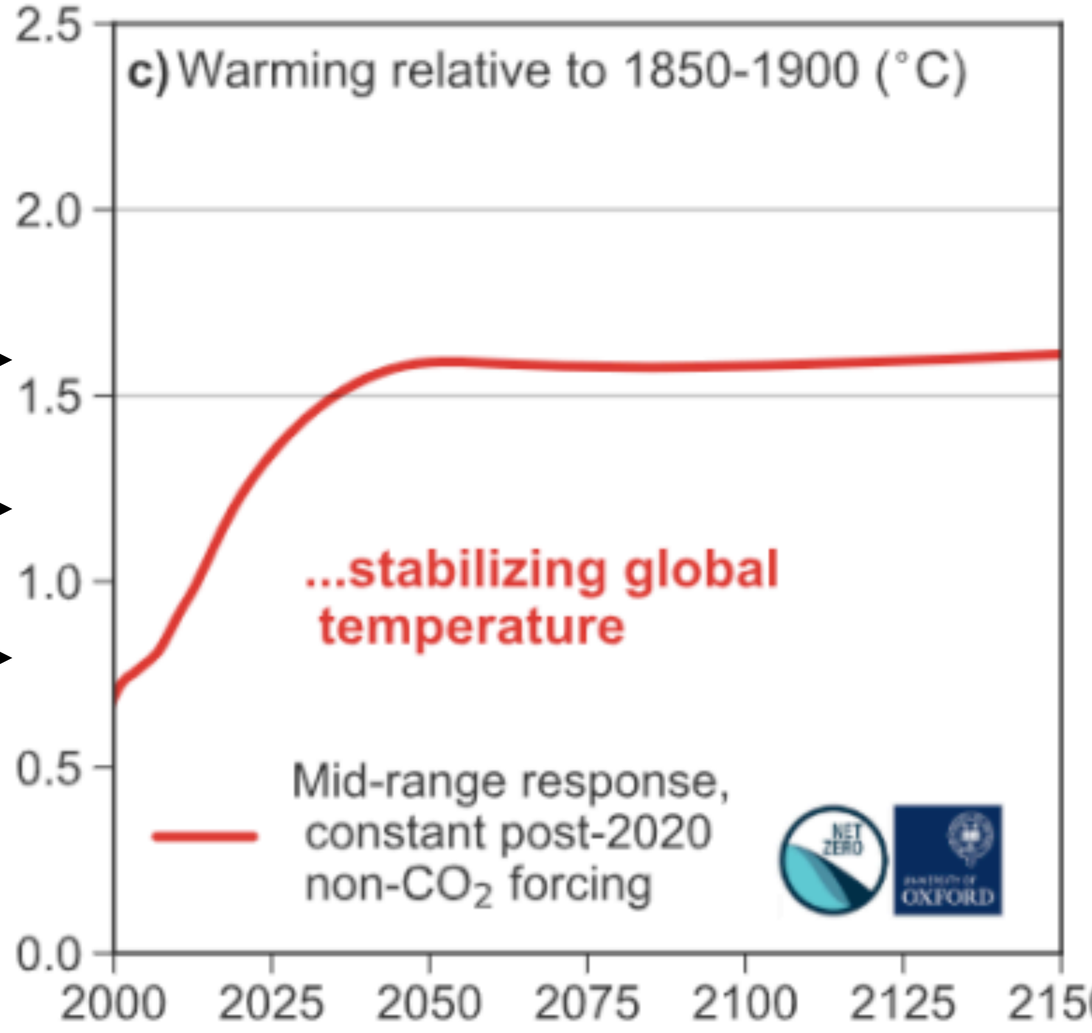
Global governance nightmare

May have other, unintended climate consequences (e.g., precipitation)

NONE OF THESE HAVE BEEN DEMONSTRATED TO WORK ON A SCALE NECESSARY TO ADDRESS CLIMATE CHANGE (YET).

The only thing that we know works is to ***leave it in the ground***





https://www.nature.com/articles/s41586-024-08326-8

Think back over the session. What are the three things you most want to remember? Take 60 seconds

MORE EMISSIONS = MORE WARMING; Warming only stops when emissions stop

Avoiding the worst outcomes will require BOTH ***adaptation*** and ***mitigation***

Any policy decisions will need to consider lots of ***uncertainties*** in terms of climate system response, co-benefits and tradeoffs

Geoengineering proposals are stopgaps, at best, and have never been demonstrated to work at scale

THANK YOU