INTRODUÇÃO À MUDANÇA CLIMÁTICA



Benjamin I Cook

ORIENTAÇÕES PARA HOJE

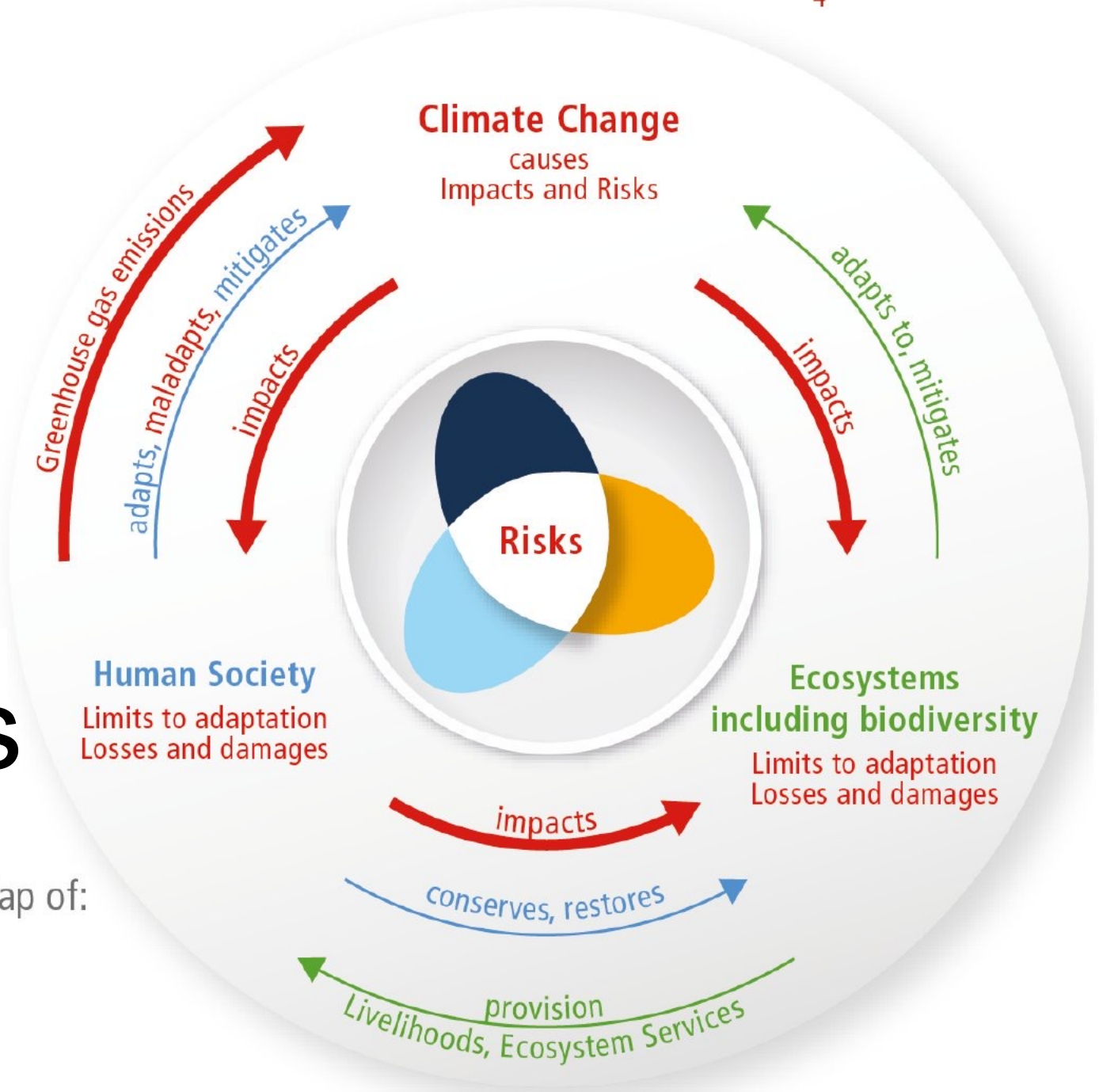
OBJETIVO: oferecer uma compreensão física fundamental da mudança climática e das incertezas associadas, e mostrar como a ciência pode embasar a adaptação e a mitigação

FAÇA PERGUNTAS conforme surgirem no chat do Zoom

PERGUNTA DE AQUECIMENTO

QUE PERCENTUAL DO AQUECIMENTO GLOBAL PODE SER ATRIBUÍDO ÀS ATIVIDADES HUMANAS?

A mudança climática é um fator central dos riscos futuros



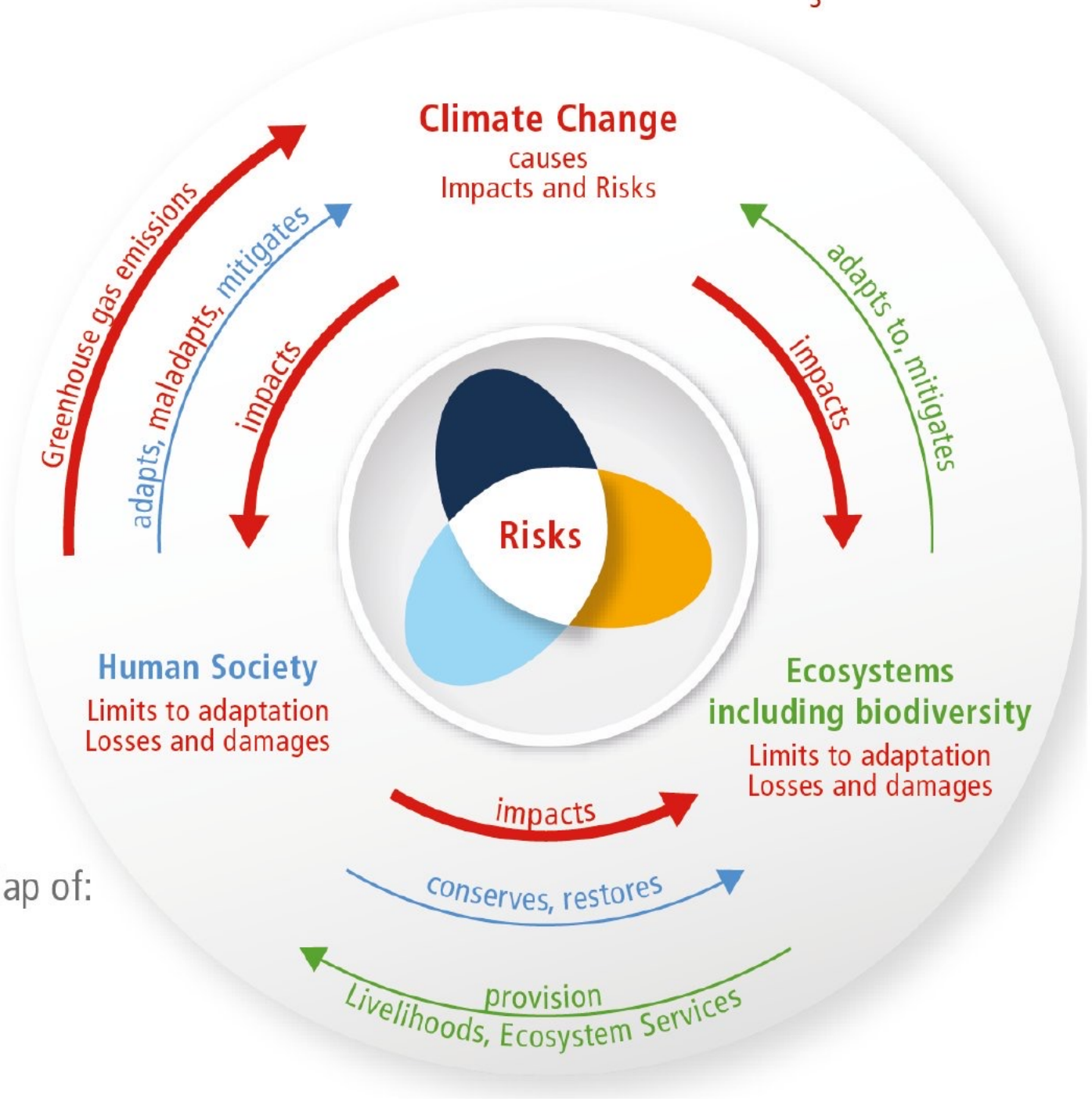
The risk propeller shows that risk emerges from the overlap of:

Climate hazard(s) | Vulnerability | Exposure

...of human systems, ecosystems and their biodiversity

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

Os impactos
TAMBÉM dependem:
de onde você vive (exposição)
e do quanto
está adaptado (vulnerabilidade)



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/

Lidar com riscos climáticos envolve

Entender o que está acontecendo

(ciência do clima)

Lidar com riscos climáticos envolve

Entender o que está acontecendo

(ciência do clima)

Evitar o máximo de aquecimento possível

(mitigação)

Lidar com riscos climáticos envolve

Entender o que está acontecendo

(ciência do clima)

Evitar o máximo de aquecimento possível

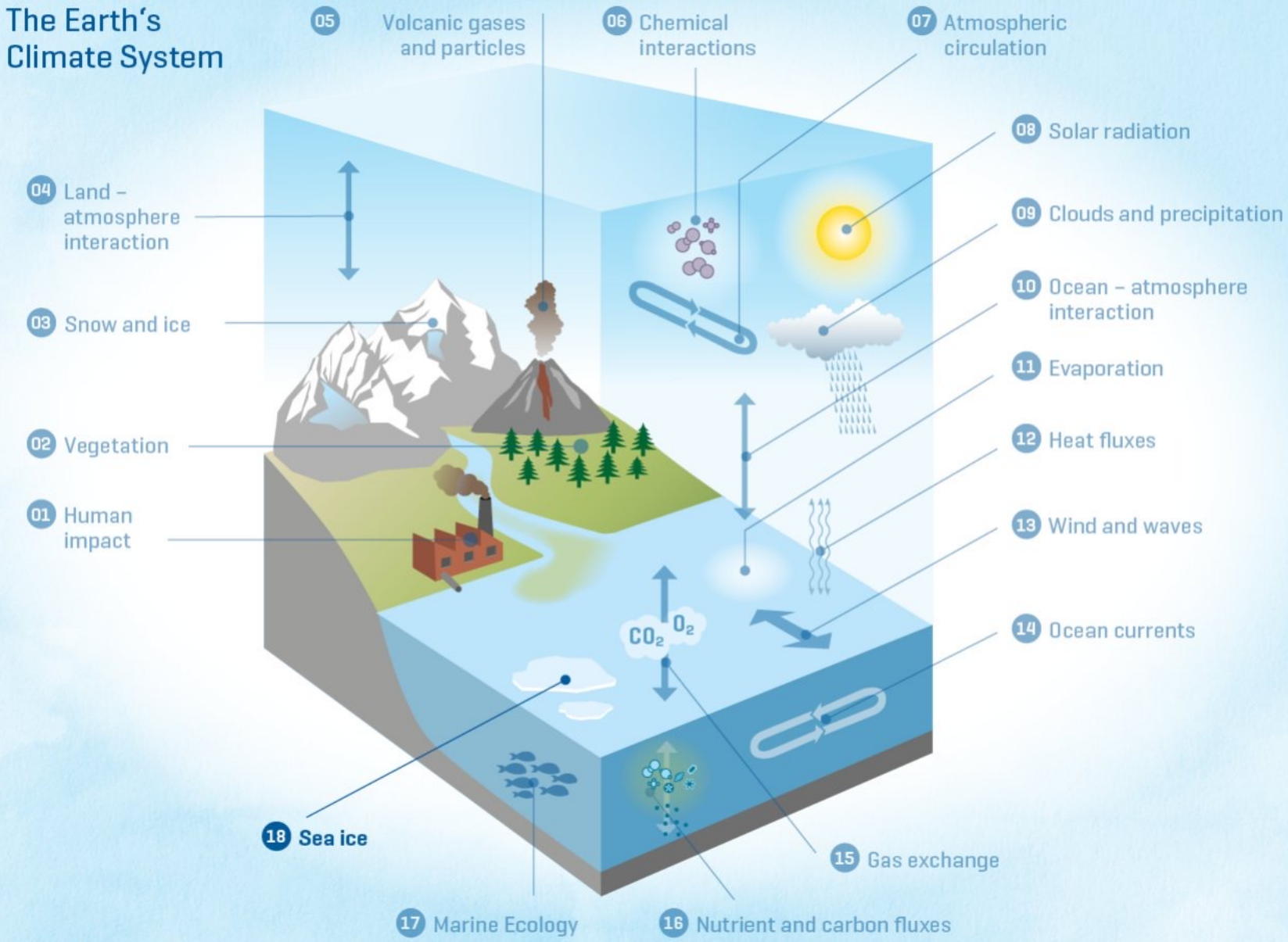
(mitigação)

Lidar com as mudanças que acontecem

(adaptação)

CIÊNCIA DO CLIMA

O sistema climático da Terra



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

O que é o clima?

WEATHER

WHAT YOU GET

CONDITIONS OF THE ATMOSPHERE OVER A SHORT PERIOD OF TIME

CAN CHANGE WITHIN MINUTES OR HOURS



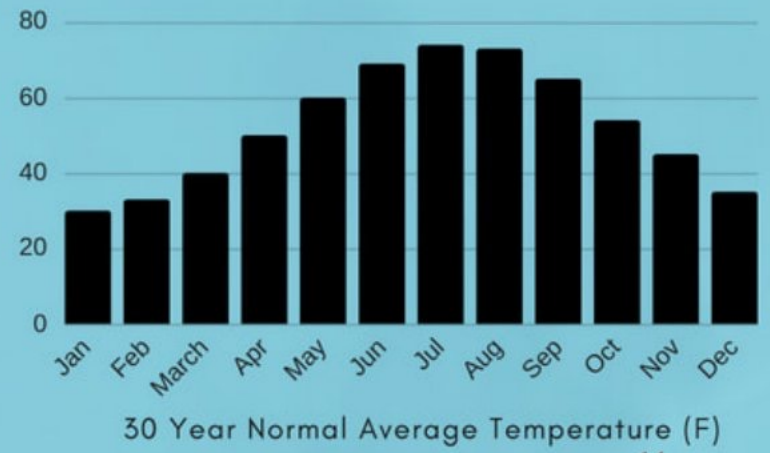
VS

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


CLIMA
é o que você espera
O TEMPO
é o que você recebe

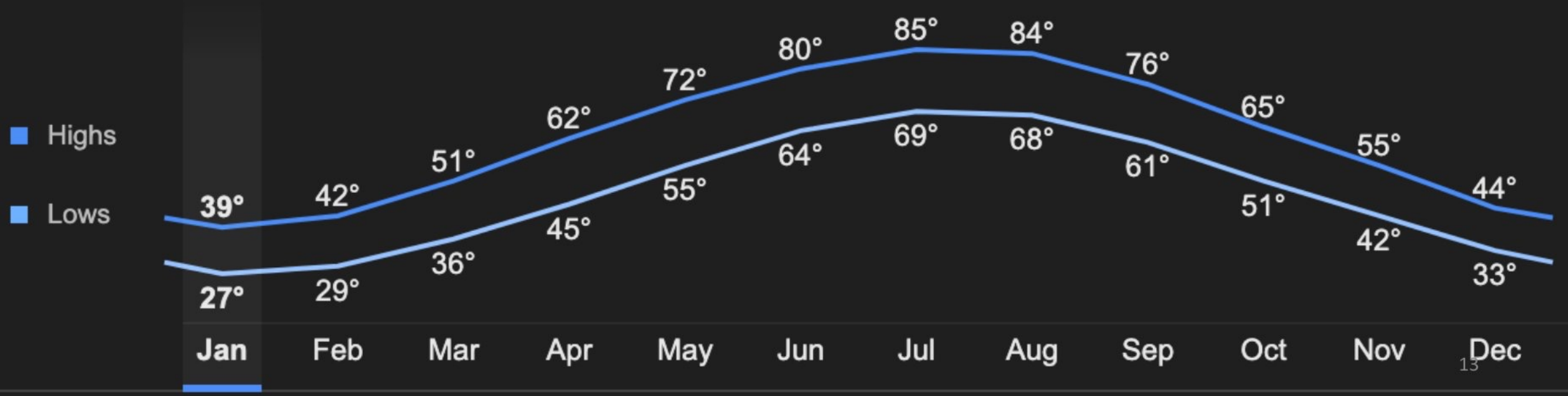
21 °F | °C
Precipitation: 0%
Humidity: 50%
Wind: 14 mph

Weather

Tuesday 2:00 PM
Sunny

Temperature | Precipitation | Wind

Temperatures (°F)



QUANDO FALAMOS DE MUDANÇA CLIMÁTICA, NÃO TENTAMOS PREVER O TEMPO

Vai chover em 14 de abril de 2091?

Que calor fará em 21 de julho de 2085?

QUANDO FALAMOS DE MUDANÇA CLIMÁTICA, NÃO TENTAMOS PREVER O TEMPO

Vai chover em 14 de abril de 2091?

-> Qual será a chuva média de abril na década de 2090?

Que calor fará em 21 de julho de 2085?

QUANDO FALAMOS DE MUDANÇA CLIMÁTICA, NÃO TENTAMOS PREVER O TEMPO

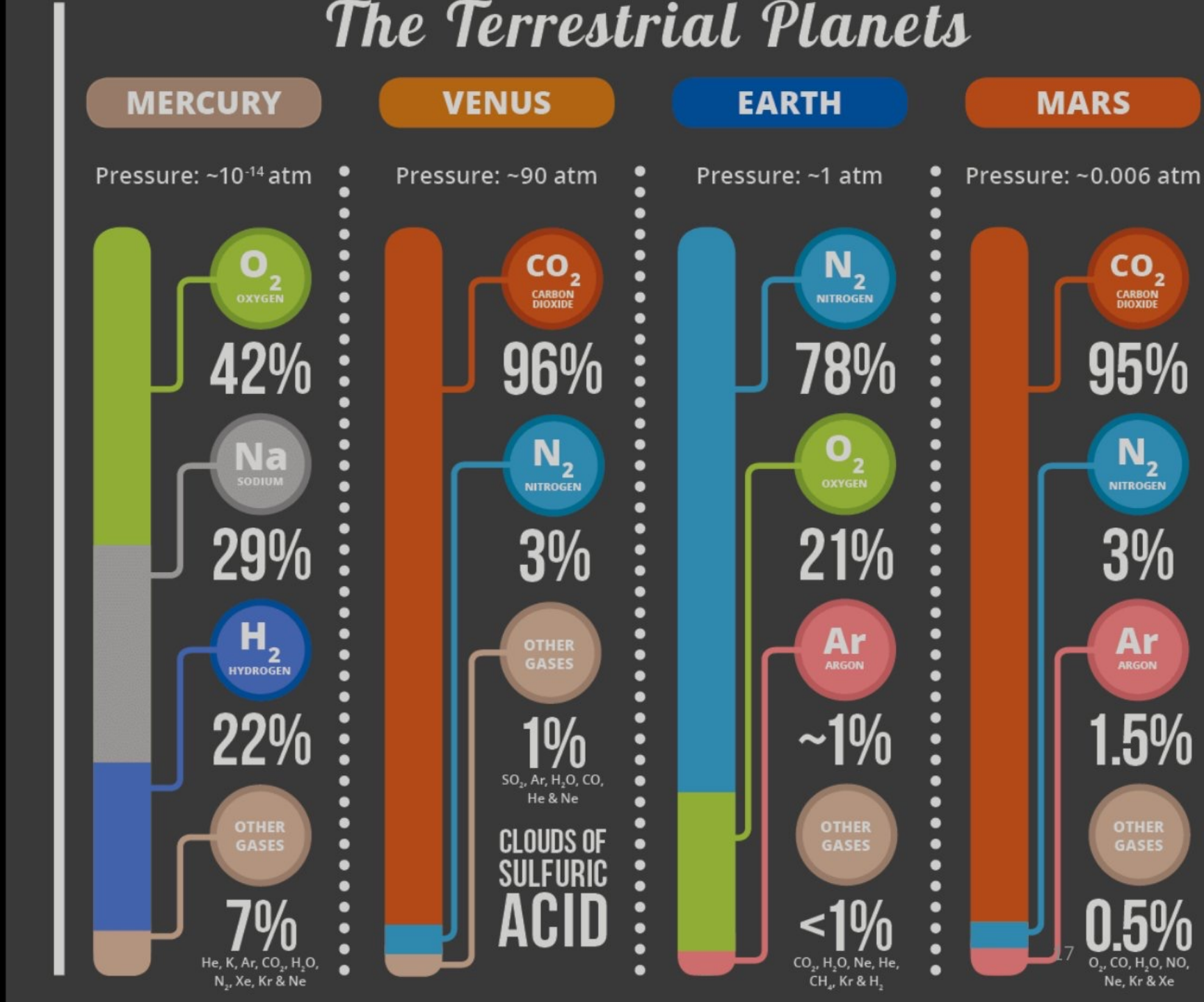
Vai chover em 14 de abril de 2091?

-> Qual será a chuva média de abril na década de 2090?

Que calor fará em 21 de julho de 2085?

-> Quanto terão aumentado o severidade das ondas de calor no fim do século XXI?

A atmosfera da Terra



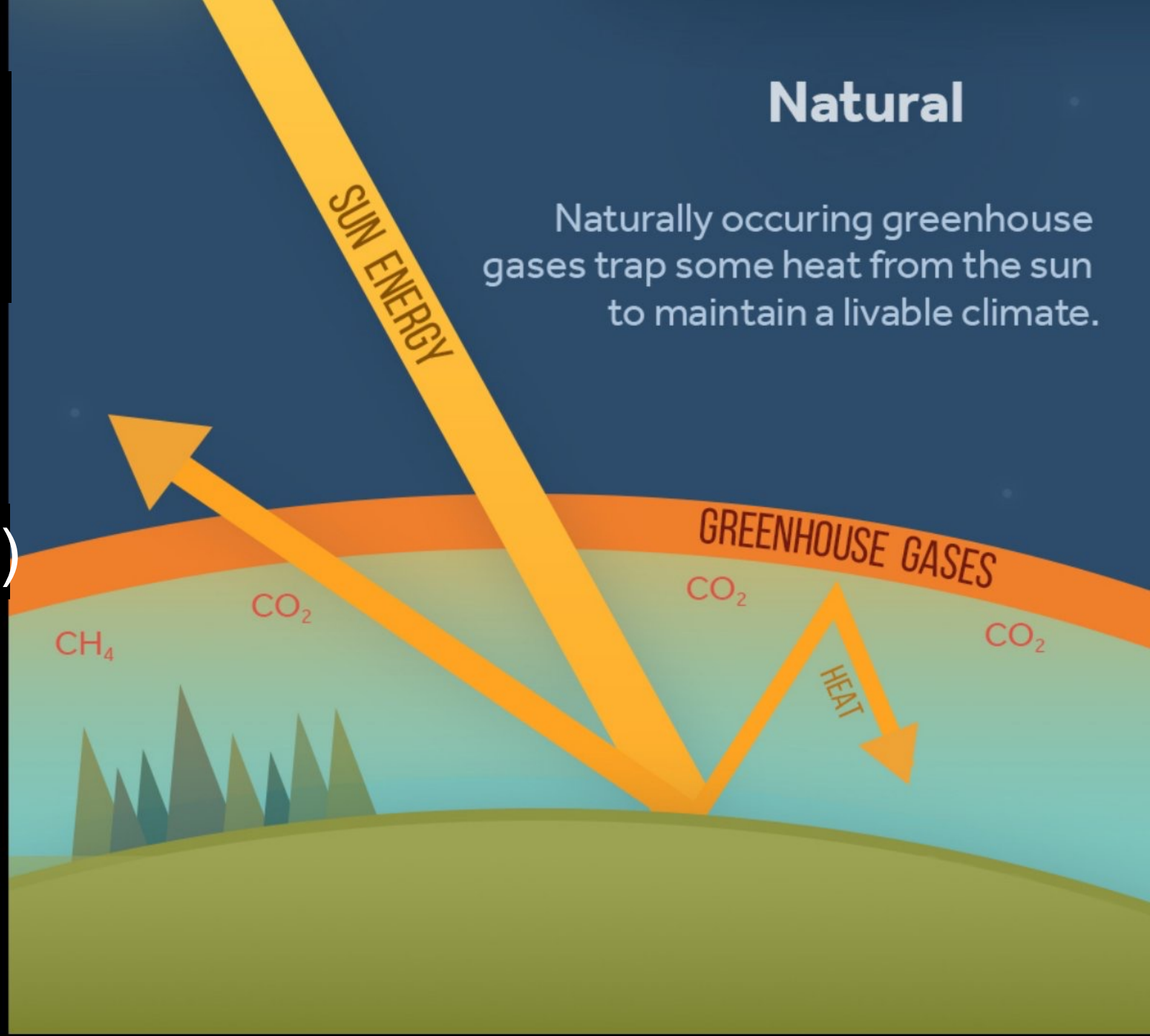
O efeito estufa

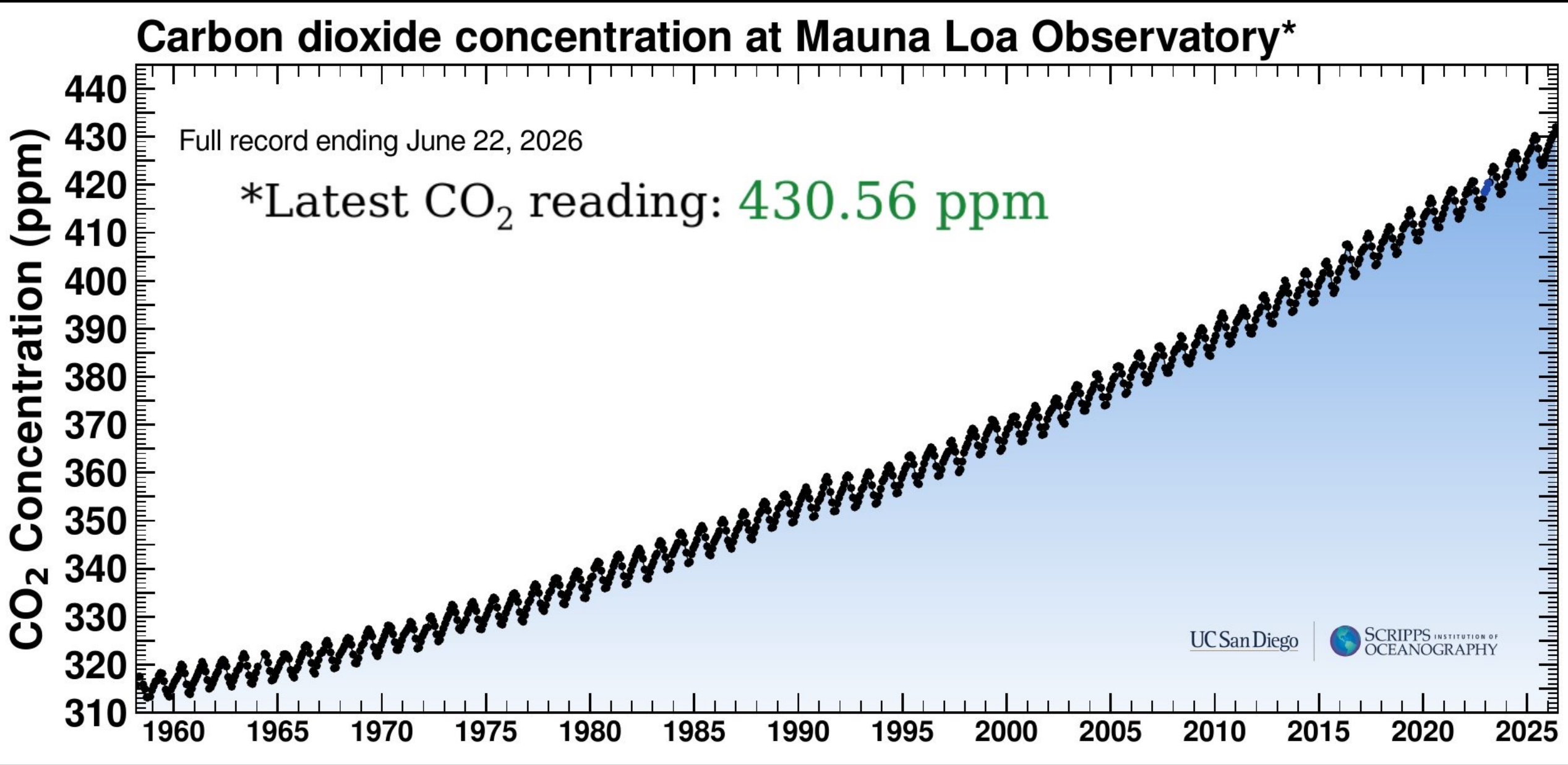
vapor d’água

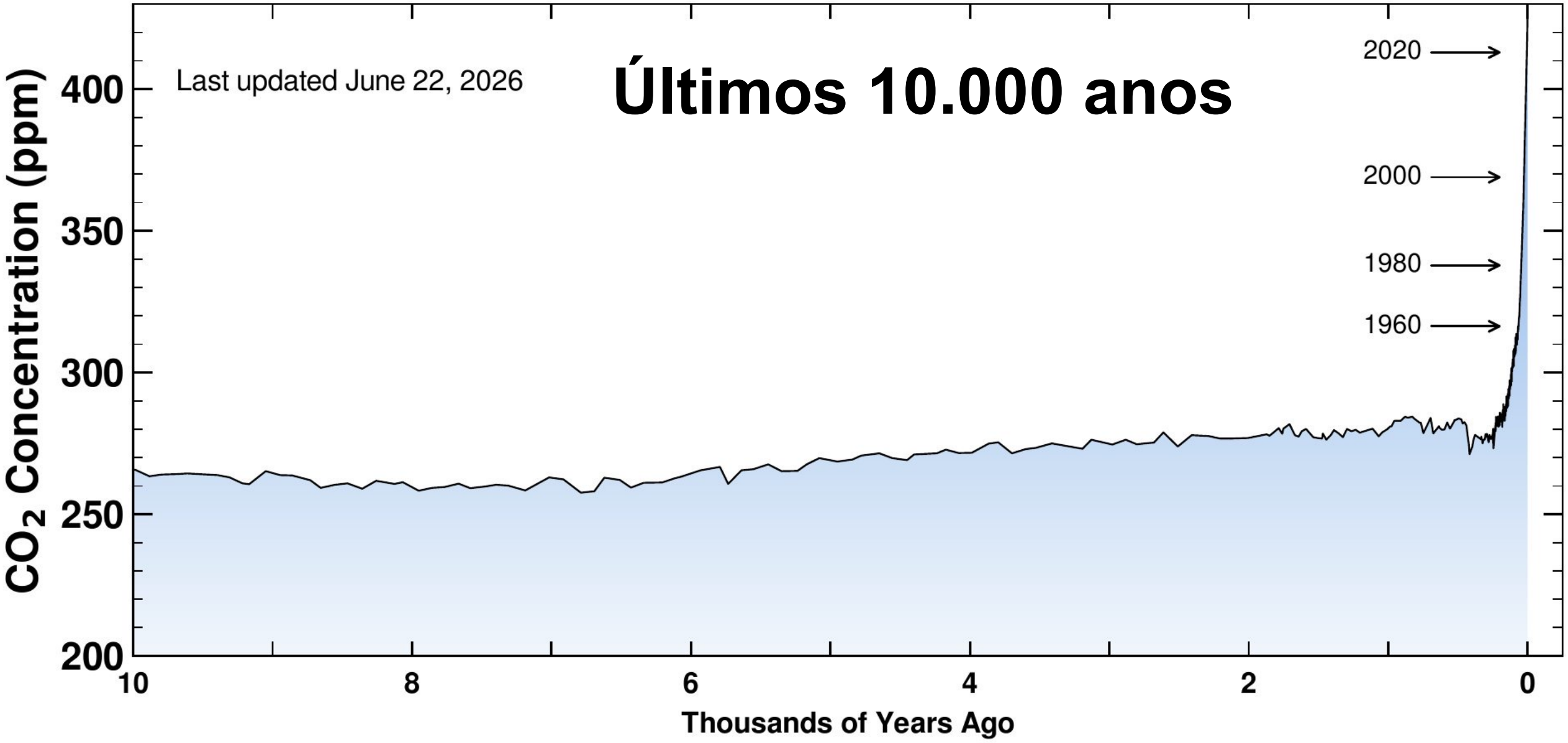
dióxido de carbono (CO_2)

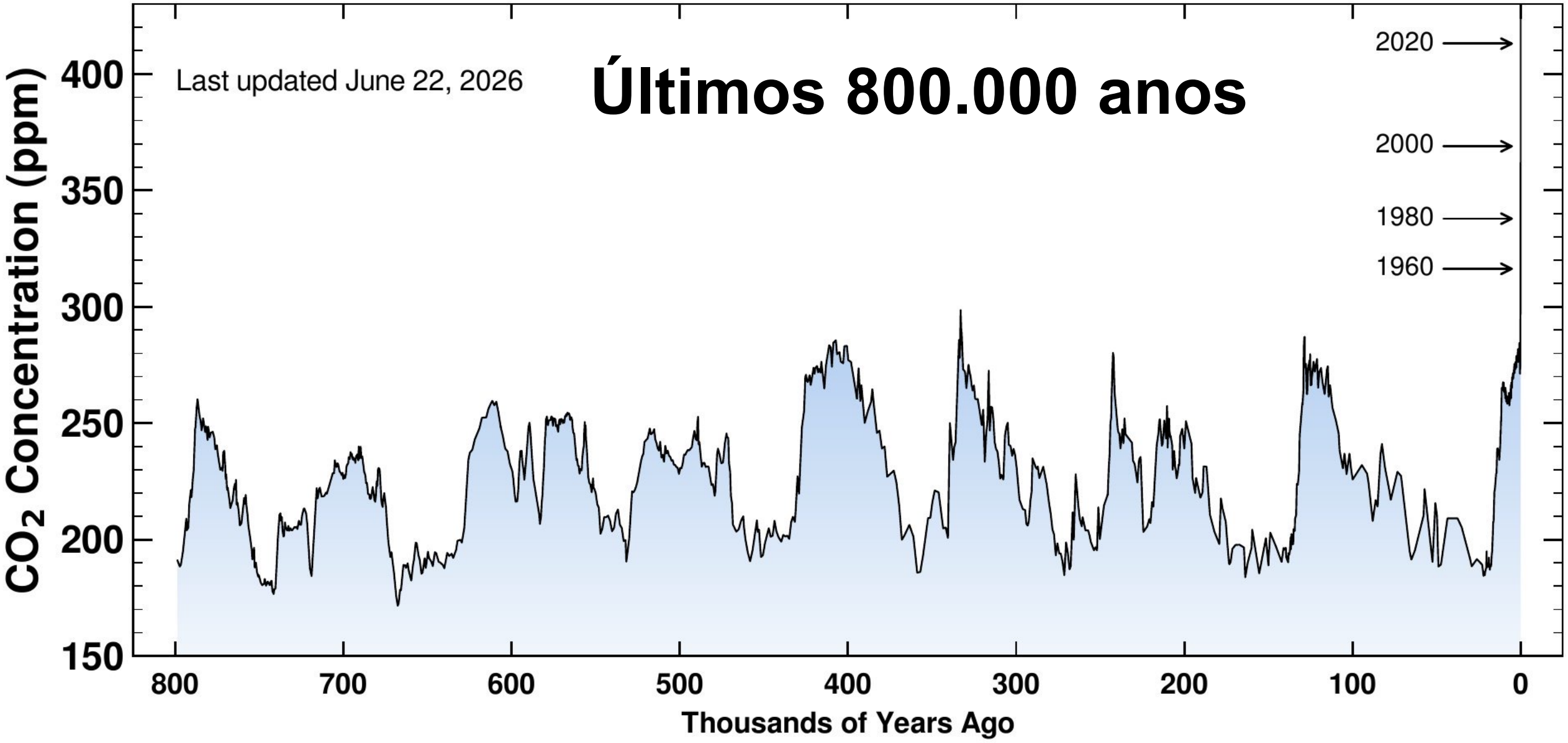
metano (CH_4)

óxido nitroso (N_2O)

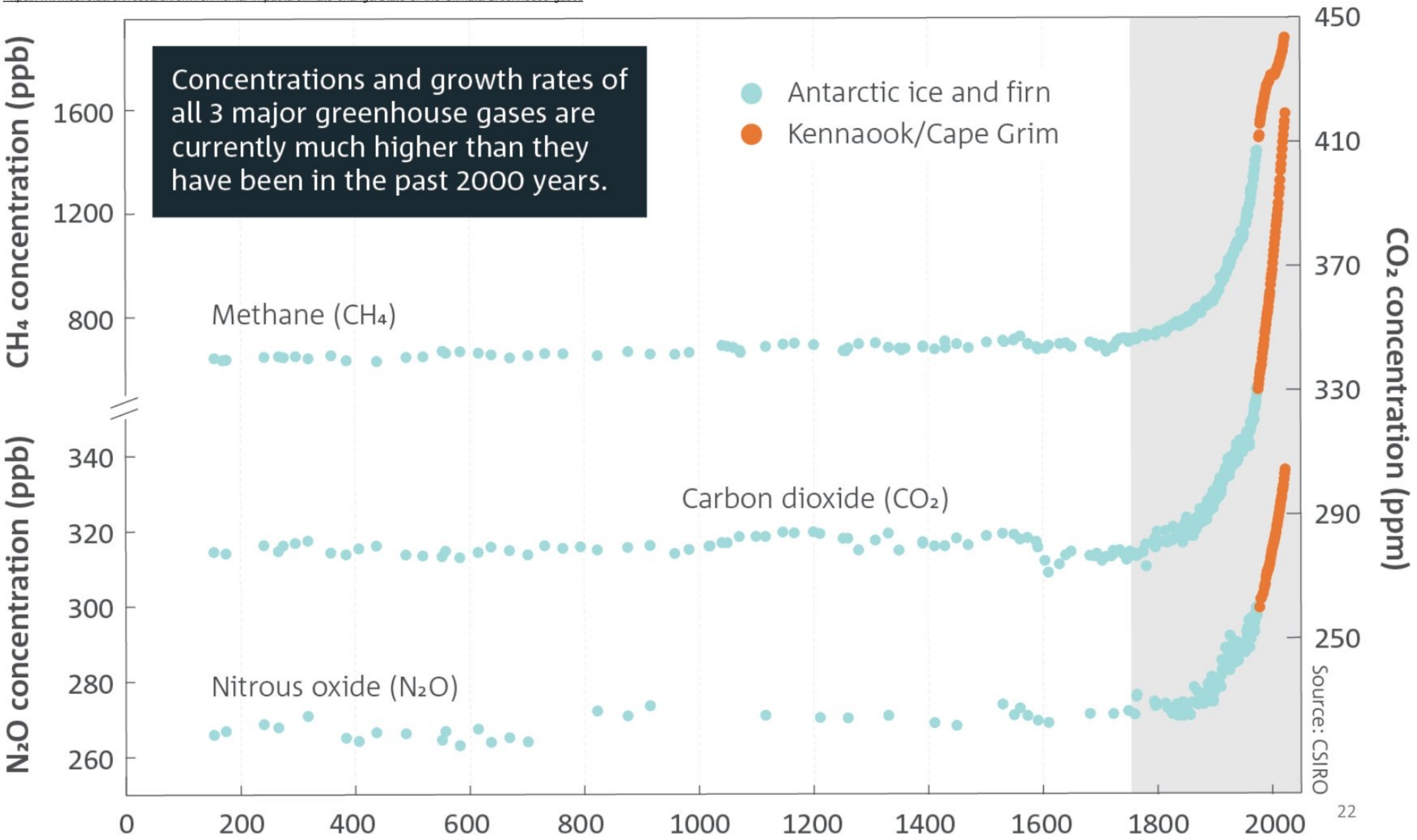



Carbon dioxide concentration at Mauna Loa Observatory*
Full record ending June 22, 2026
*Latest CO_2 reading: 430.56 ppm
CO_2 Concentration (ppm)
440
430
420
410
400
390
380
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
UC San Diego
SCRIPPS INSTITUTION OF OCEANOGRAPHY

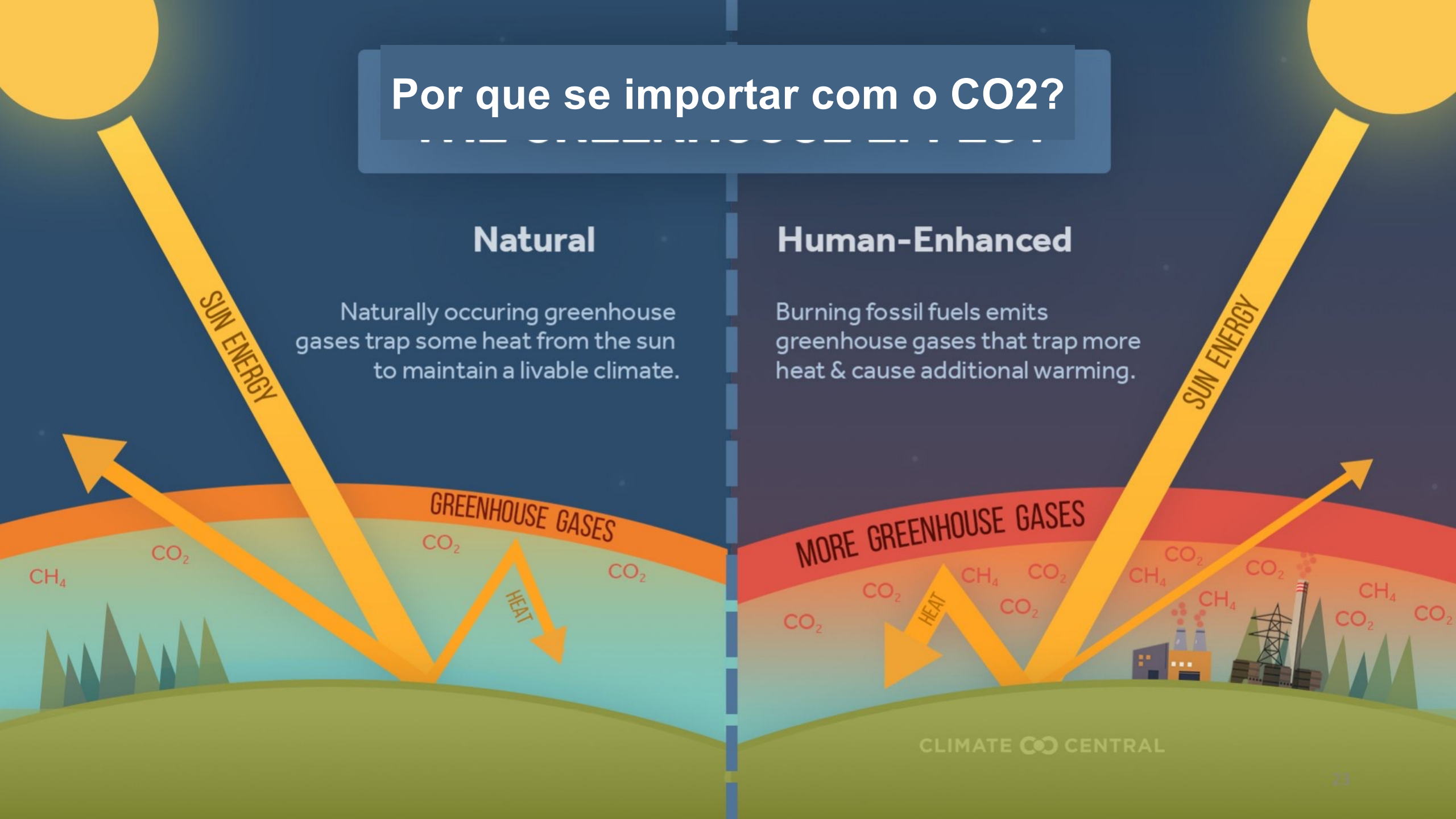

Last updated June 22, 2026
Últimos 10.000 anos
2020
2000
1980
1960
CO2 Concentration (ppm)
400
350
300
250
200
10
8
6
4
2
0
Thousands of Years Ago


Last updated June 22, 2026
Últimos 800.000 anos
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

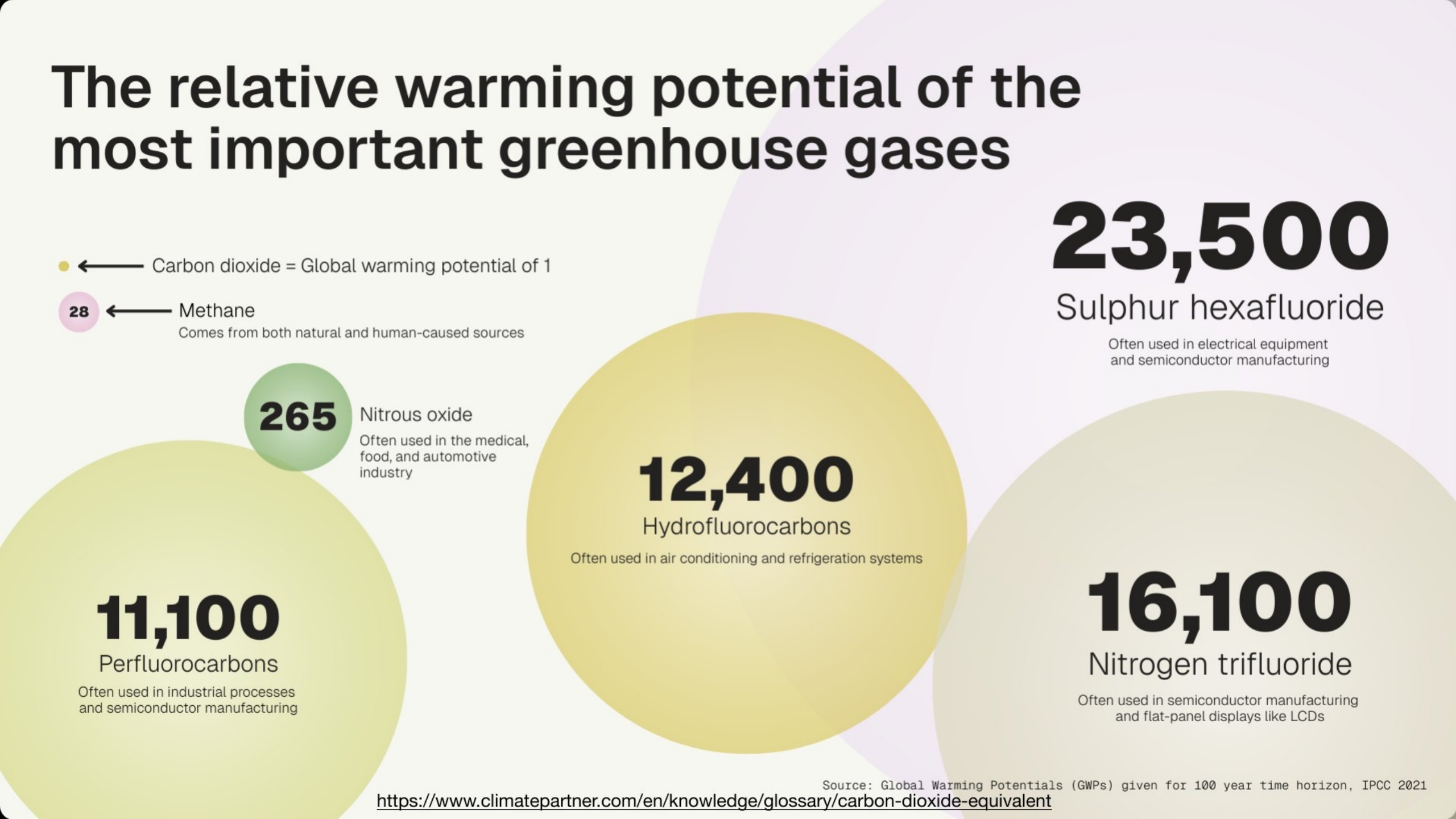
https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate/Greenhouse-gases



Por que se importar com o CO2?



The relative warming potential of the most important greenhouse gases

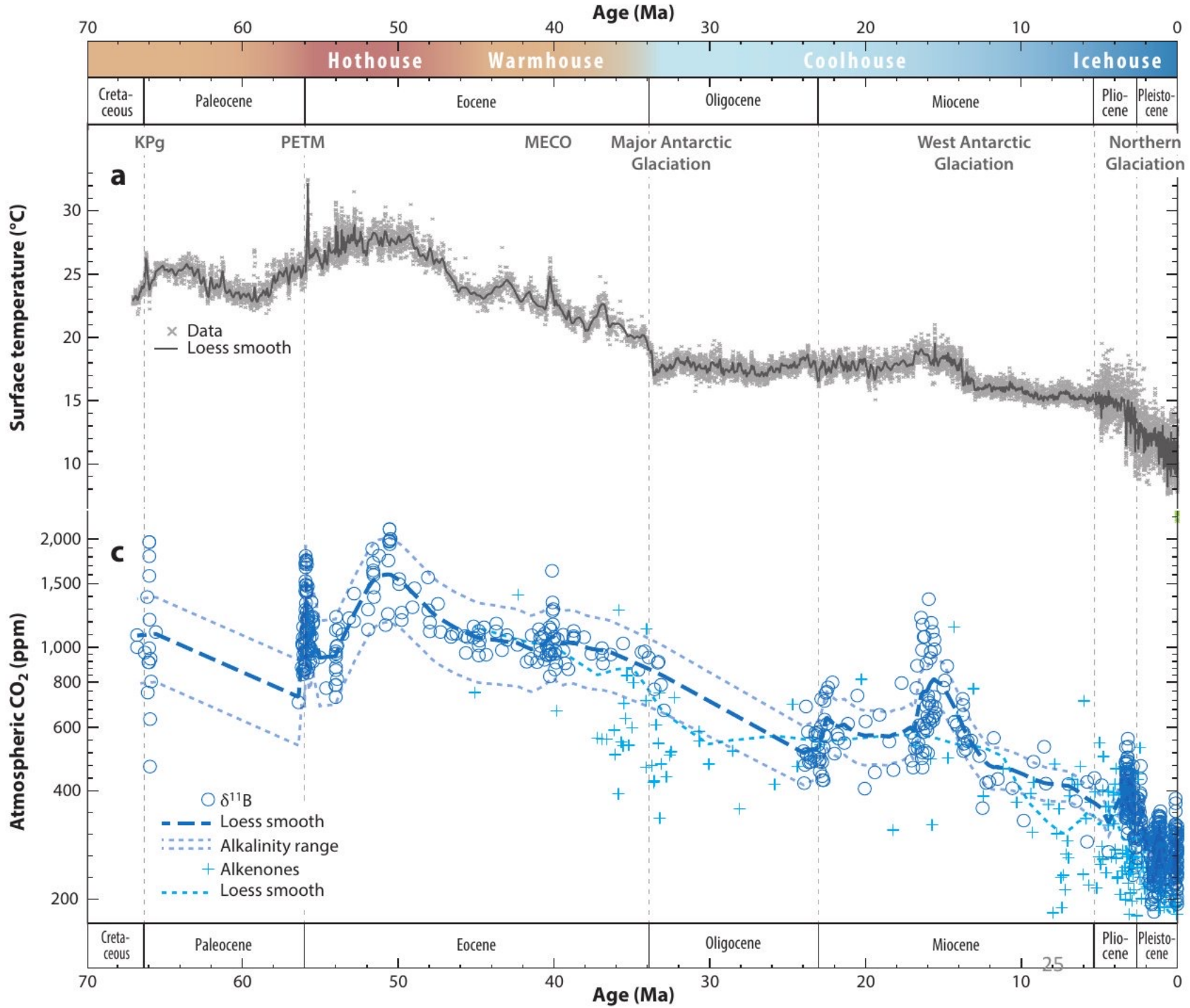


Source: Global Warming Potentials (GWPs) given for 100 year time horizon, IPCC 2021

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

No passado, quando o CO2 é

alto, as temperaturas são altas

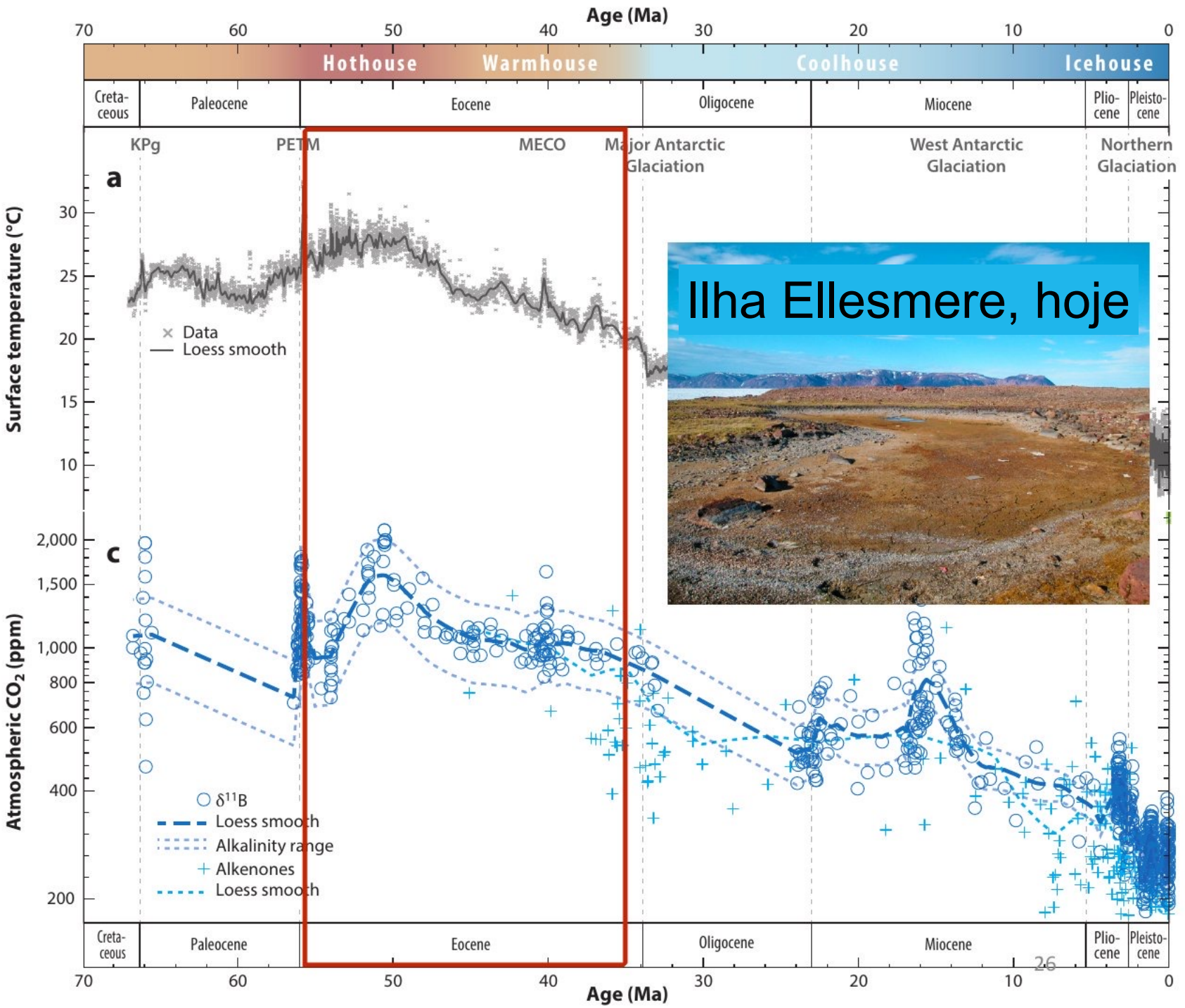


https://www.annualreviews.org/doi/abs/10.1146/annurev-earth-082420-063026

O Eoceno (56-33,9 Ma)

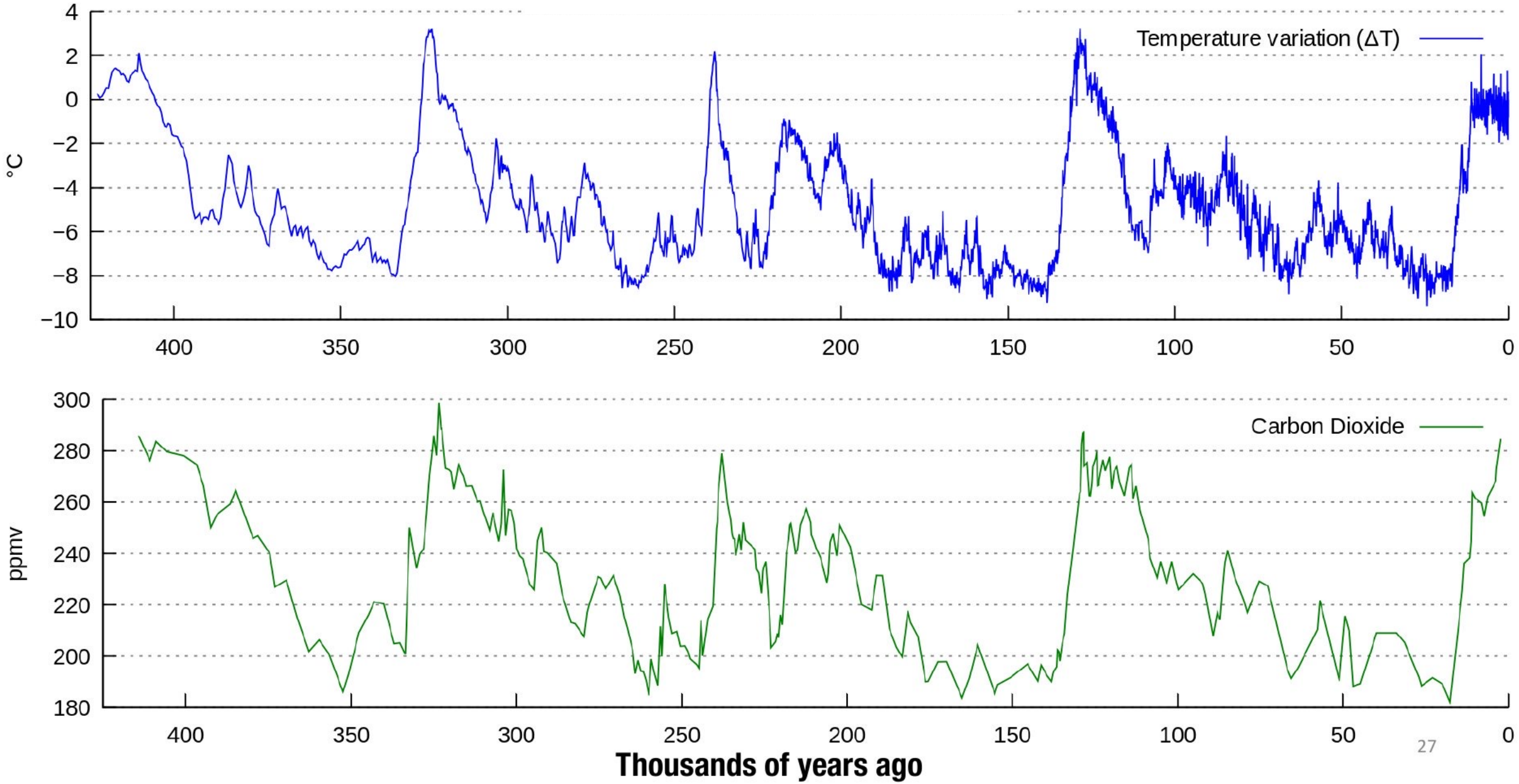
Ilha Ellesmere, há 50 Ma



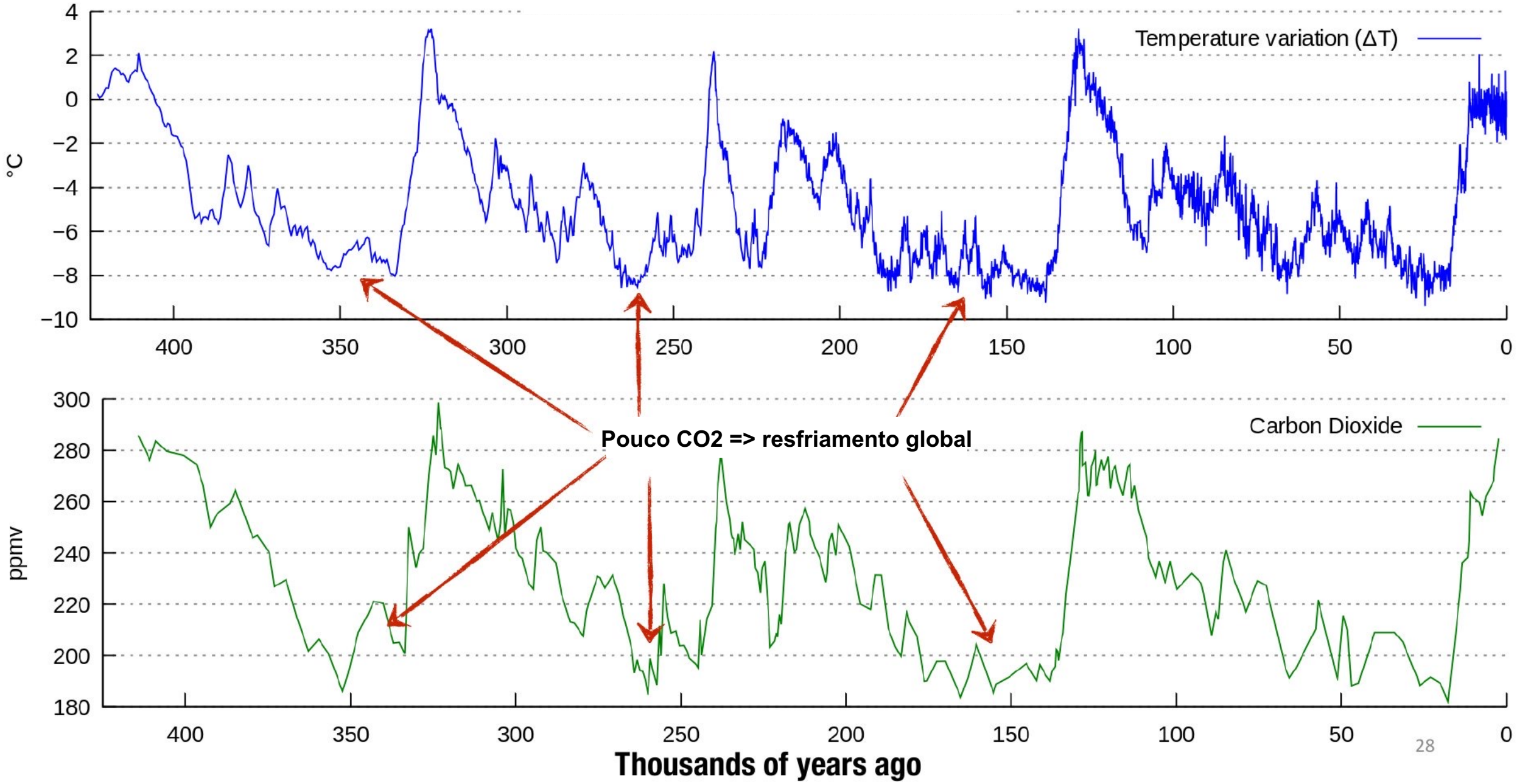


https://www.annualreviews.org/doi/abs/10.1146/annurev-earth-082420-063026

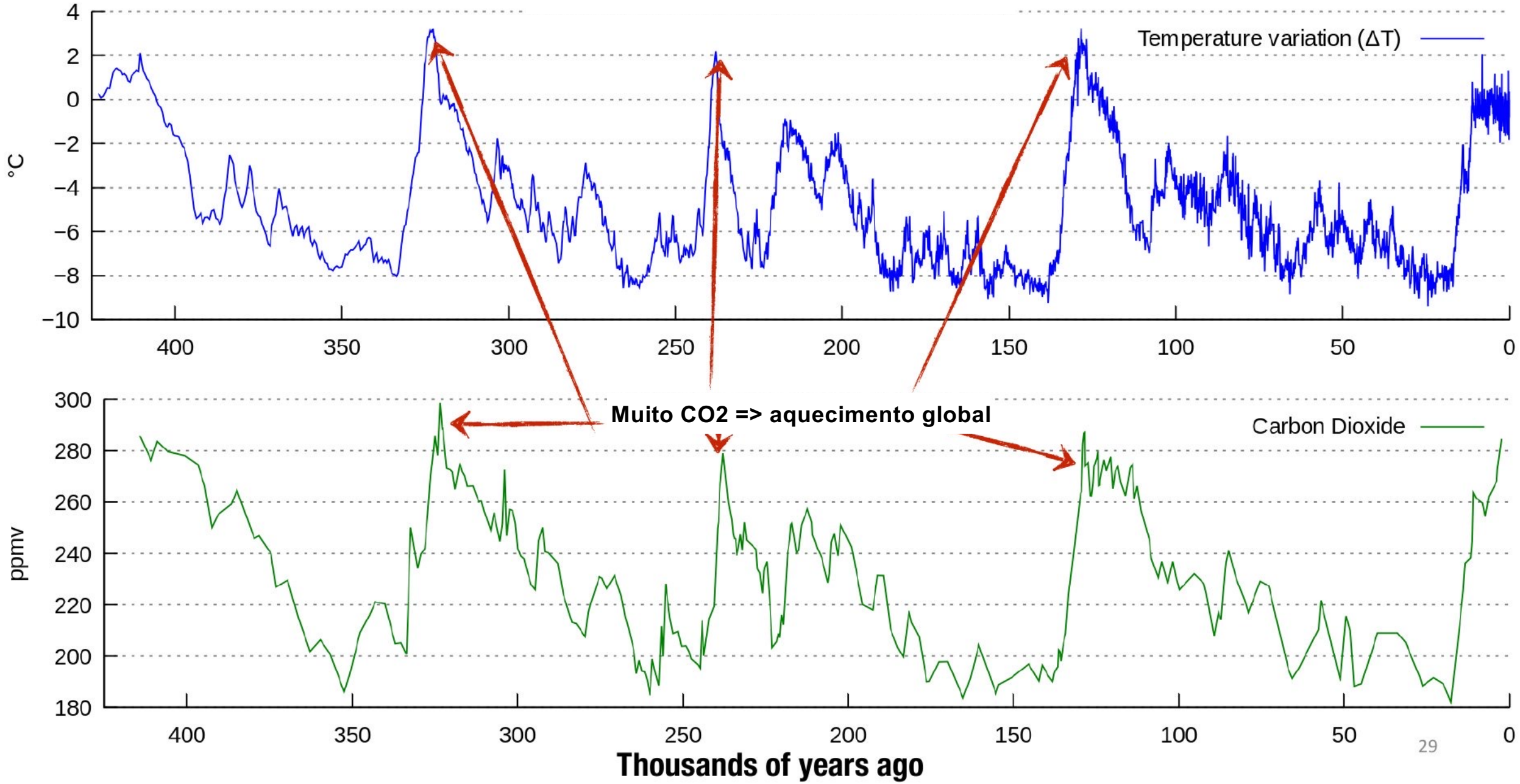
Ciclos glaciais



Ciclos glaciais



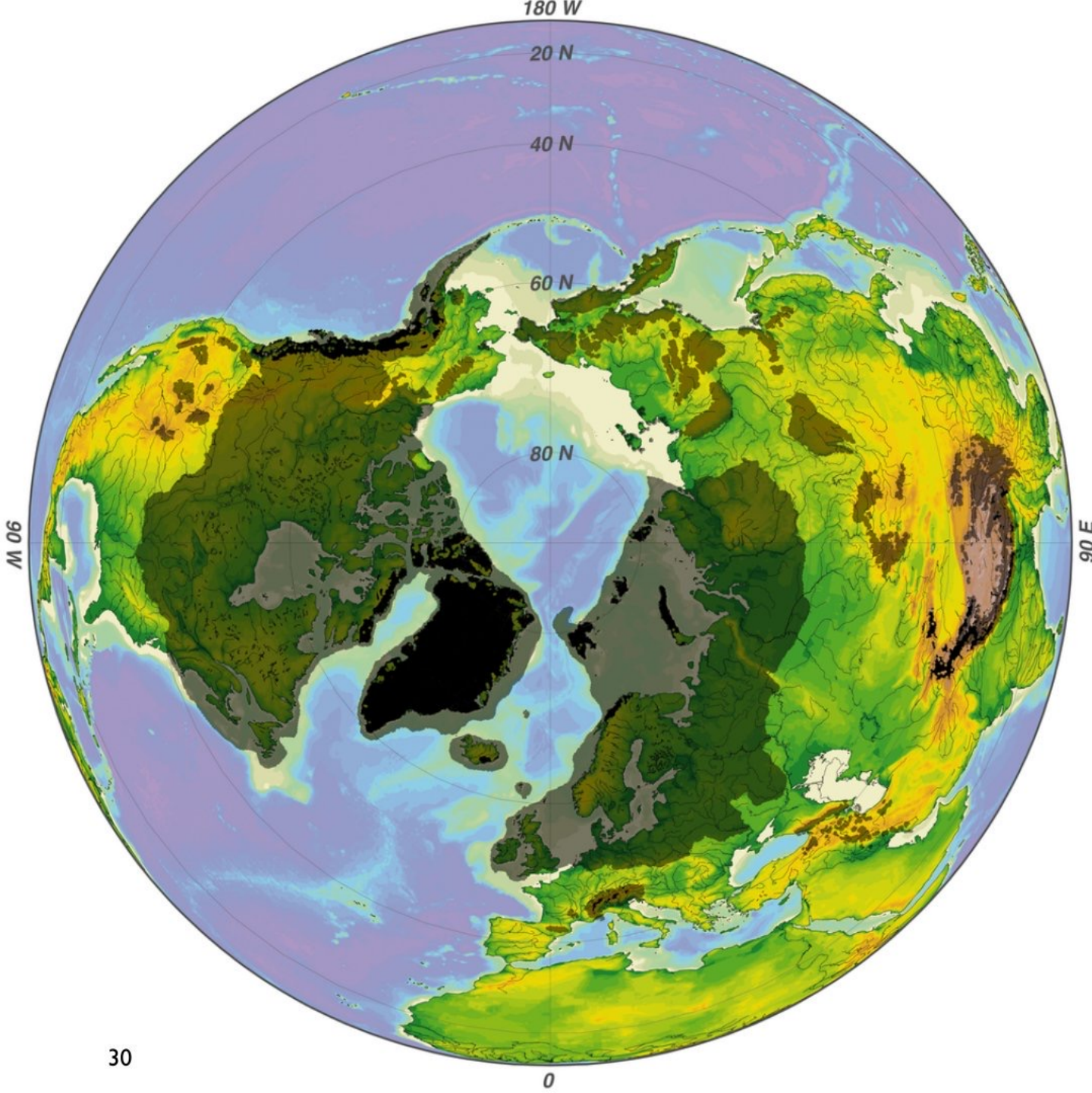
Ciclos glaciais



Mantos de gelo durante o UMG

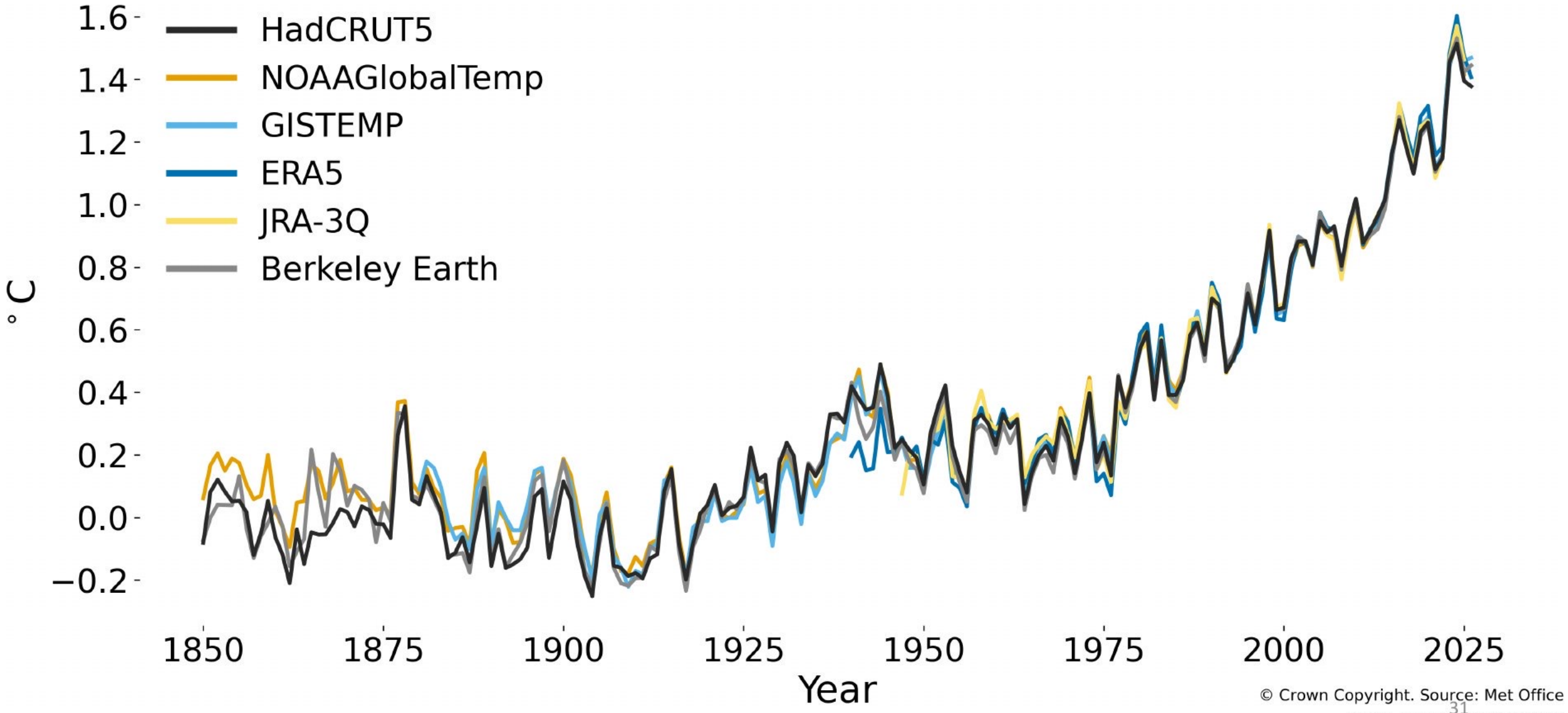
escuro = hoje

claro = há ~25 mil anos



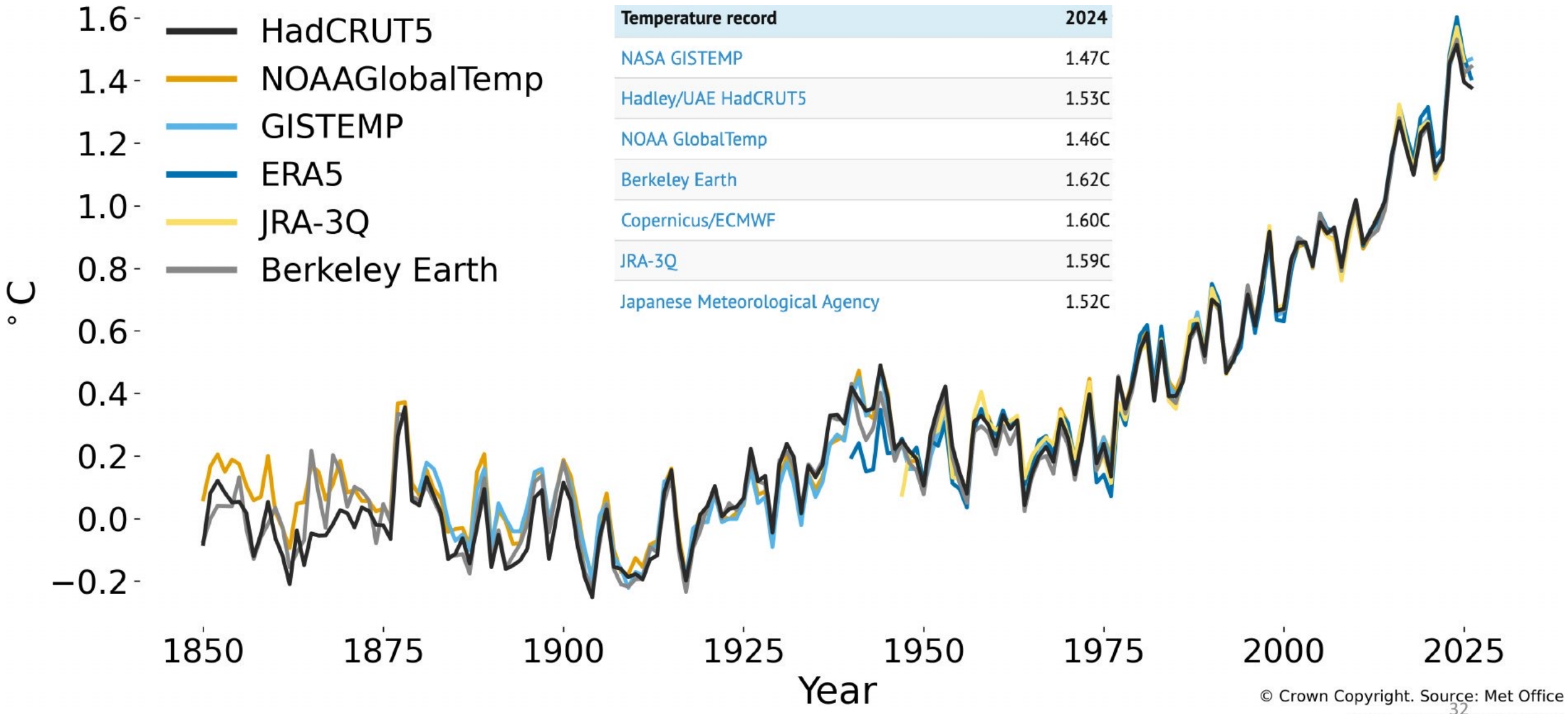
images from: http://en.wikipedia.org/wiki/Ice_age

O MUNDO ESTÁ ESQUENTANDO



© Crown Copyright. Source: Met Office
Figure updated: 09/06/2026

RECORDE DE CALOR: 2024



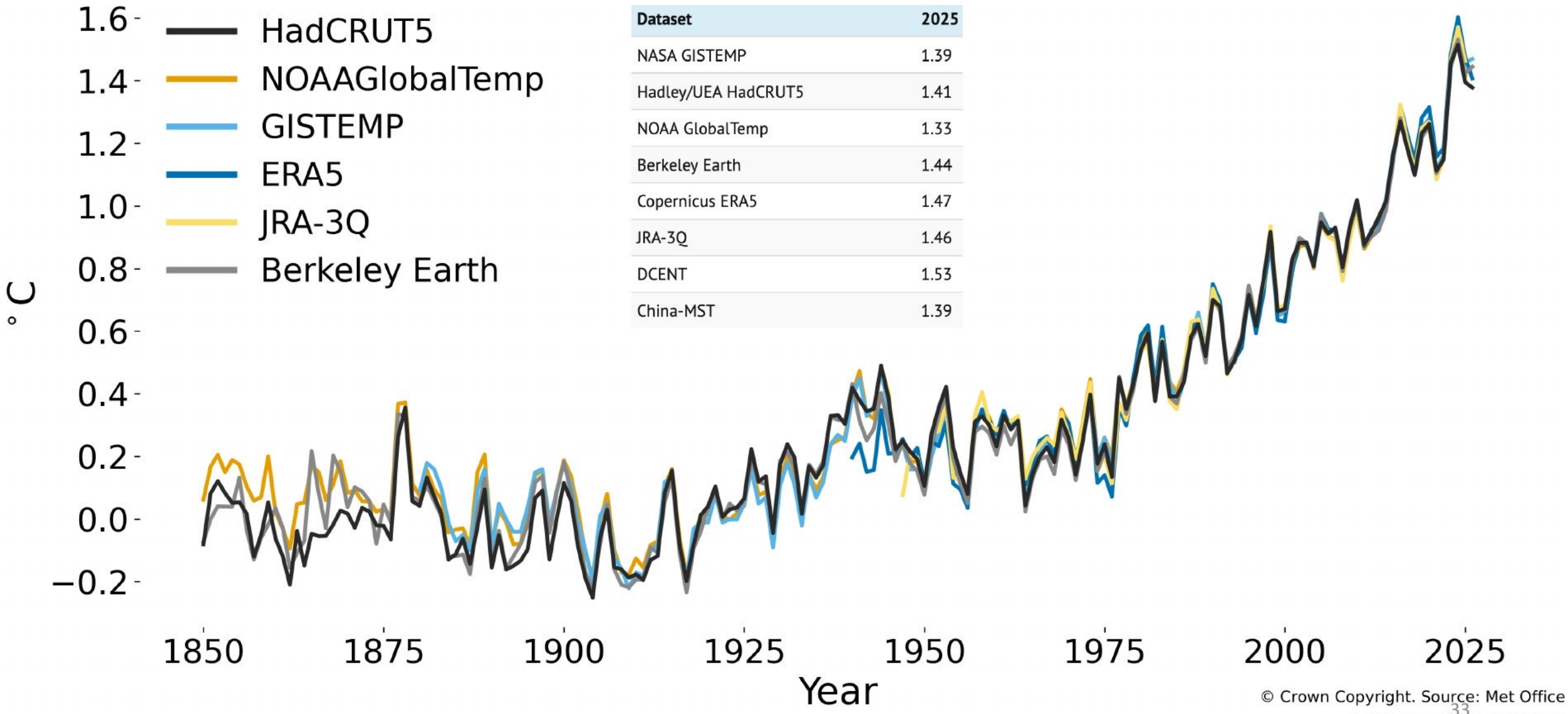
Temperature record	2024
NASA GISTEMP	1.47C
Hadley/UAE HadCRUT5	1.53C
NOAA GlobalTemp	1.46C
Berkeley Earth	1.62C
Copernicus/ECMWF	1.60C
JRA-3Q	1.59C
Japanese Meteorological Agency	1.52C

© 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: 2º OU 3º LUGAR

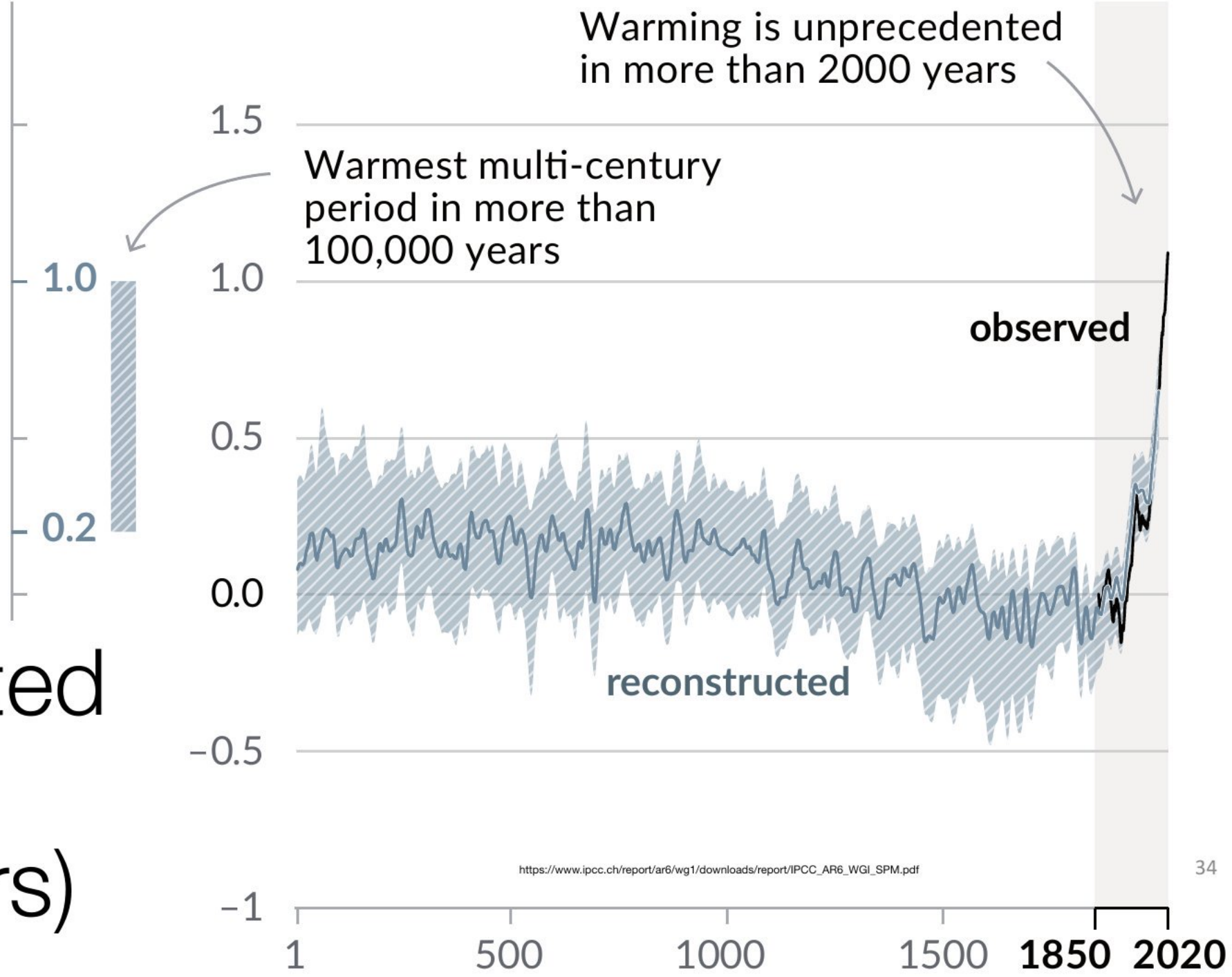
Dataset	2025
NASA GISTEMP	1.39
Hadley/UEA HadCRUT5	1.41
NOAA GlobalTemp	1.33
Berkeley Earth	1.44
Copernicus ERA5	1.47
JRA-3Q	1.46
DCENT	1.53
China-MST	1.39



© Crown Copyright. Source: Met Office
Figure updated: 09/06/2026

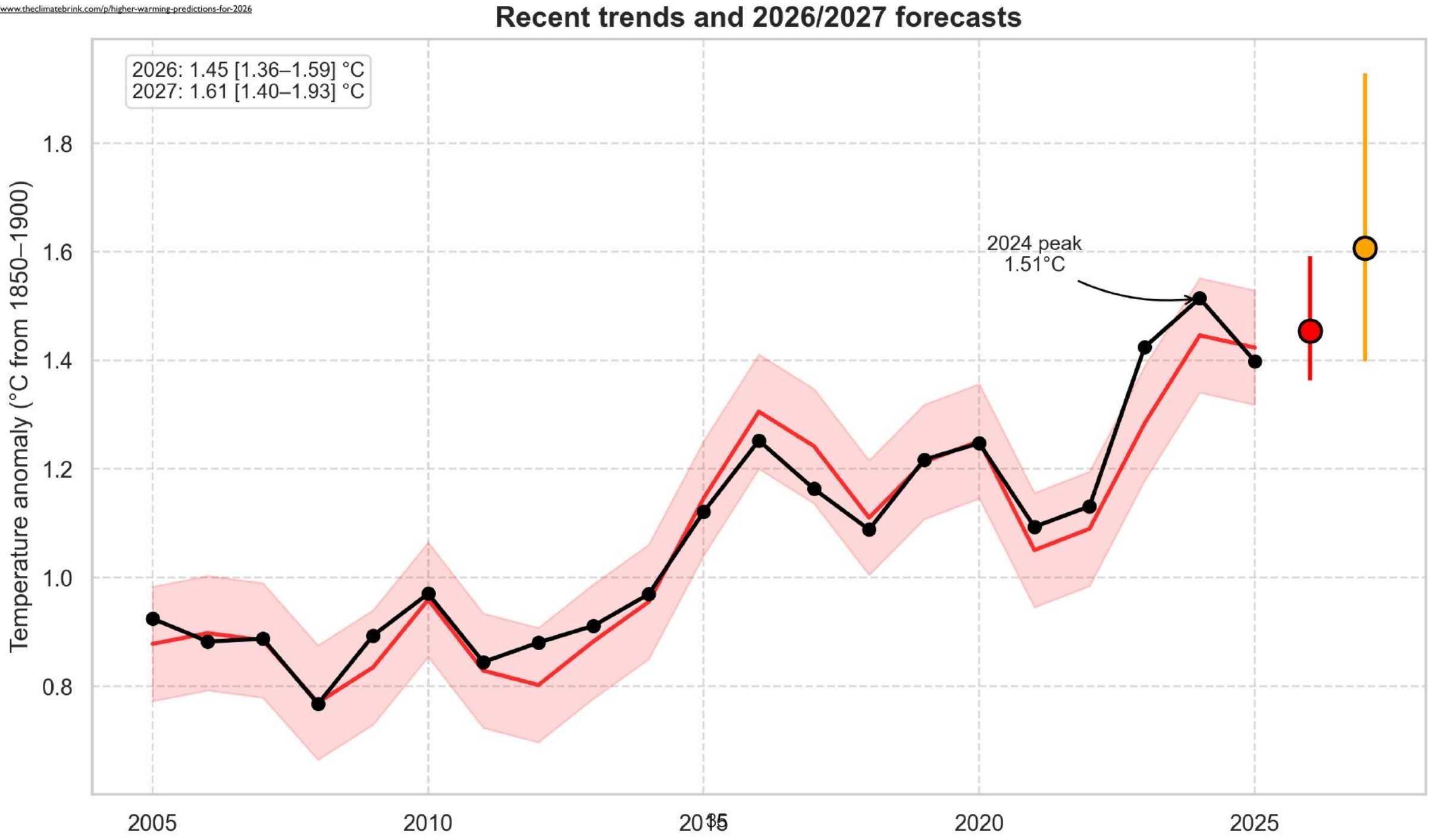
https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges/

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

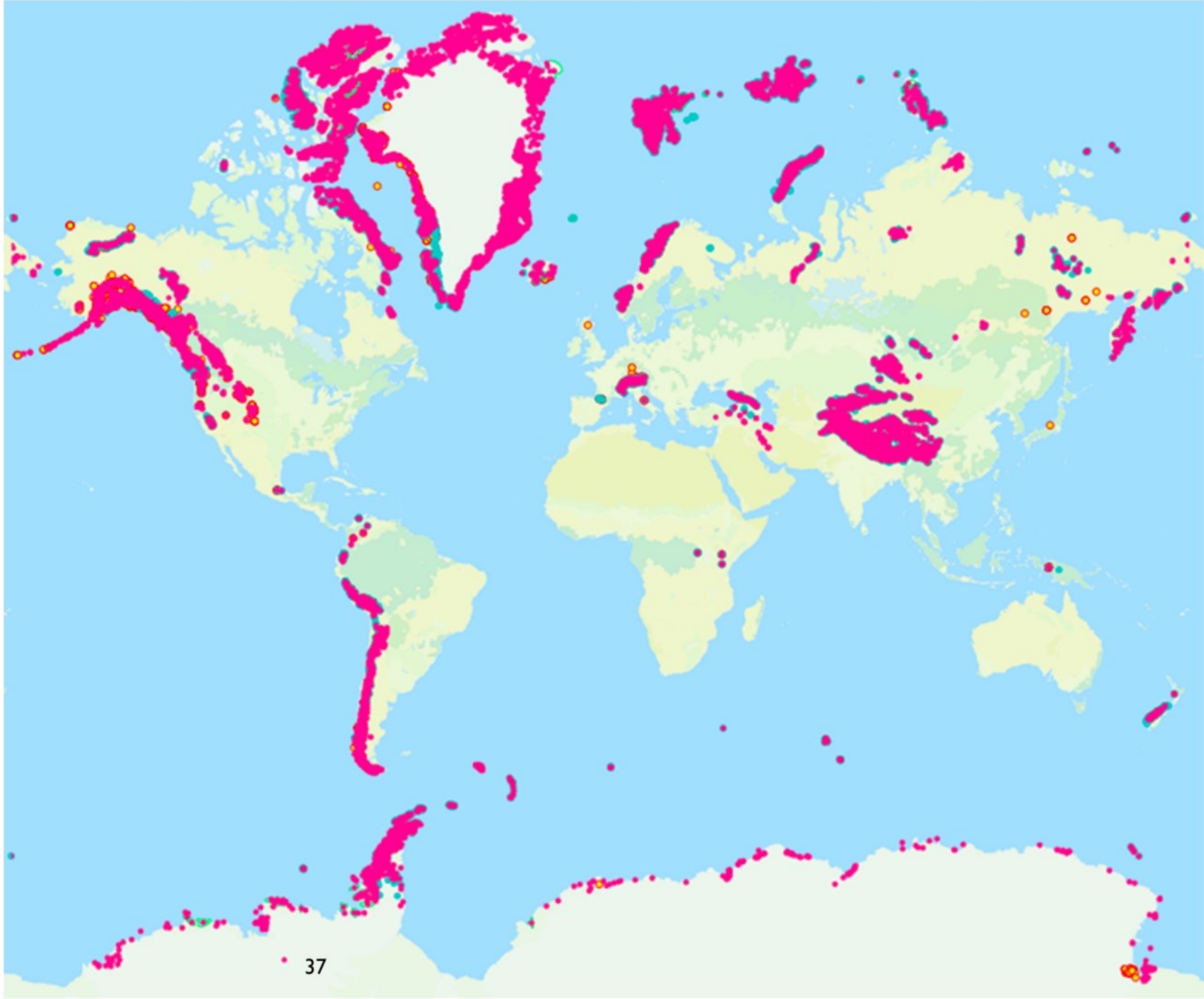




Sinais de um mundo mais quente

Geleiras / mantos de gelo

Enormes massas de gelo que se movem devagar sobre a terra



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

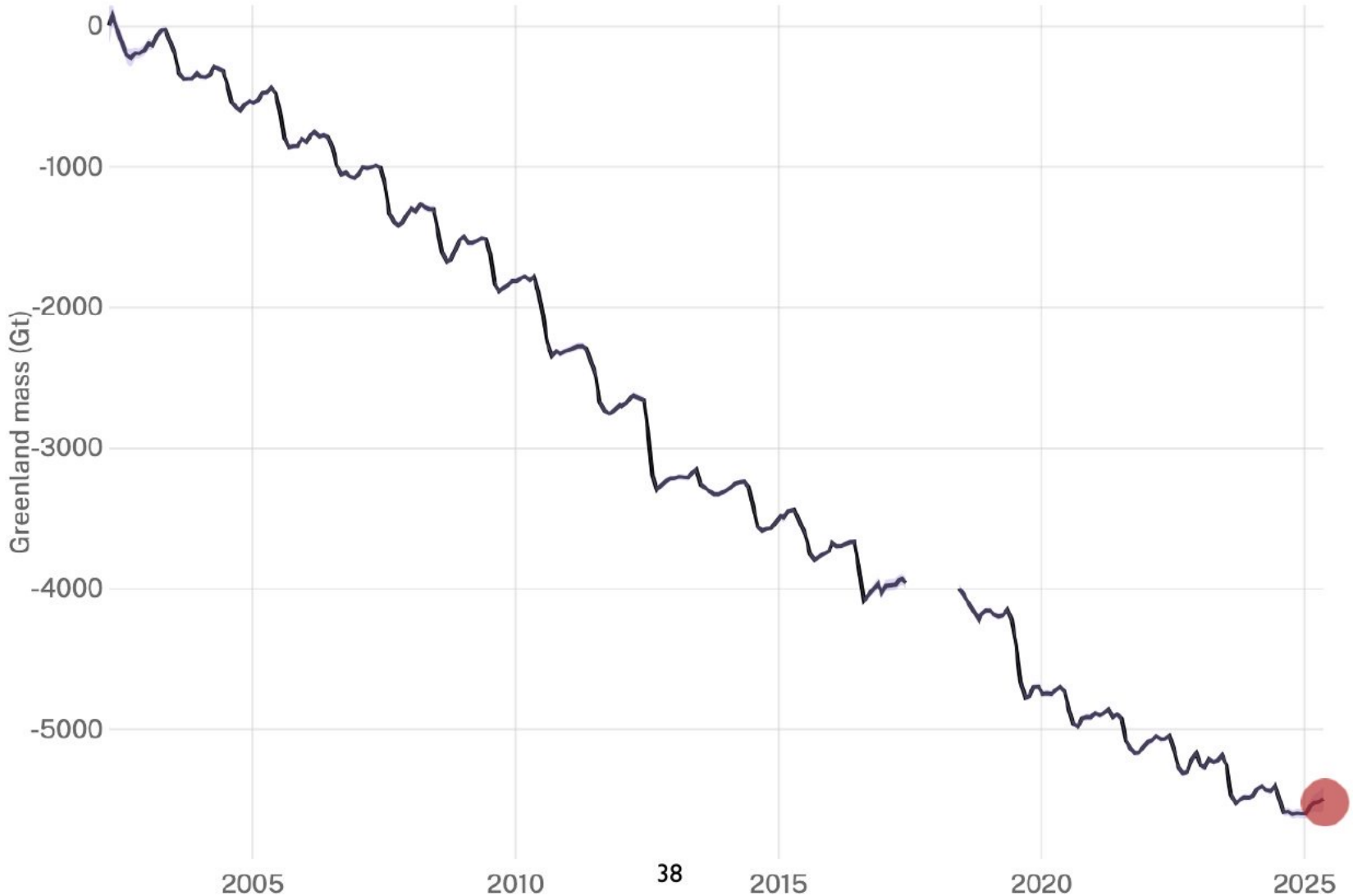
GREENLAND MASS VARIATION SINCE 2002

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

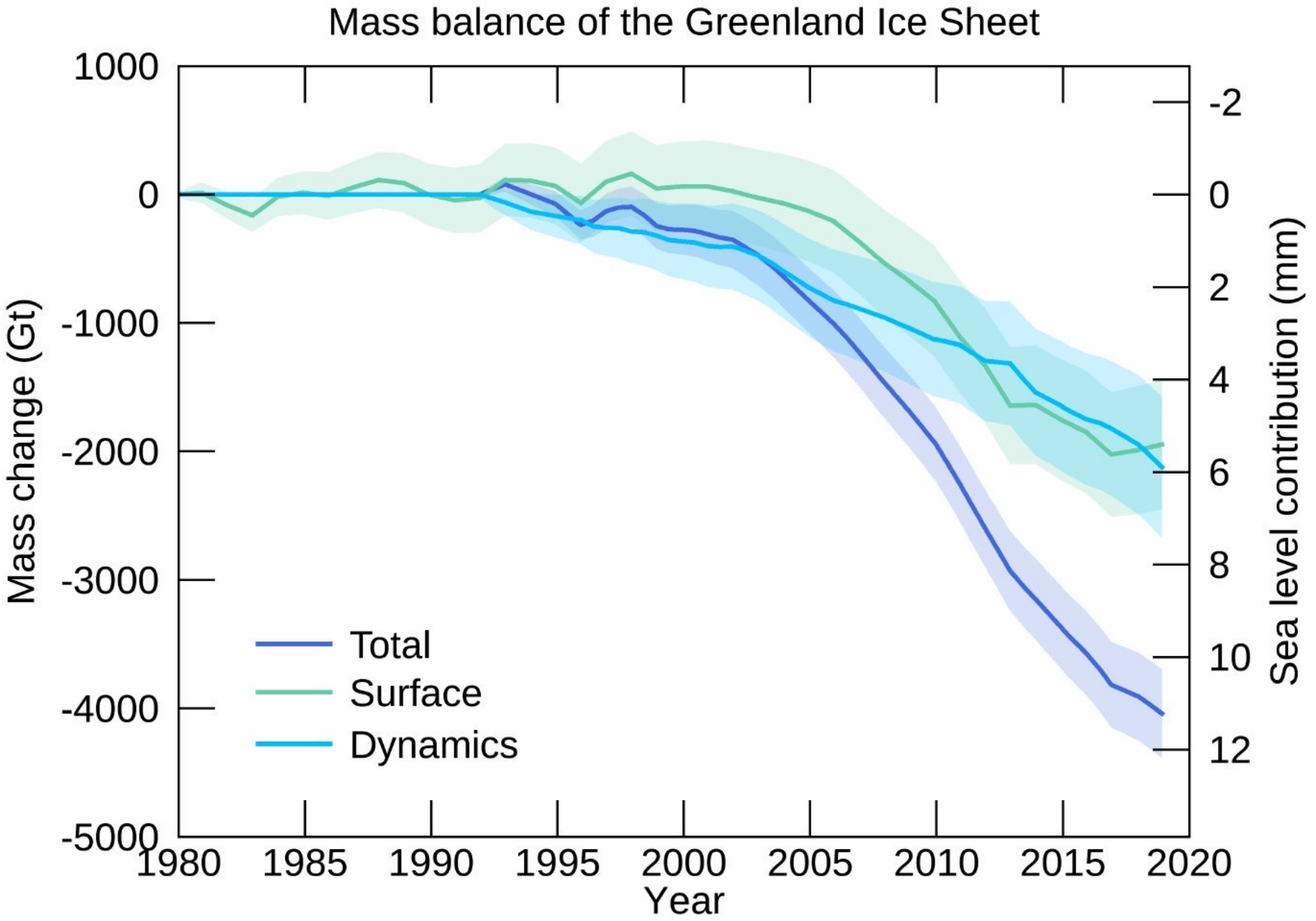


https://climate.nasa.gov/vital-signs/ice-sheets/

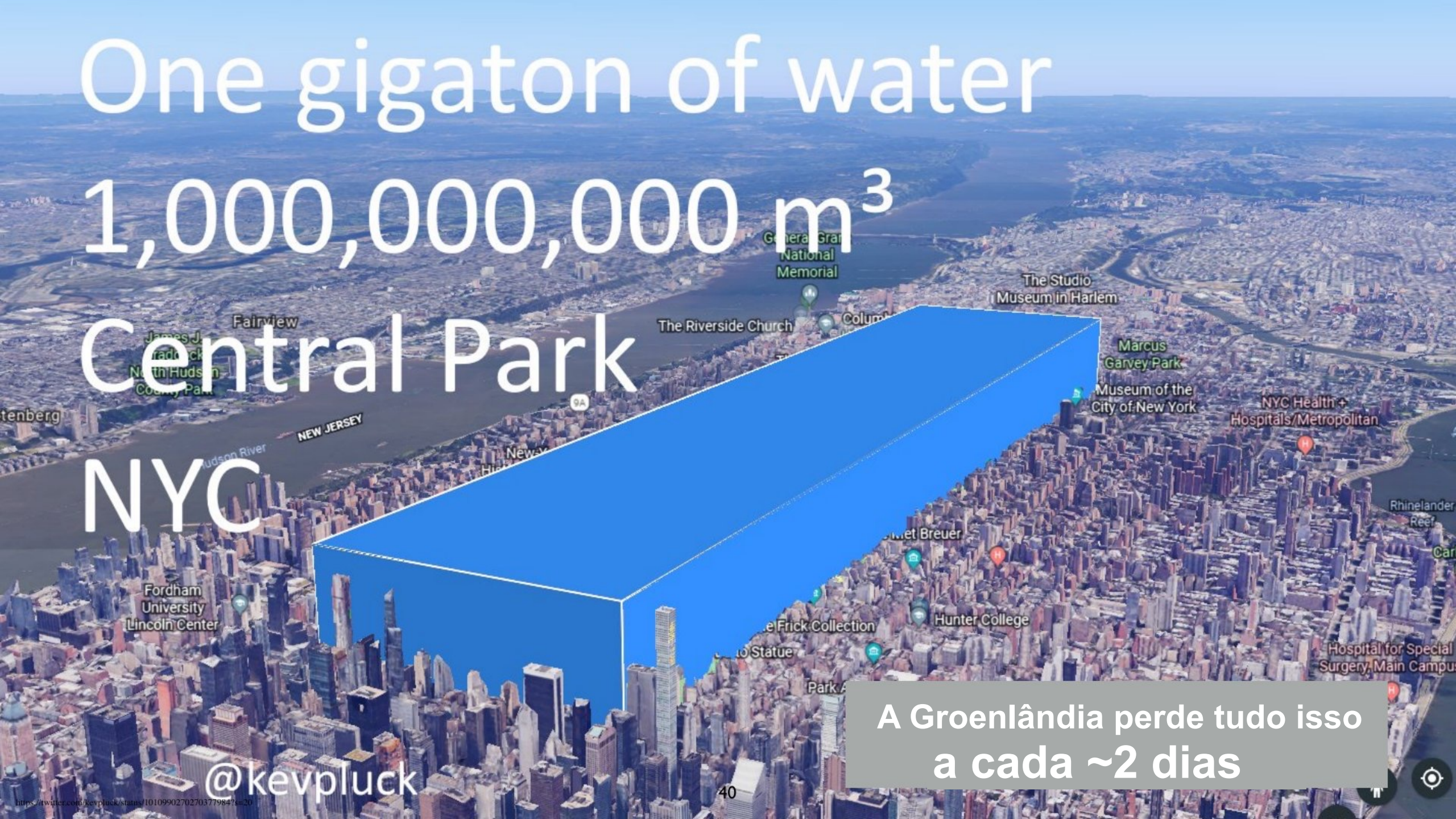
Manto de gelo da Groenlândia

1 Gt =

- Massa de todos os mamíferos terrestres (exceto os humanos)
- 2X a massa de todos os humanos da Terra
- 5,5 milhões de baleias-azuis
- 3 milhões de Boeings 747



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

Geleira McCarty, Alasca





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

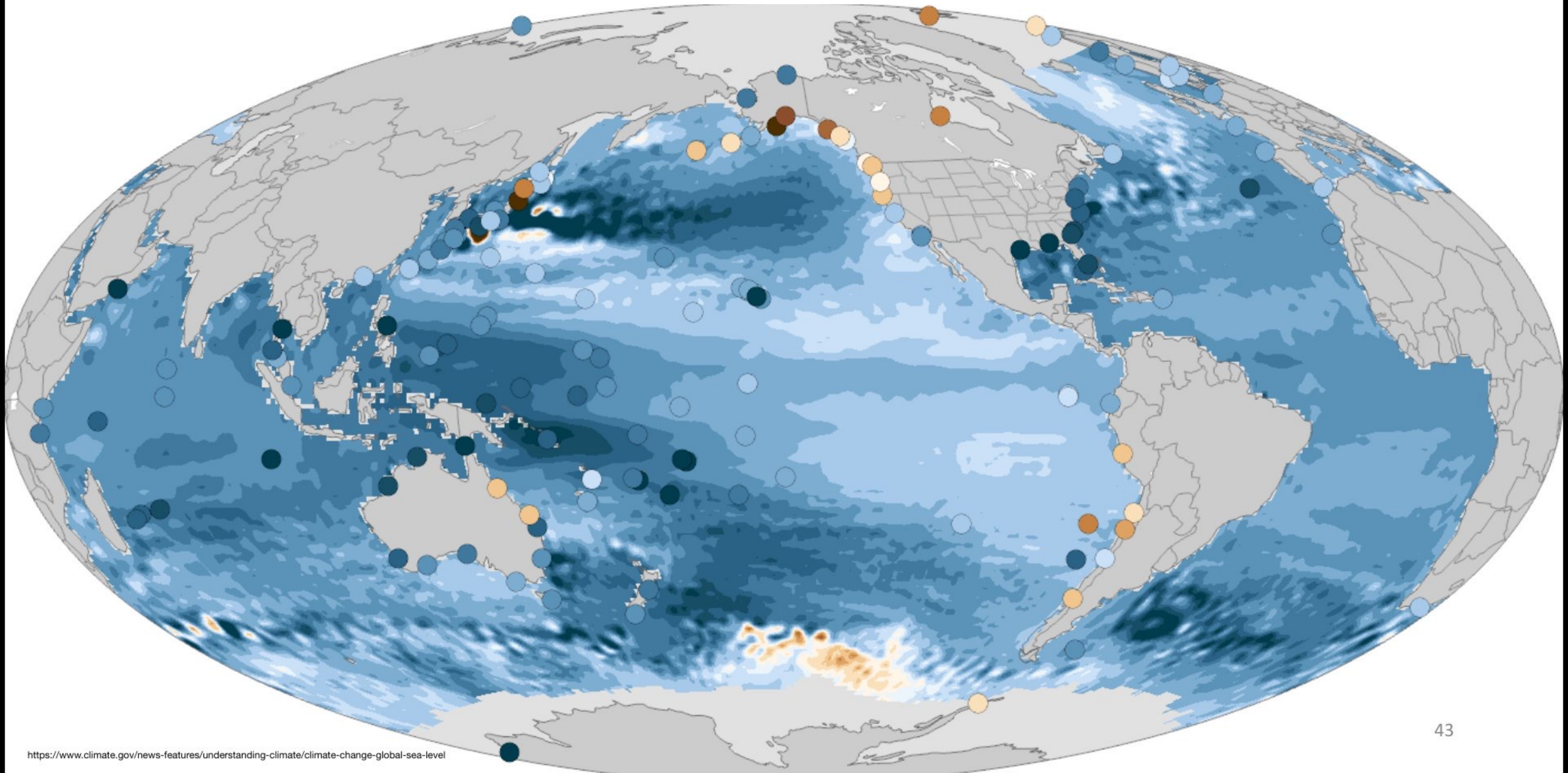
Geleira Blomstrandbreen
Svalbard, Noruega



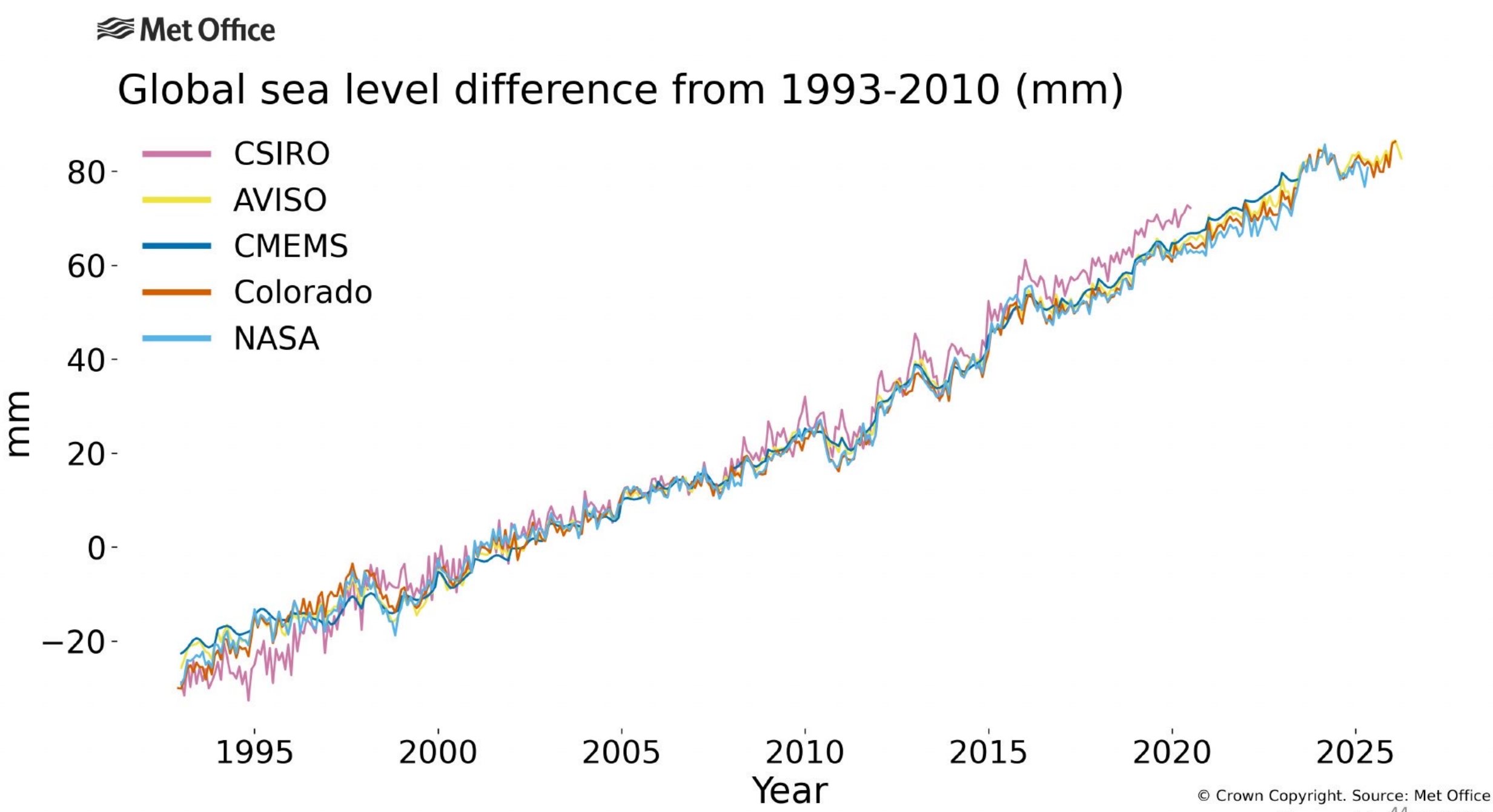


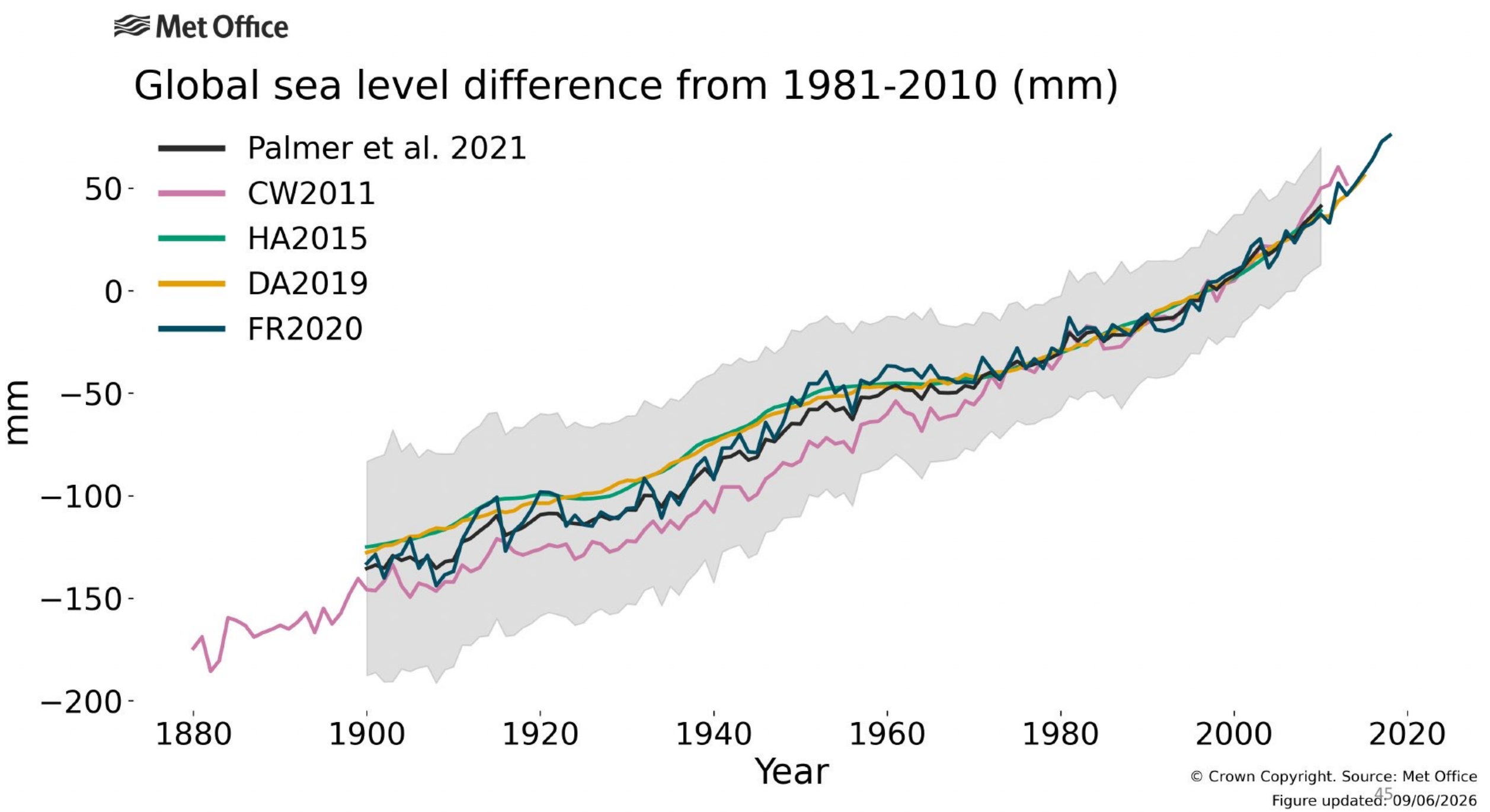
https://www.theguardian.com/environment/2024/nov/05/people-do-not-want-to-believe-it-is-true-the-photographer-capturing-the-vanishing-of-glaciers

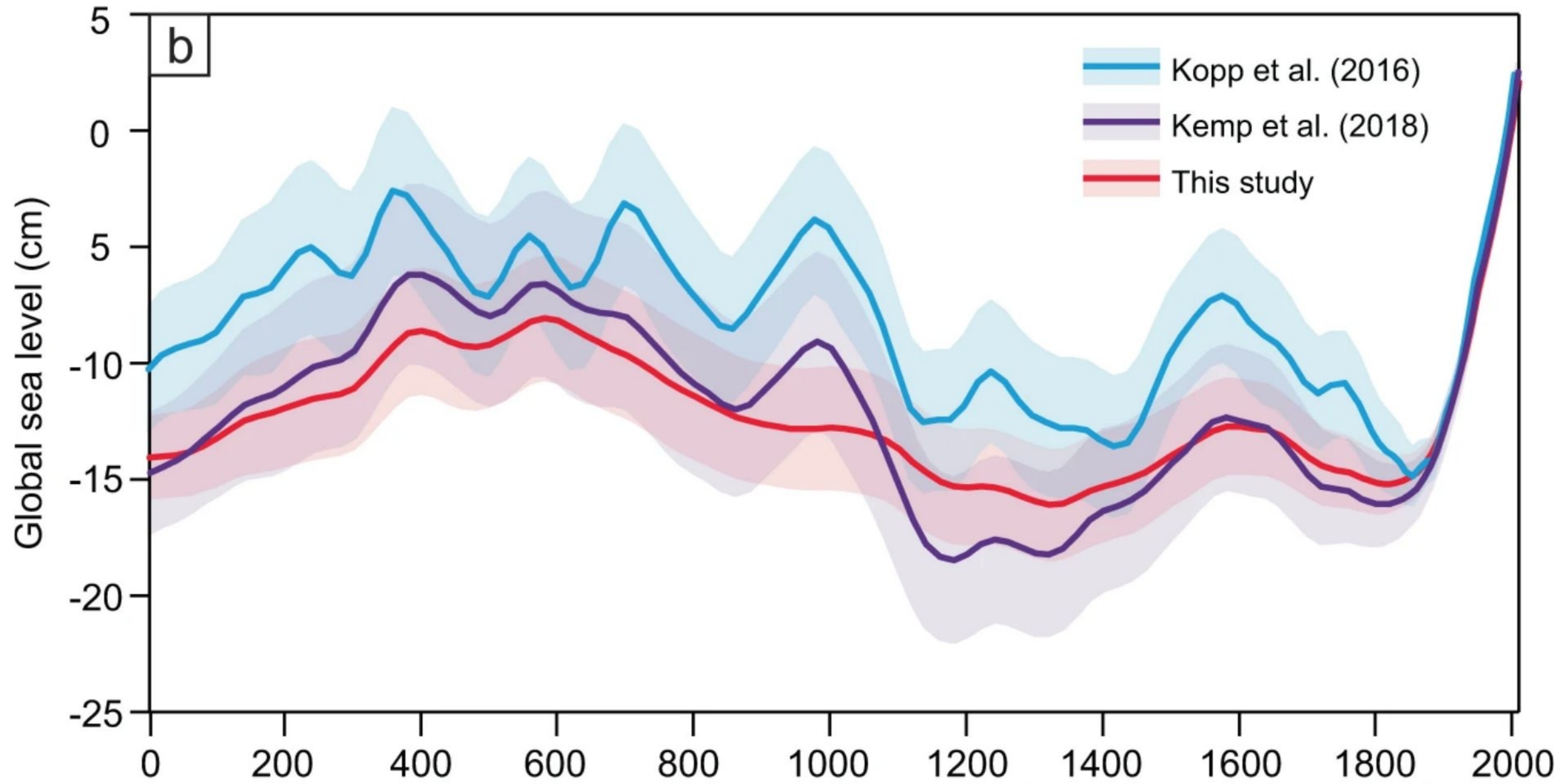
Variação do nível do mar (cm, 1993-2023)



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


Met Office
Global sea level difference from 1993-2010 (mm)
CSIRO
AVISO
CMEMS
Colorado
NASA
80
60
40
20
0
−20
mm
1995
2000
2005
2010
2015
2020
2025
Year
© Crown Copyright. Source: Met Office
Figure updated: 09/06/2026

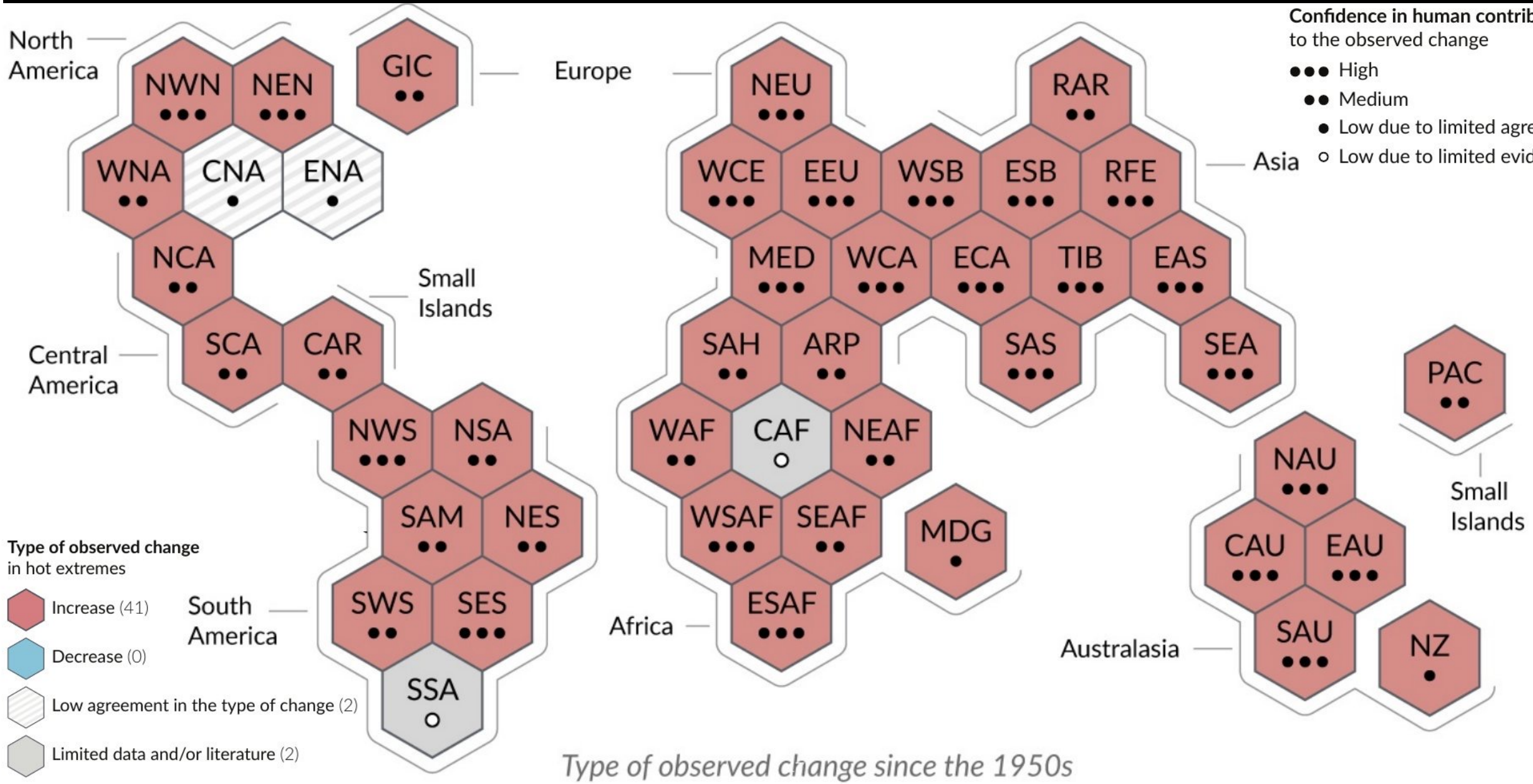

Met Office
Global sea level difference from 1981-2010 (mm)
Palmer et al. 2021
CW2011
HA2015
DA2019
FR2020
50
0
−50
−100
−150
−200
mm
1880
1900
1920
1940
1960
1980
2000
2020
Year
© Crown Copyright. Source: Met Office
Figure updated: 09/06/2026



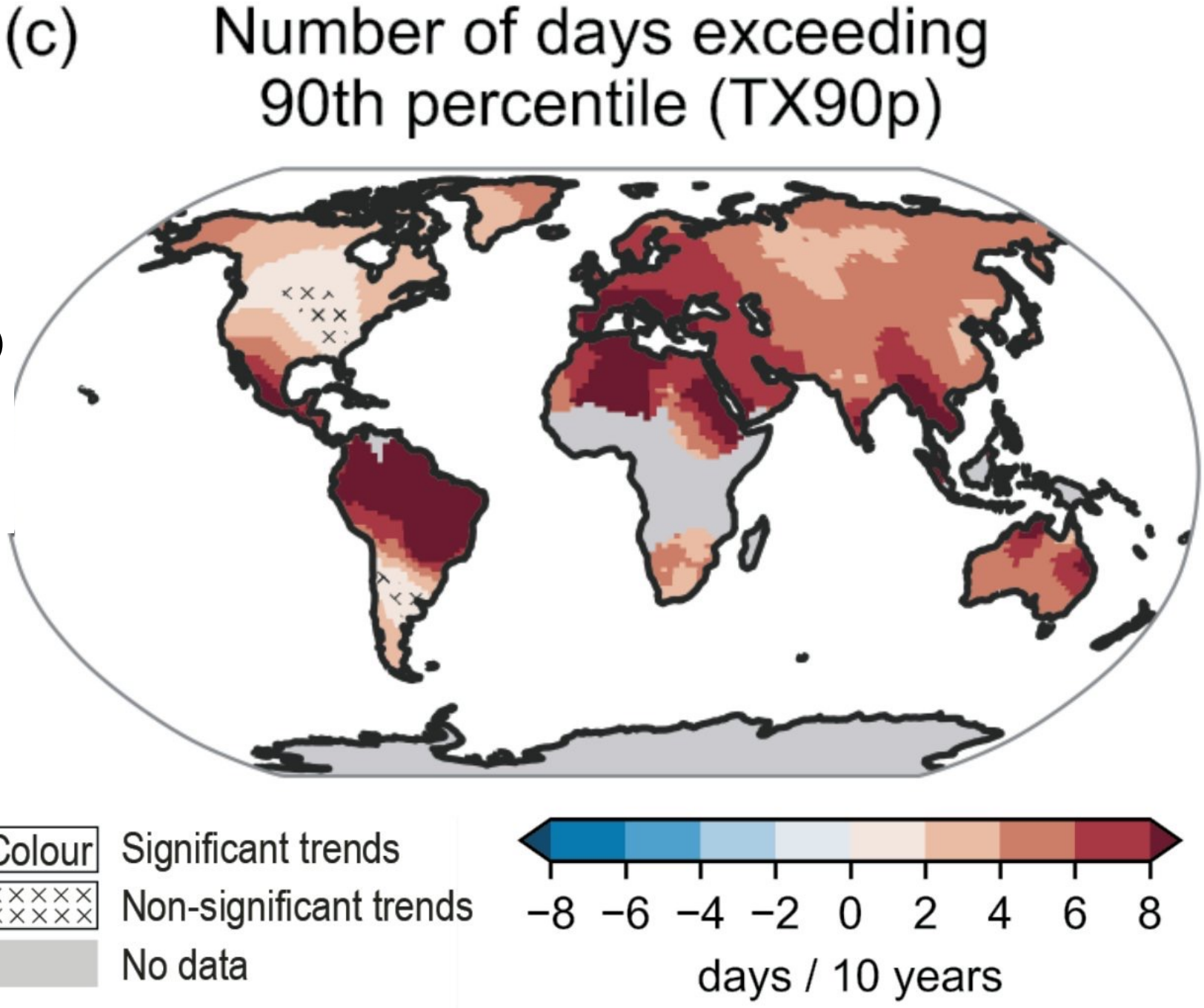
o mais alto em 2000 anos

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

As ondas de calor estão aumentando em quase toda parte



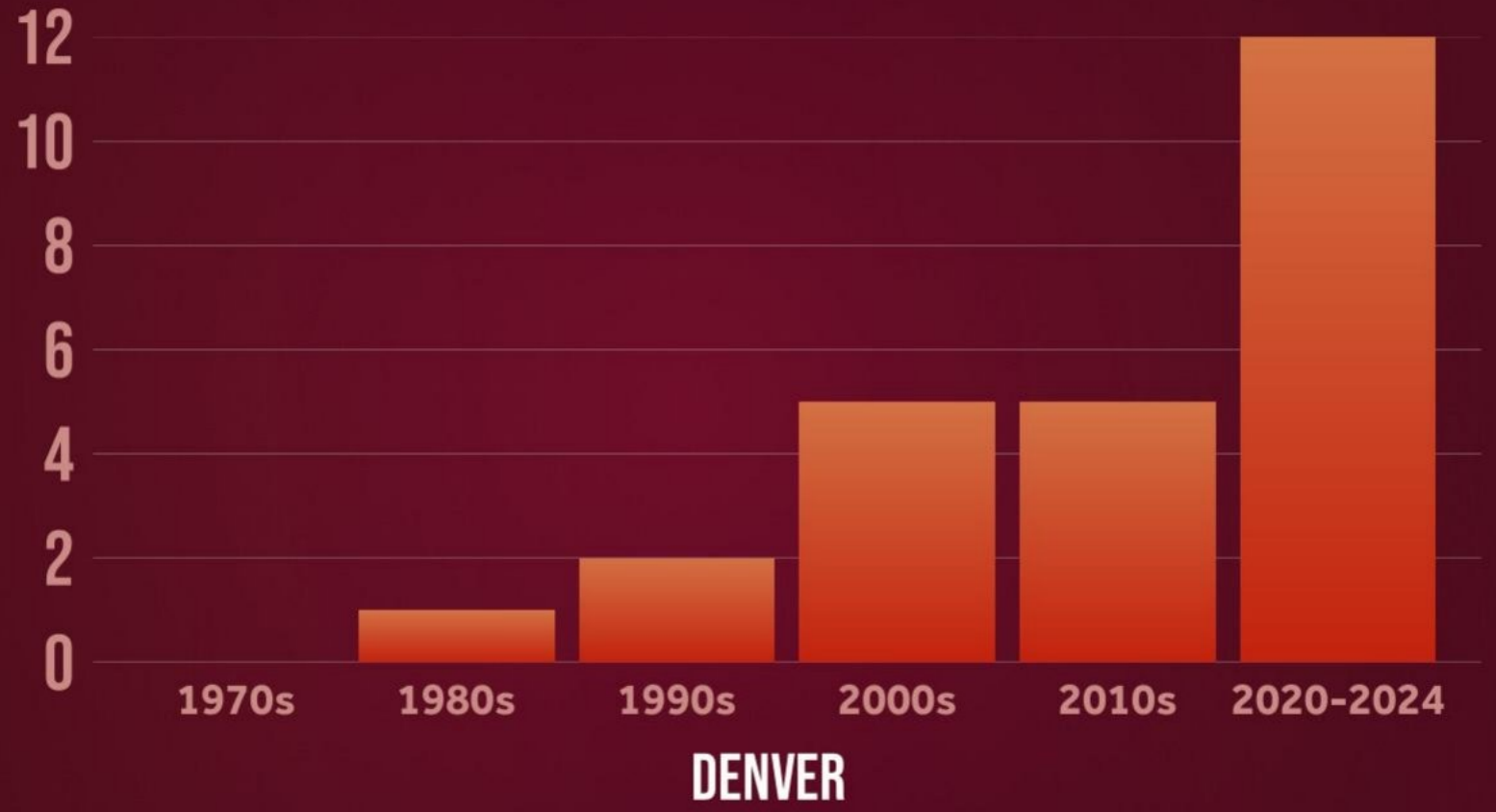
Tendência, dias de calor extremo (1960-2018)



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

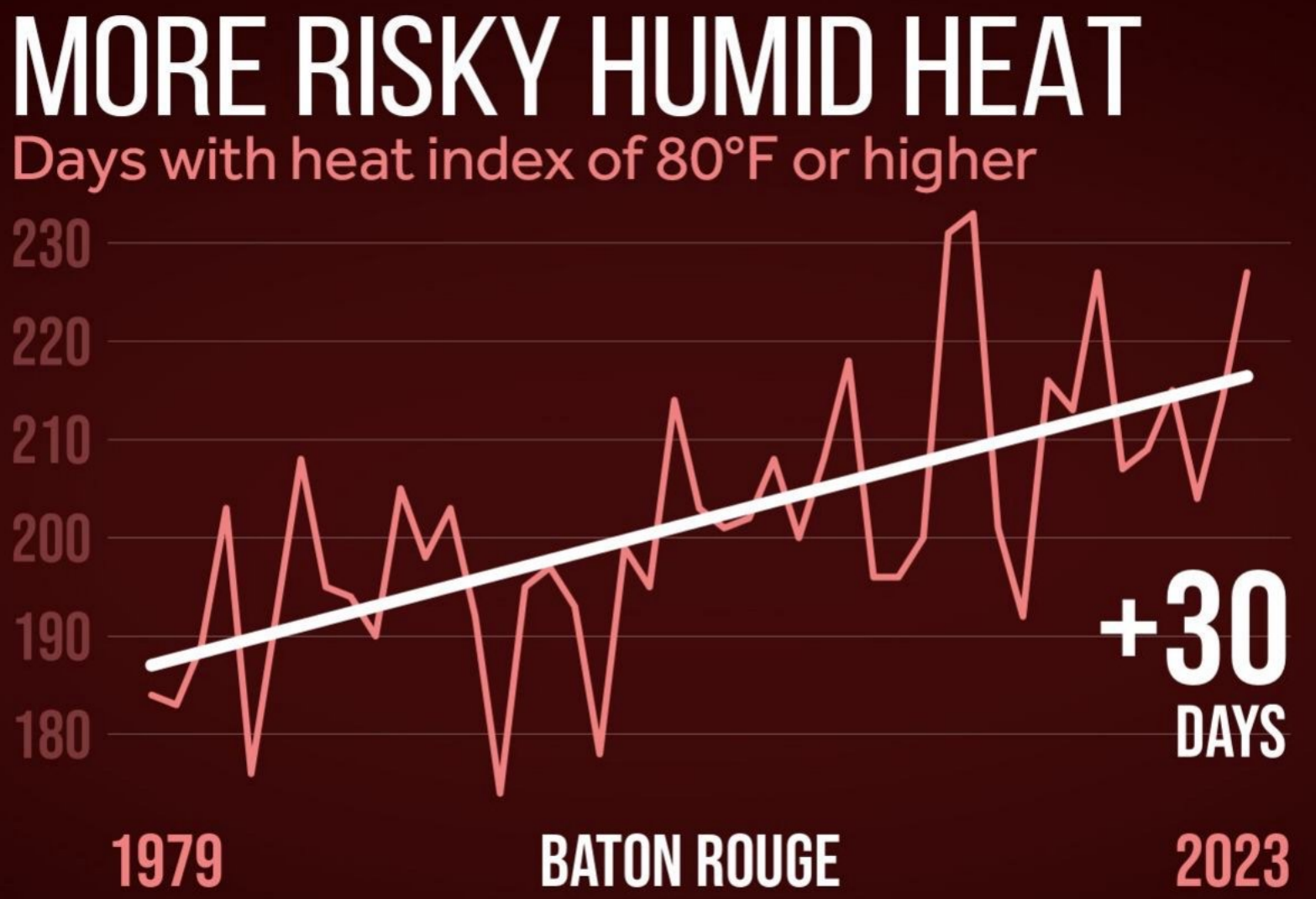
CLIMATE CHANGE-FUELED EXTREME HEAT

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

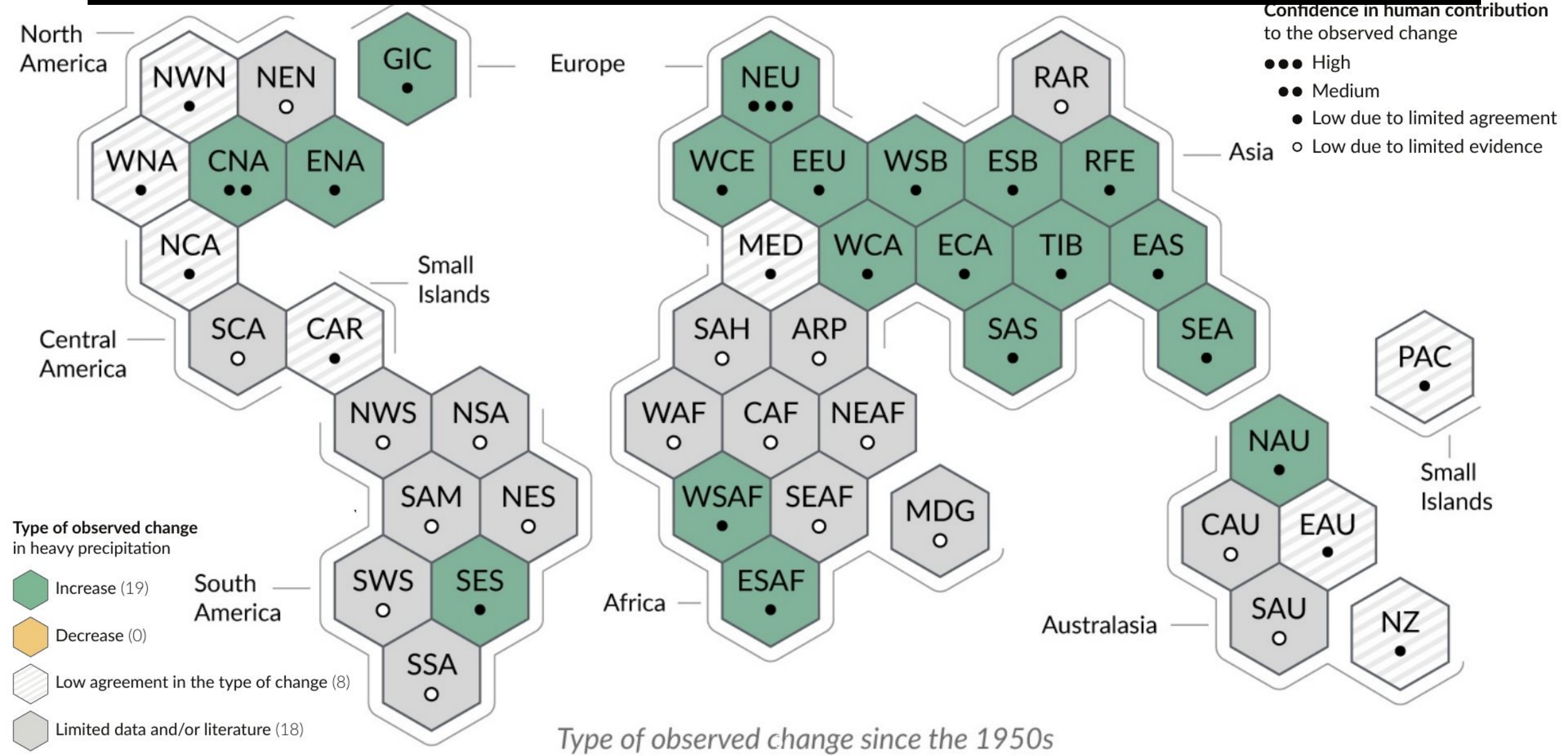


Average annual summer (June-August) days with maximum temperatures at or above 96.1°F (local 95th percentile) and a Climate Shift Index level of 2 or higher.
Source: ERA5 and Climate Central's Climate Shift Index system.

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

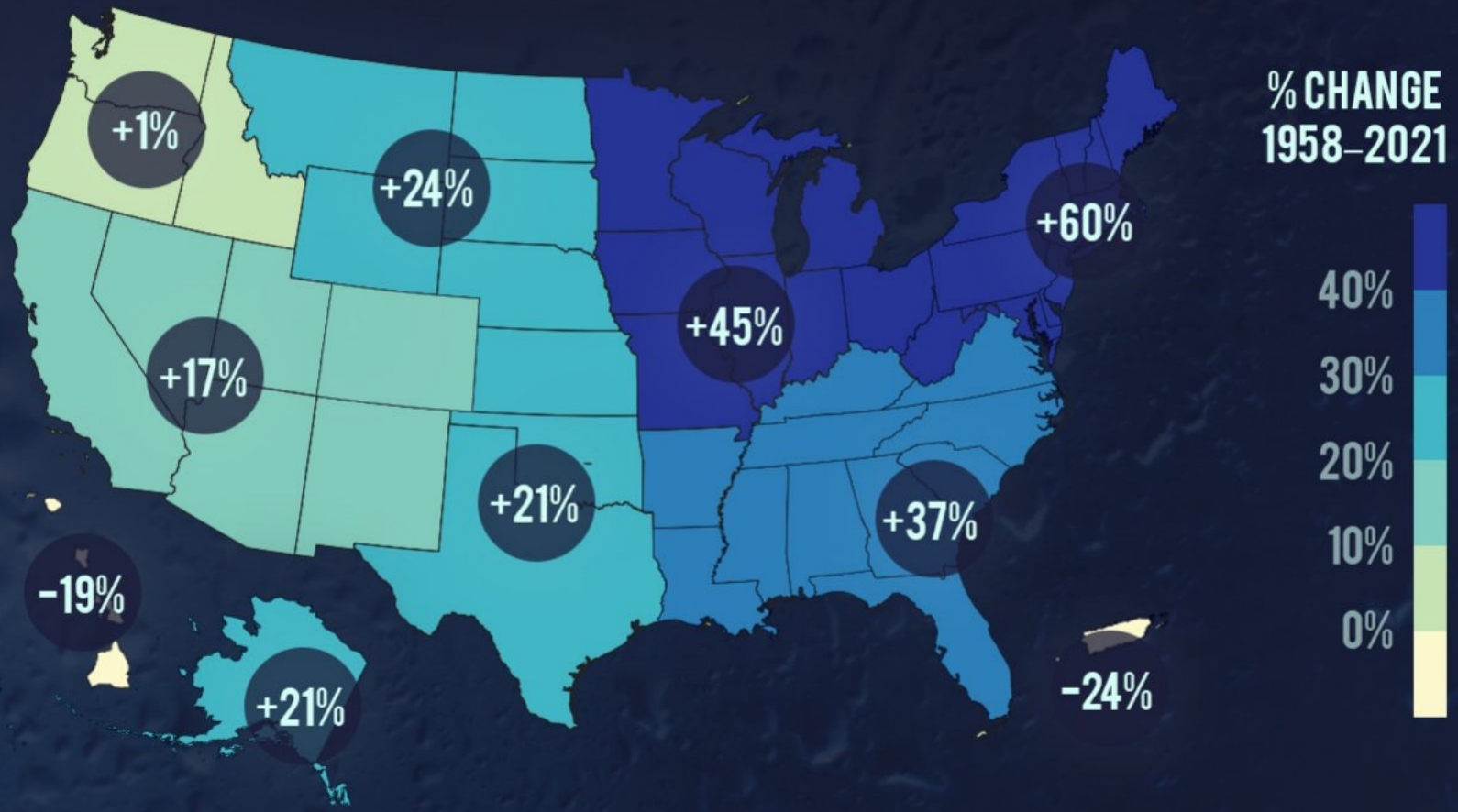
Tempestades mais intensas em algumas regiões



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

Como sabemos que as mudanças que vemos vêm das atividades humanas?

Detecção: COMO as coisas mudaram?
Ex.: está ficando mais quente?

Atribuição: POR QUE as coisas mudaram?
Ex.: está ficando mais quente por causa das emissões antrópicas de gases de efeito estufa?

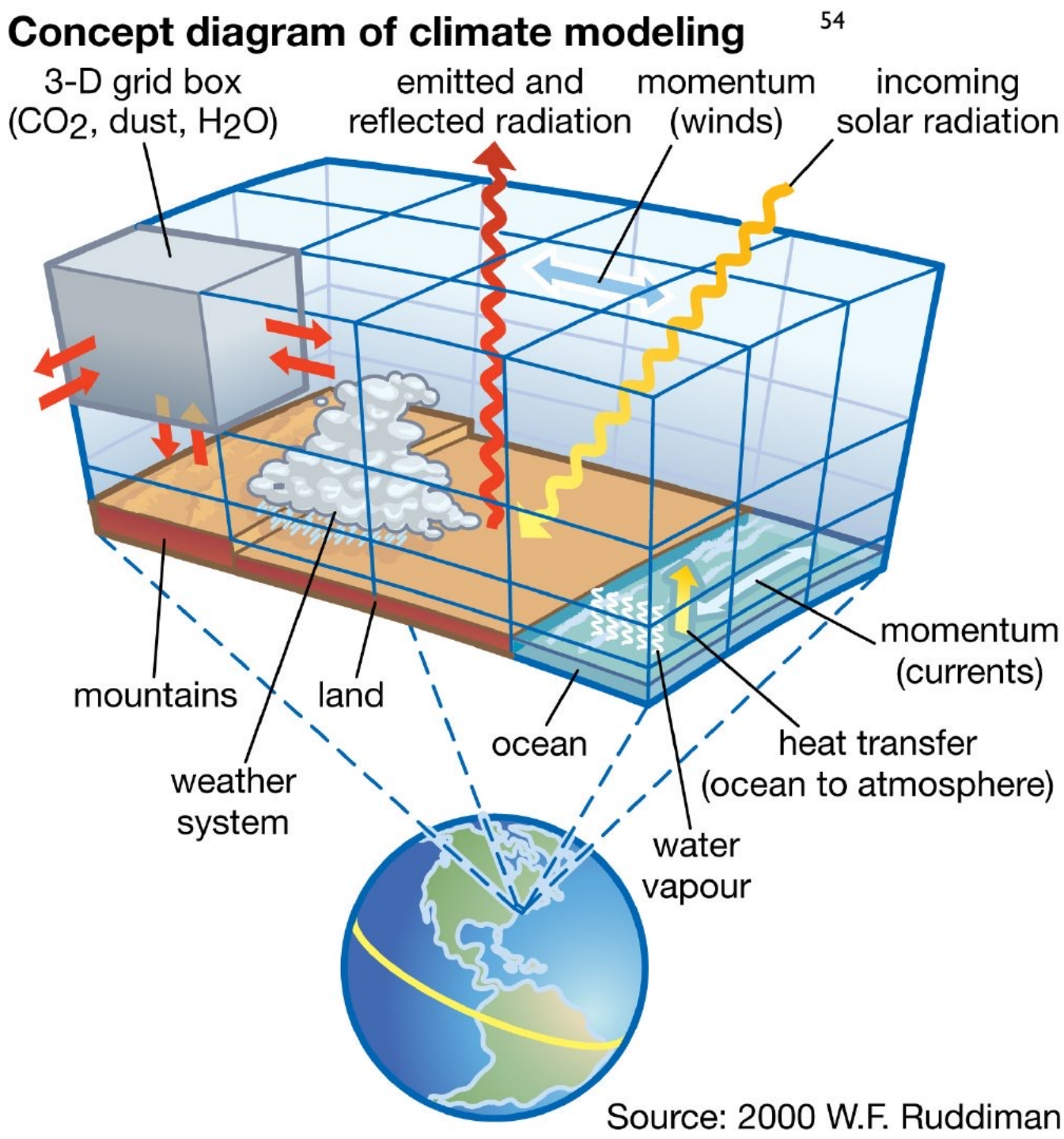
Modelos climáticos

programas de computador que simulam o estado do sistema climático com base em forçantes prescritas (vulcões, GEE, variabilidade solar etc.)

Ferramentas importantes para a atribuição e o estudo do clima futuro

a classe mais comum de modelo climático é o modelo de circulação geral (MCG)

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



Hotter

What's Really Warming the World?

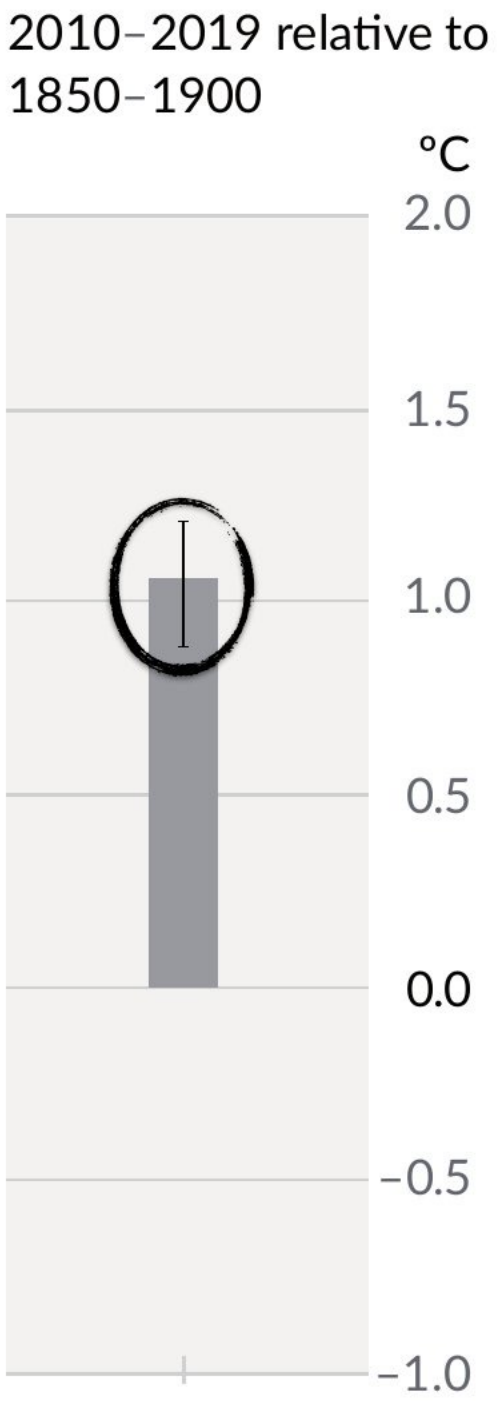
Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet's rising temperature? Watch to see how much different factors, both natural and industrial, contribute to global warming, based on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

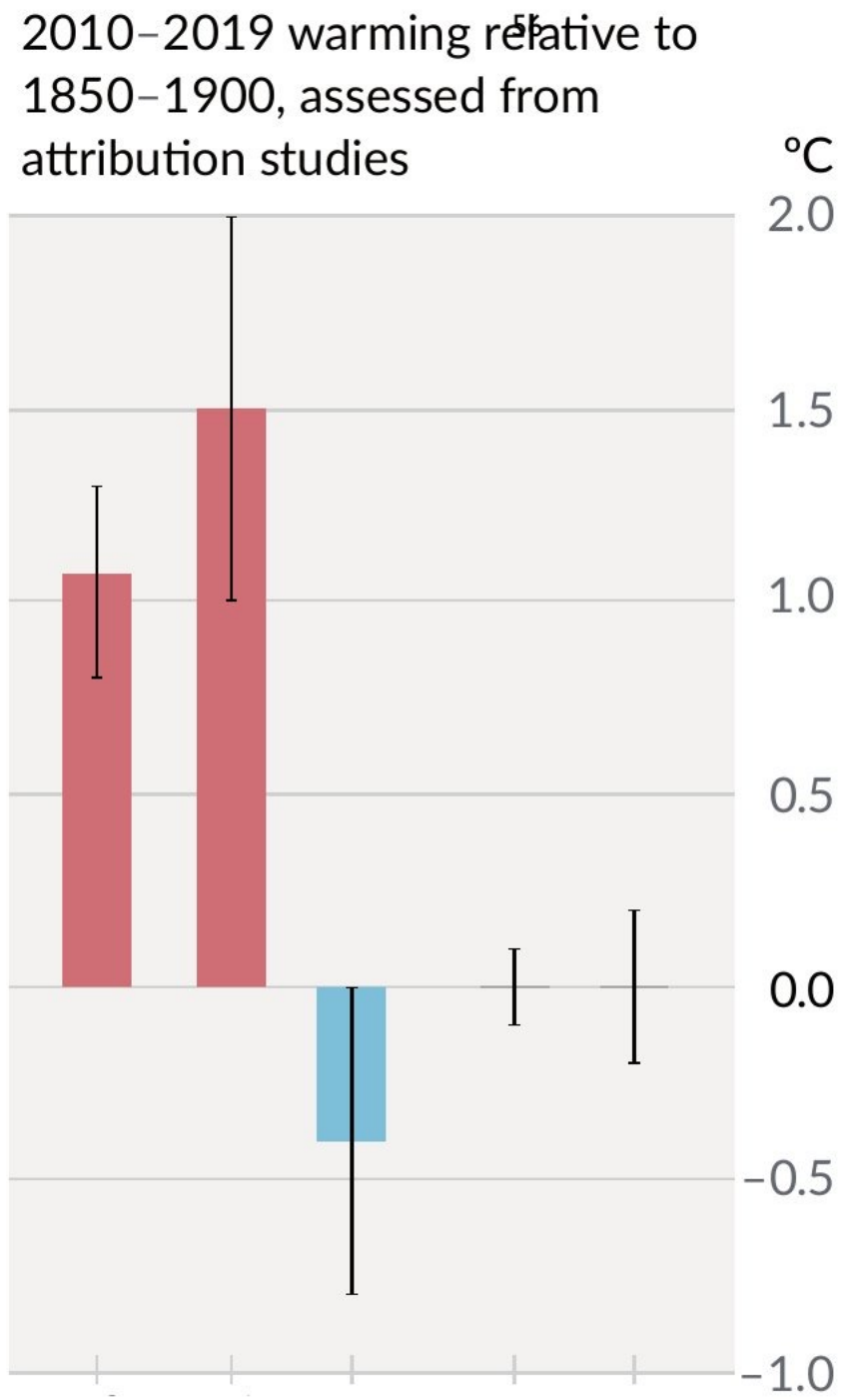


Colder

Based on an interactive by Bloomberg

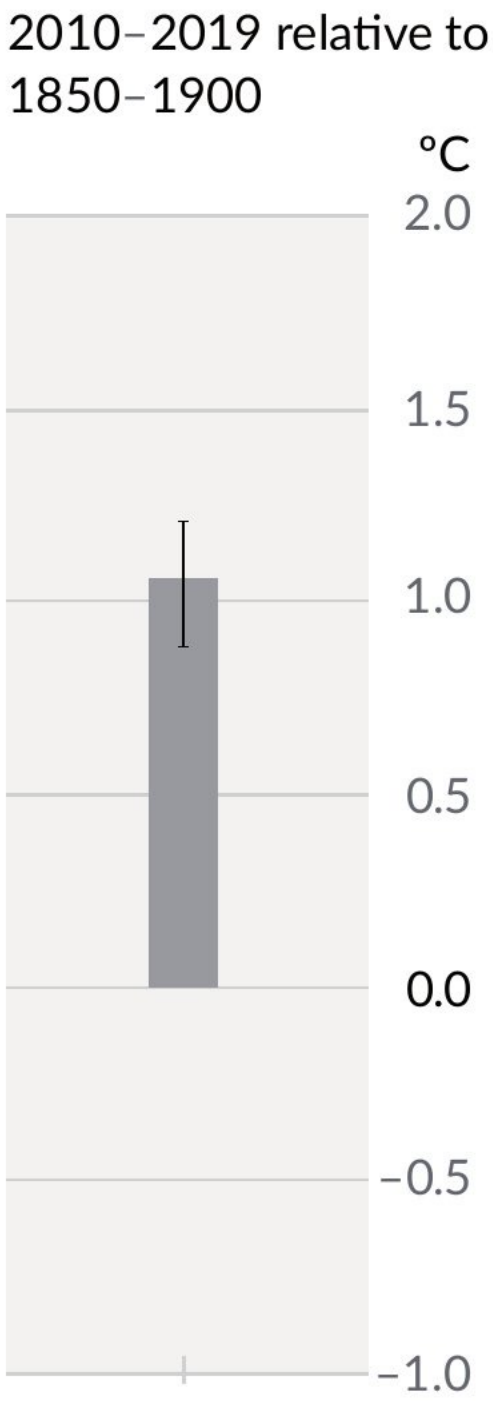
Em 2019, o mundo já tinha aquecido ~1,1 °C desde 1850-1900

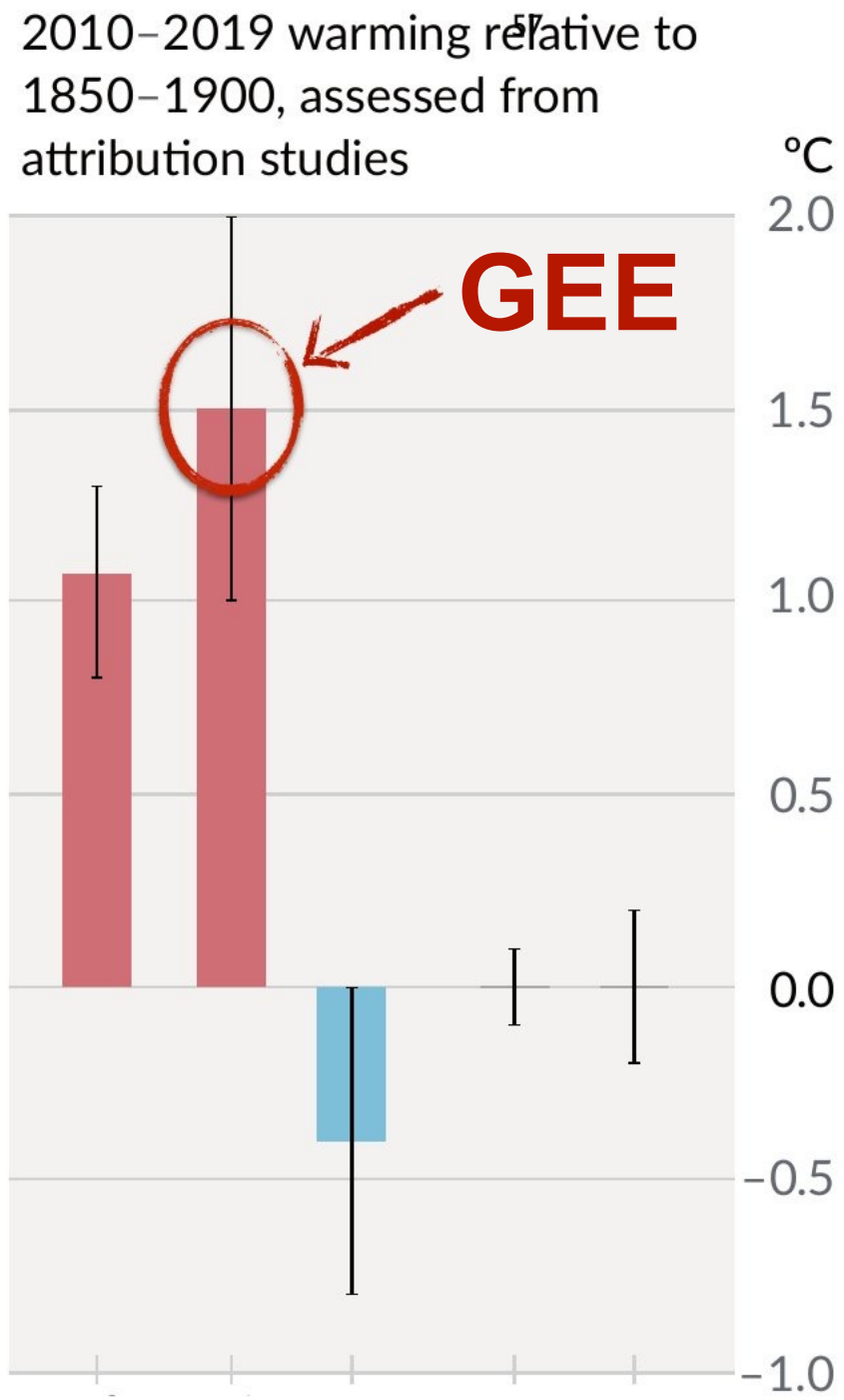




https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

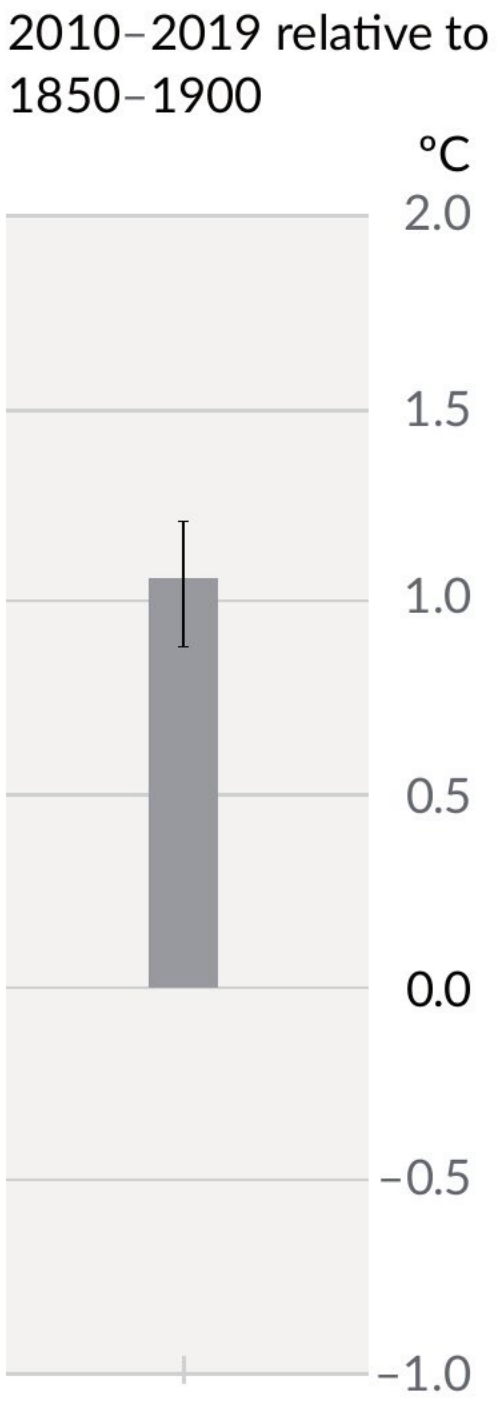
Só os GEE humanos teriam aquecido o mundo em 1.5º

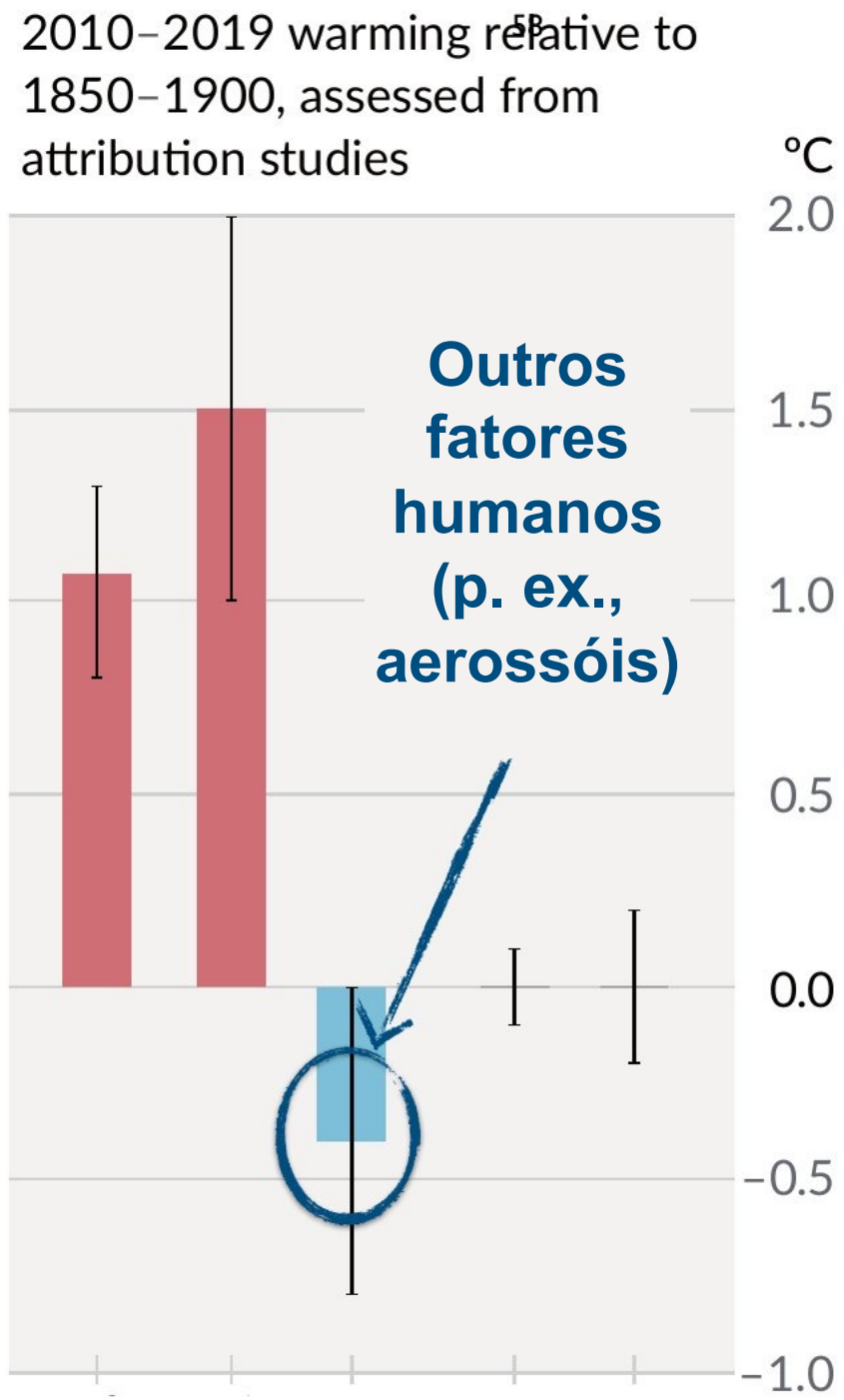




https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

Mas outros fatores humanos (aerossóis, mudança no uso da terra) compensaram parte desse aquecimento

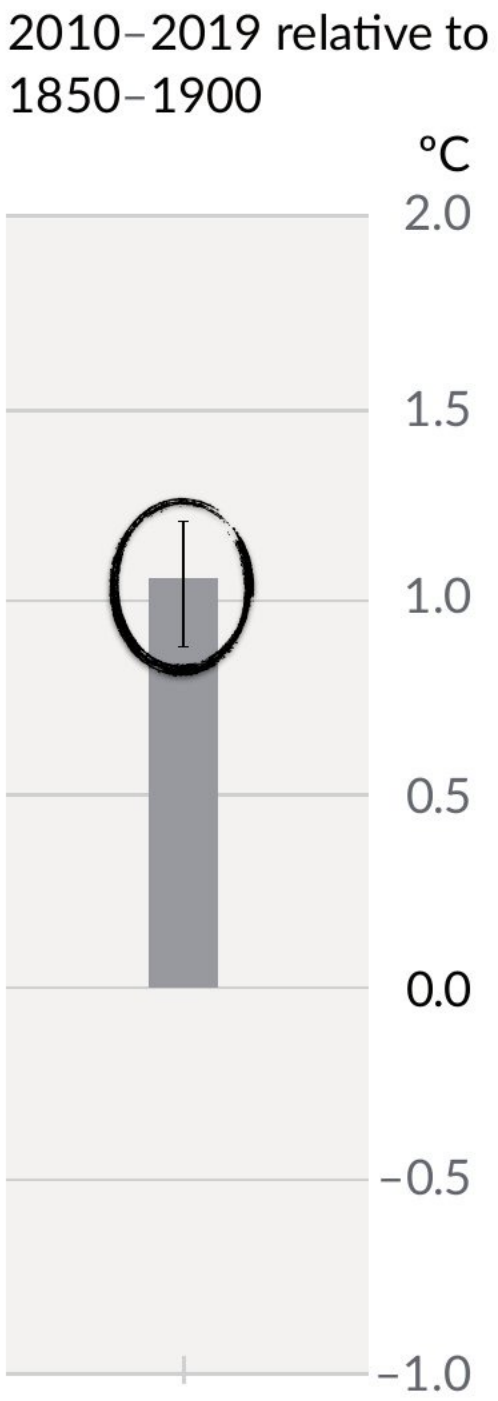


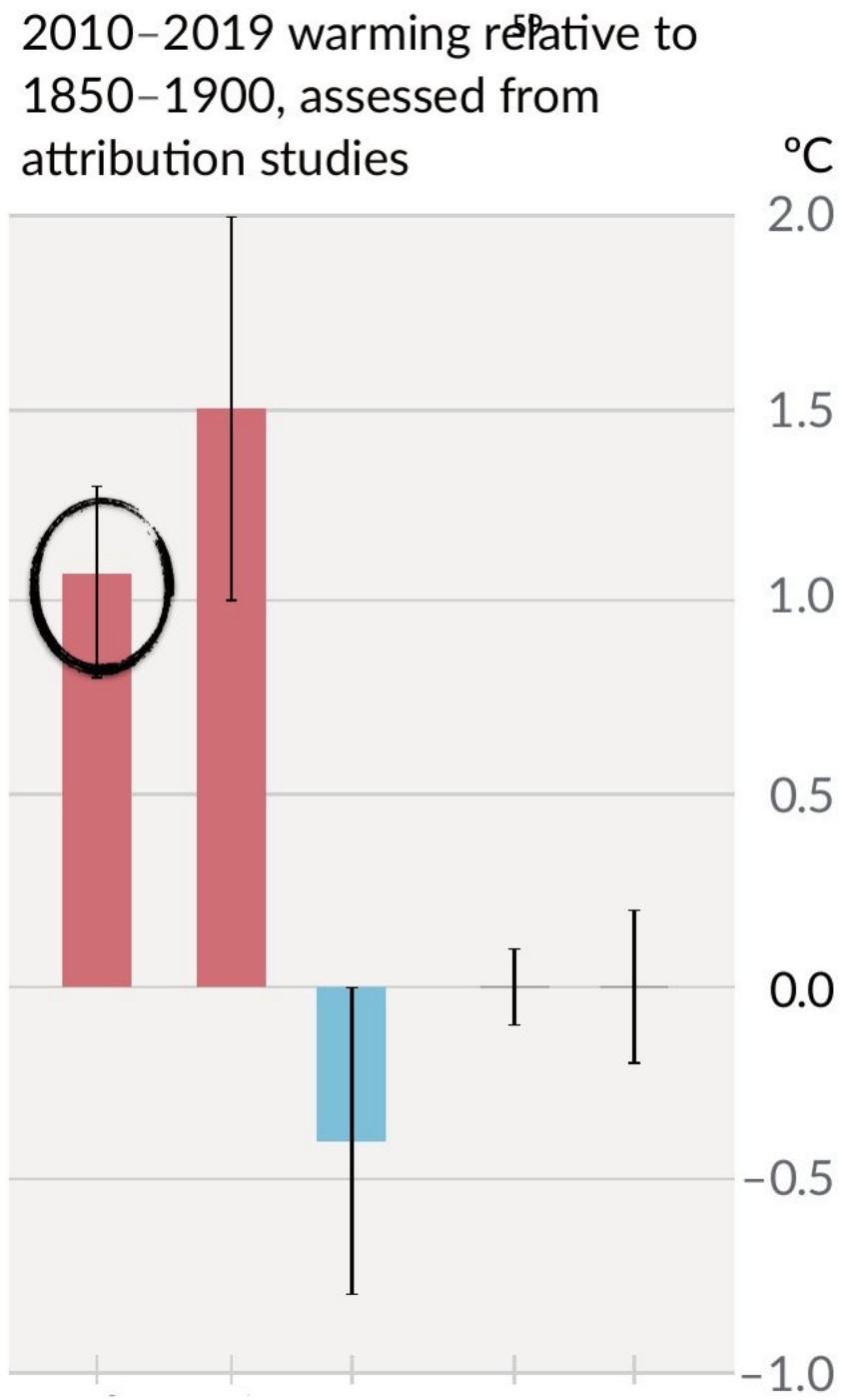


https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

Somados,
todos os
forçamentos humanos
aqueceram o

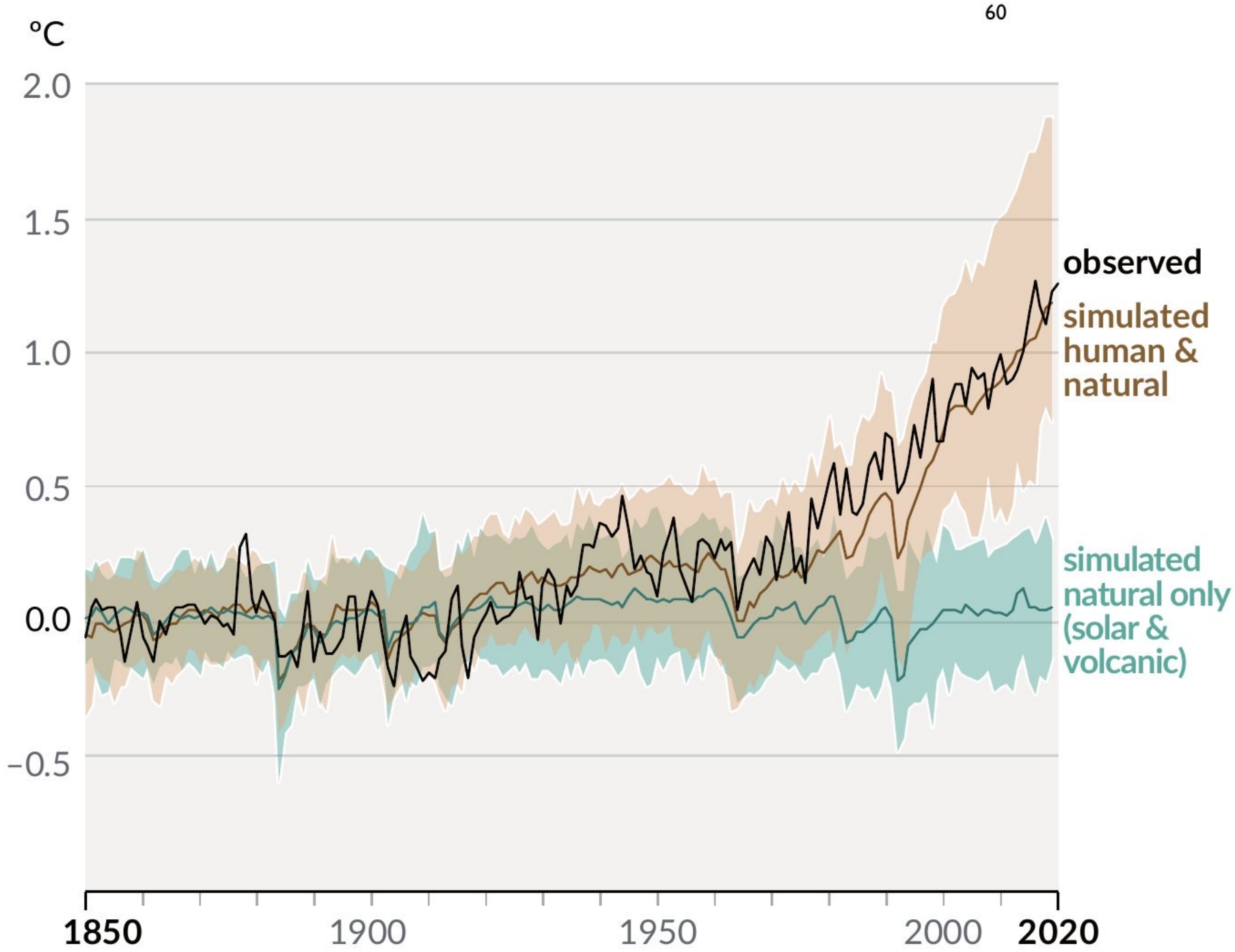
planeta em 1,1 °C





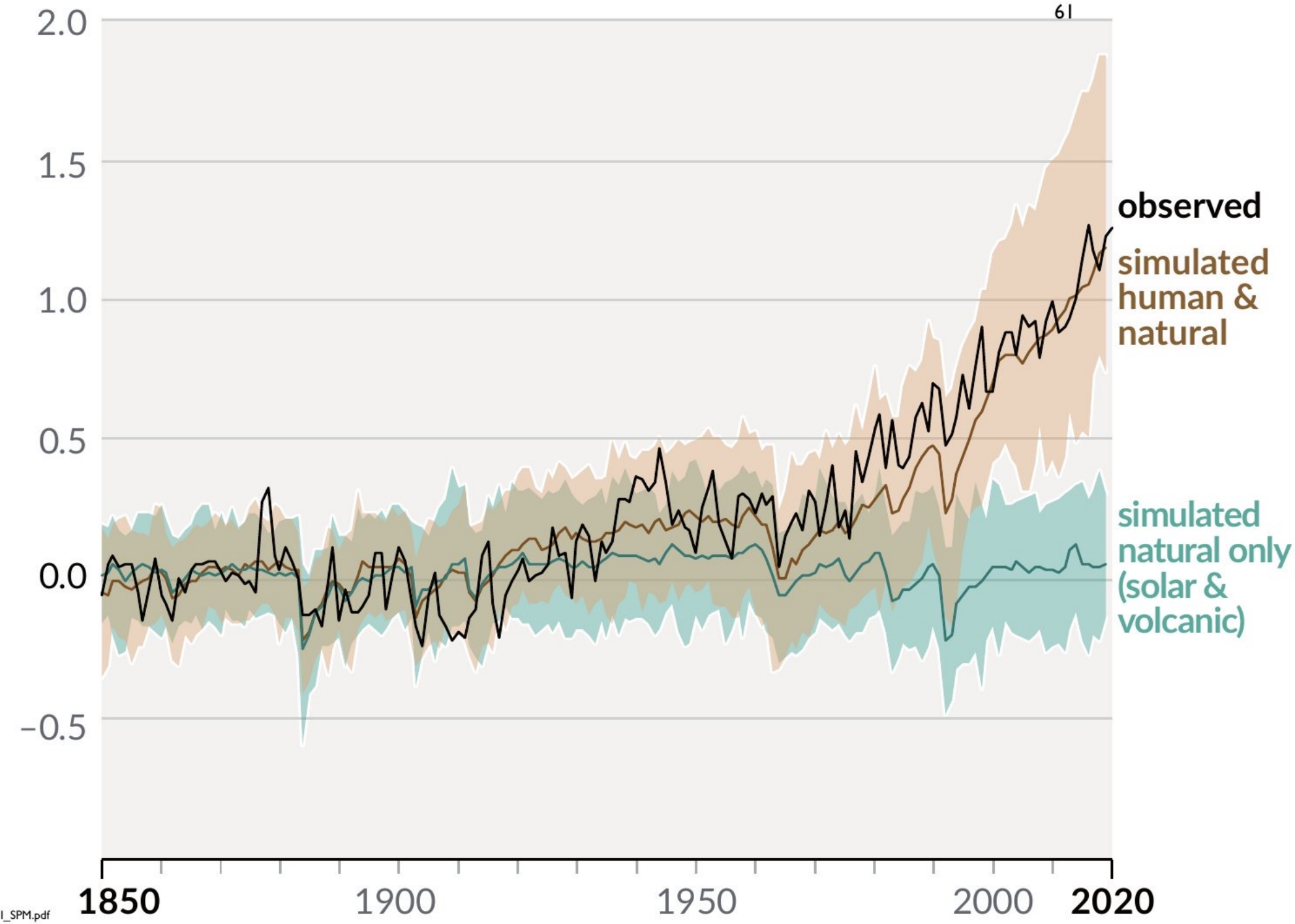
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

SÓ os modelos que incluem fatores humanos conseguem reproduzir aproximadamente o aquecimento observado



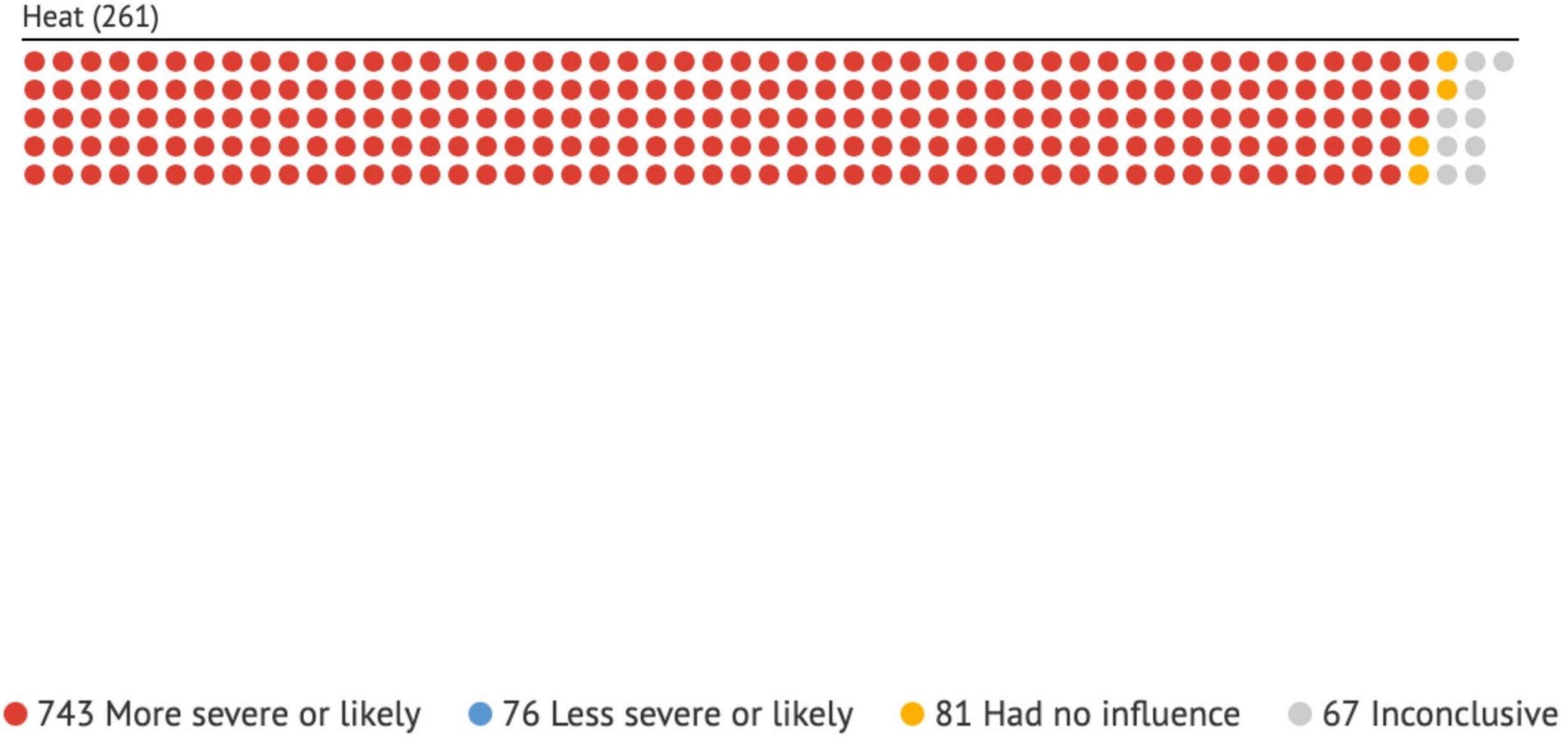
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

SÓ os modelos que incluem fatores humanos conseguem reproduzir aproximadamente o aquecimento observado



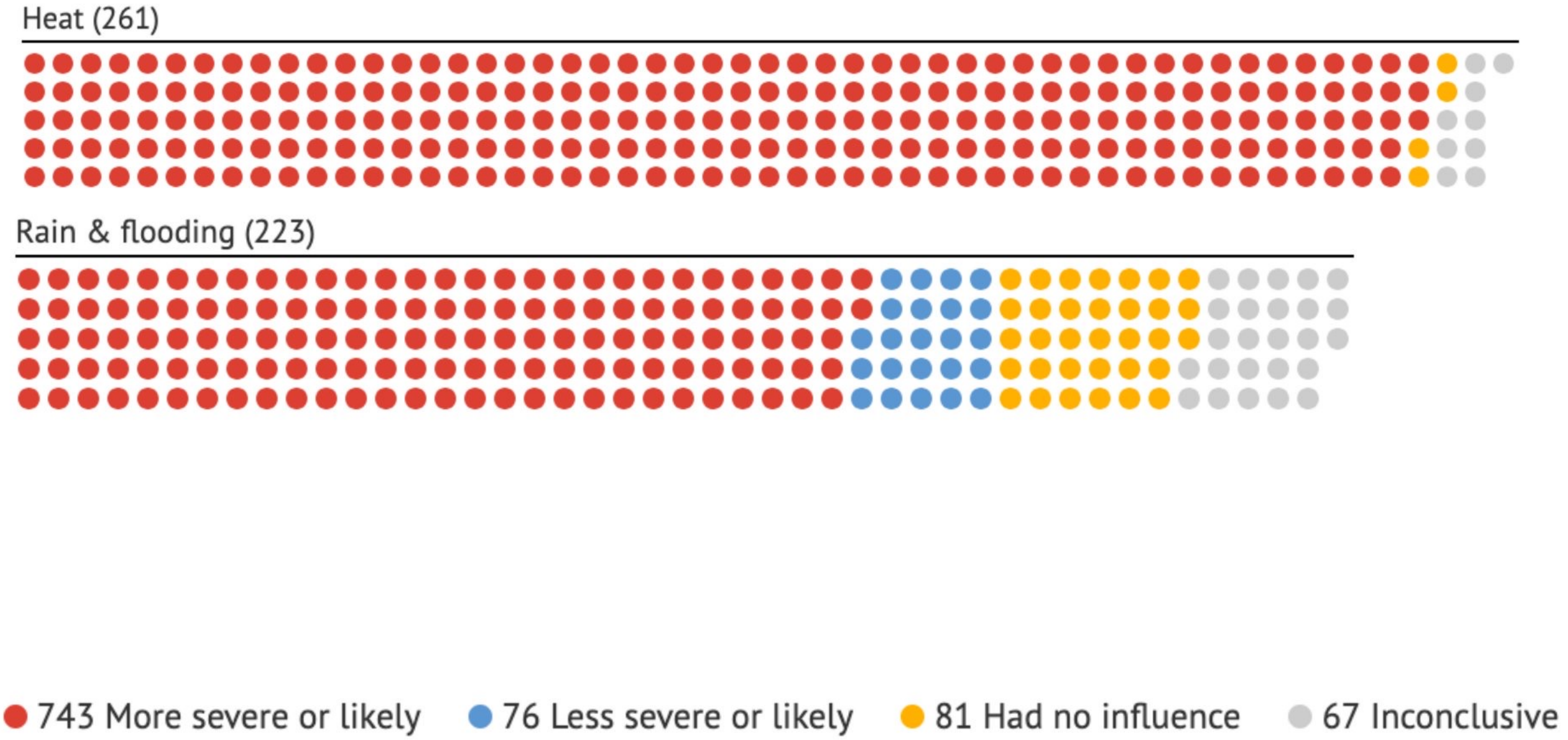
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

A mudança climática já está aumentando a severidade e o risco de muitos eventos extremos



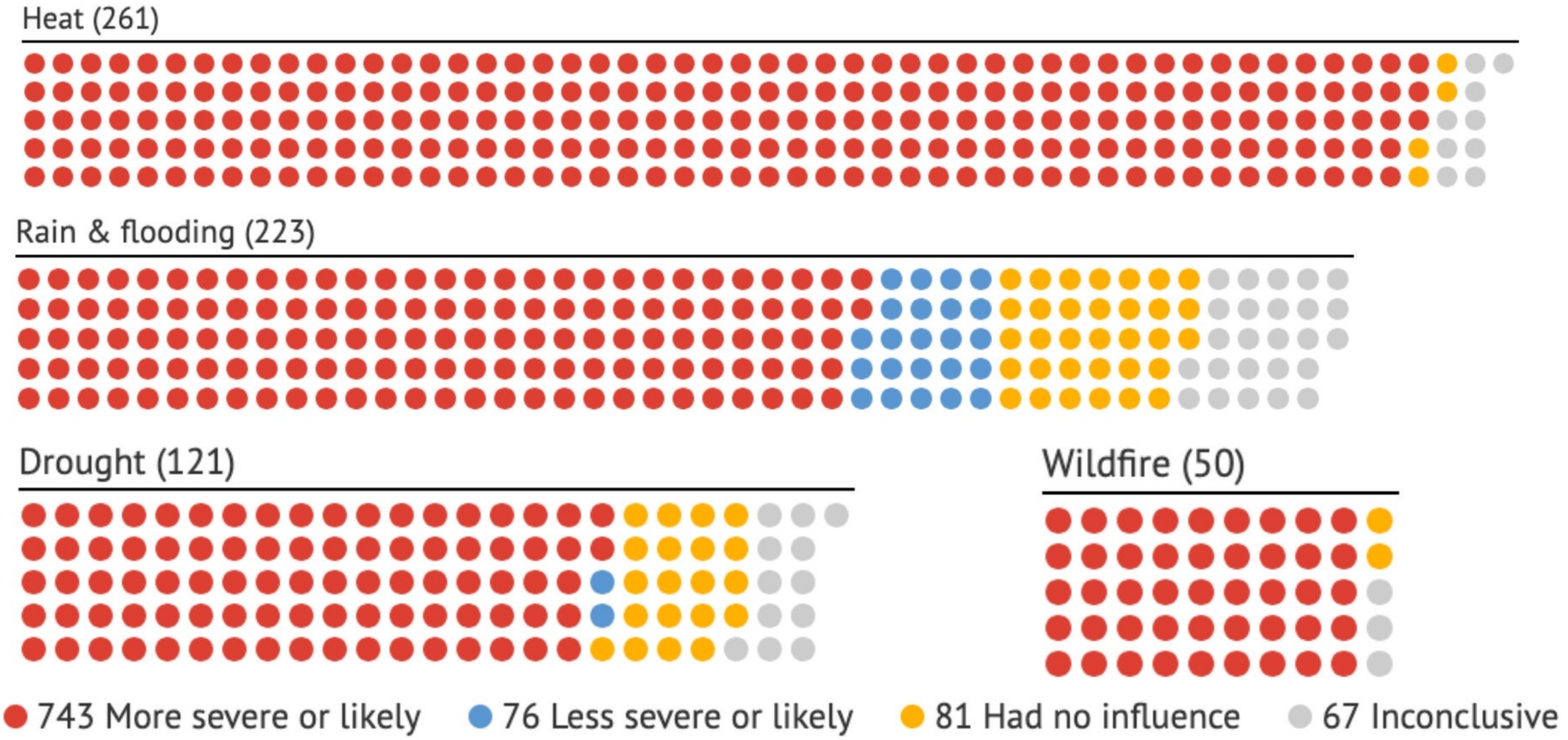
https://interactive.carbonbrief.org/attribution-studies/index.html

A mudança climática já está aumentando a severidade e o risco de muitos eventos extremos



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

A mudança climática já está aumentando a severidade e o risco de muitos eventos extremos



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

Como será o futuro?

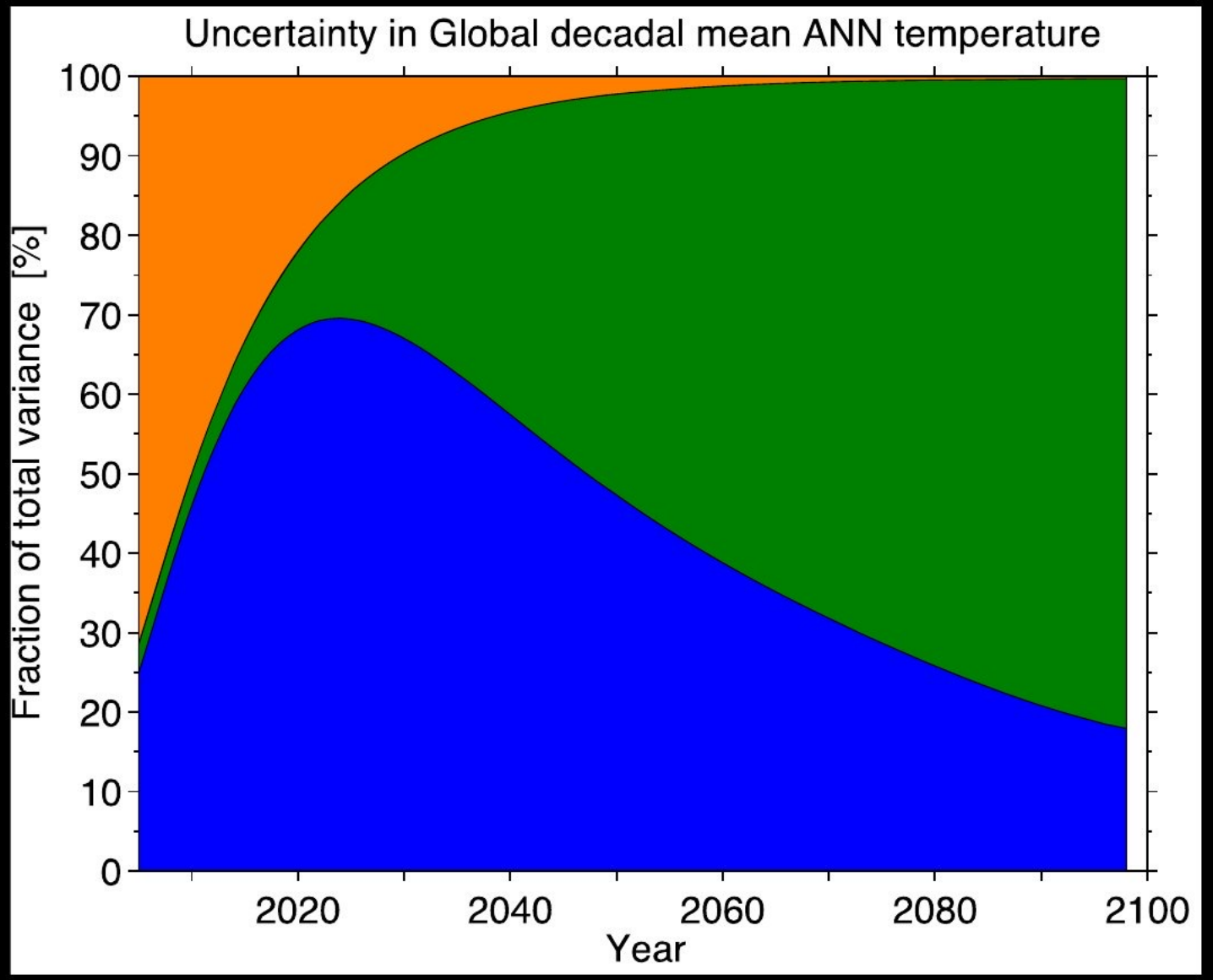
Os modelos climáticos

são nossa principal ferramenta
Muitas fontes

de incerteza
Incerteza

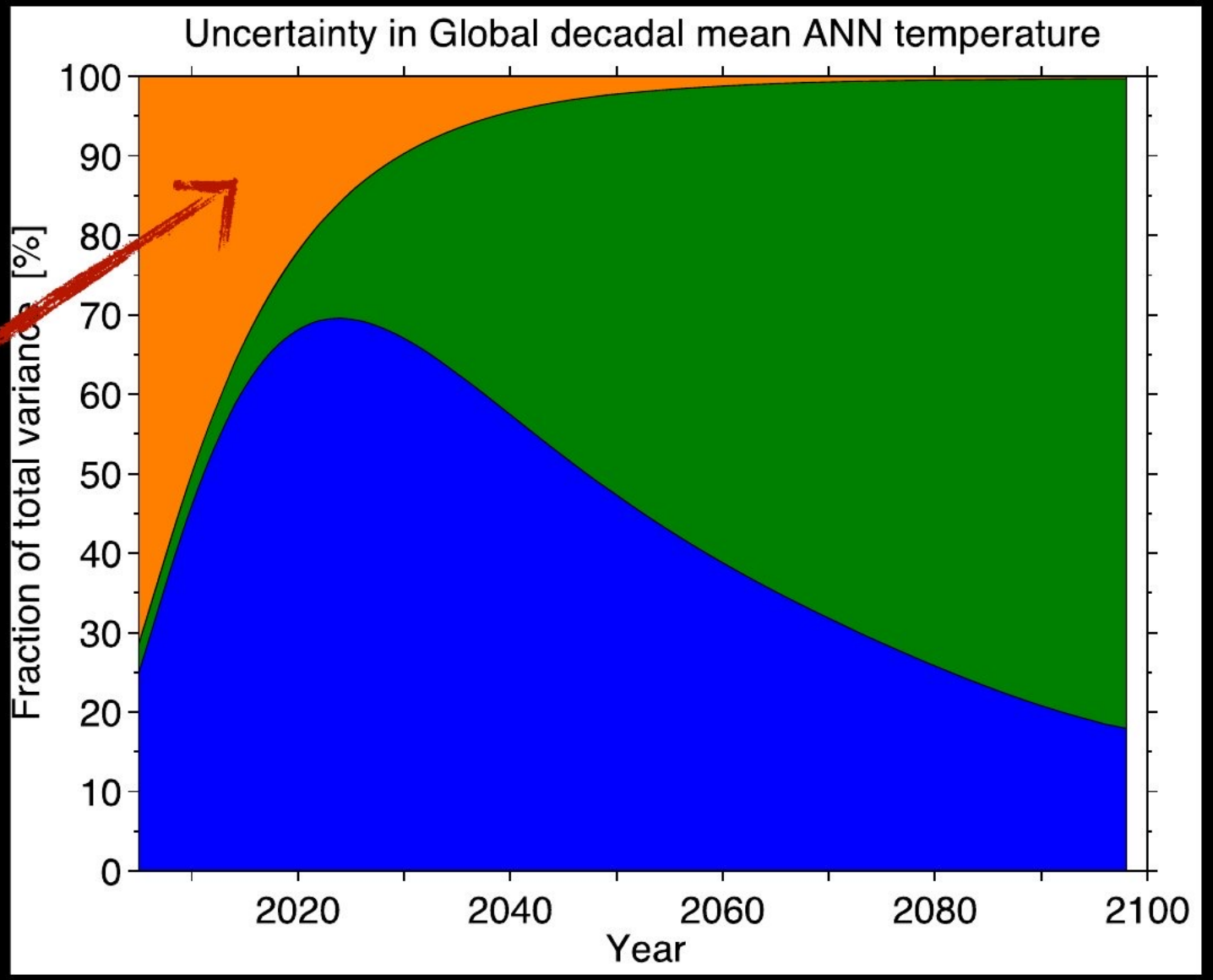
NÃO significa que

não sabemos nada



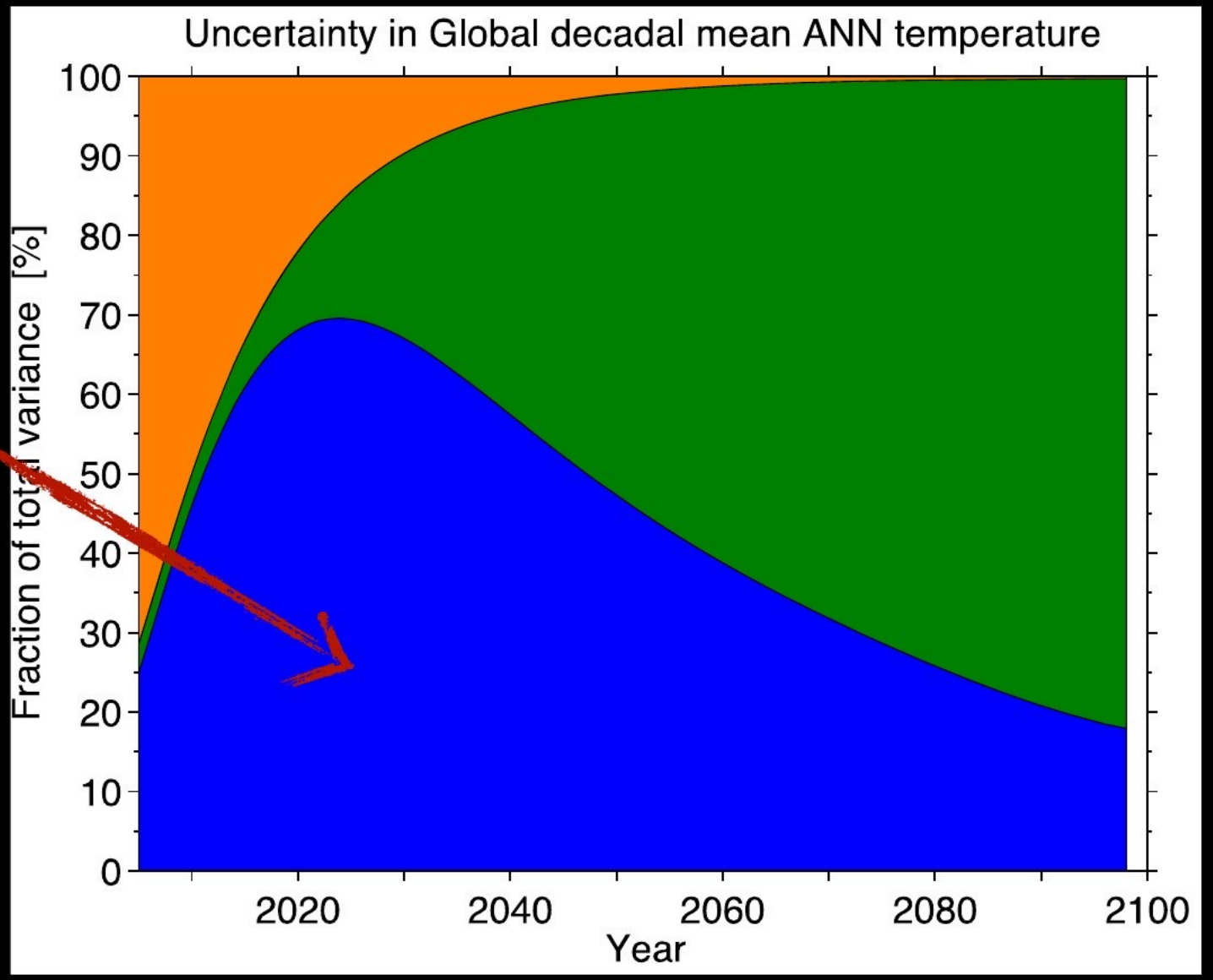
As principais incertezas mudam com o tempo

Variações naturais do tempo e do clima (variabilidade interna)



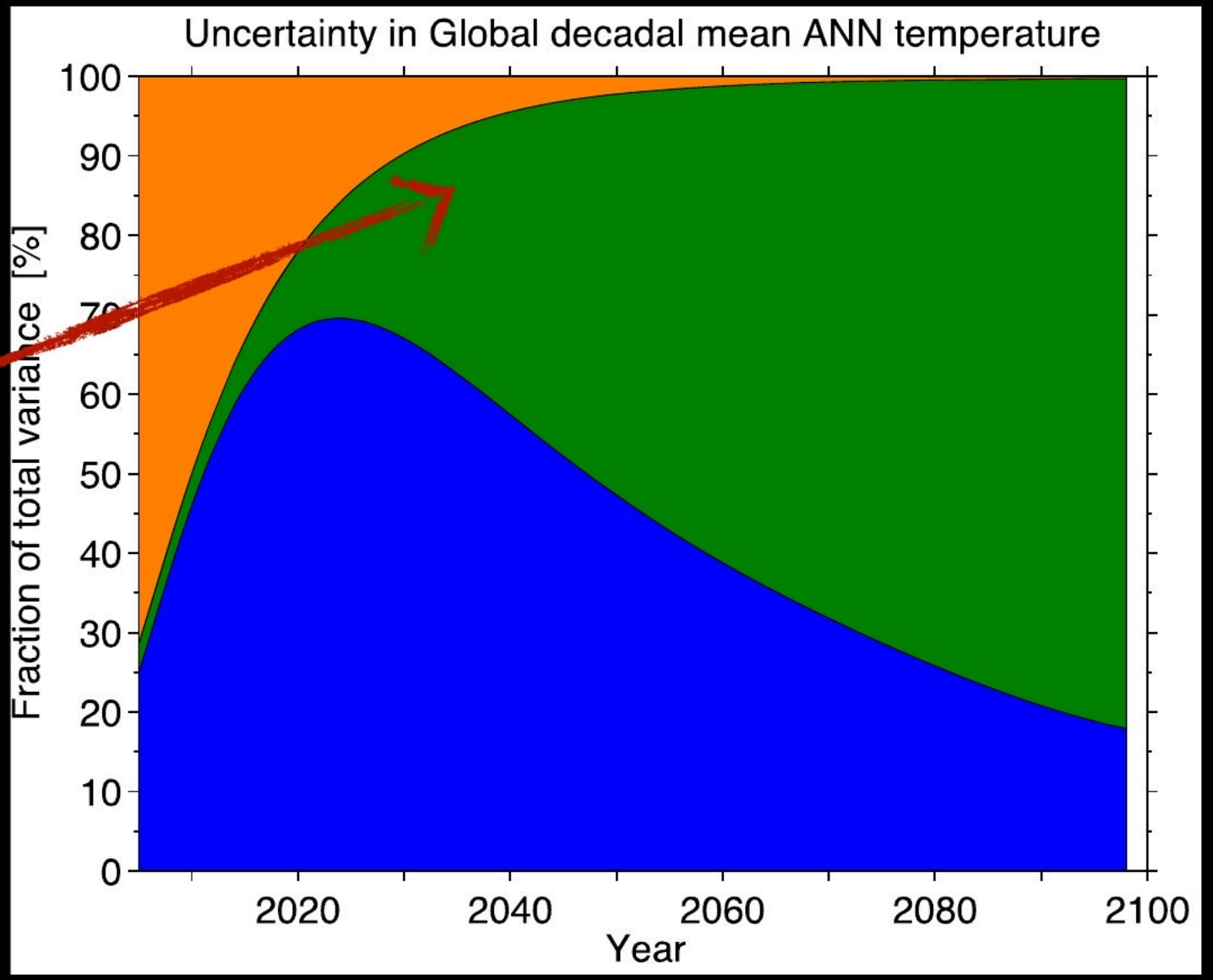
As principais incertezas mudam com o tempo

O quanto
nossos modelos
concordam
(incerteza
estrutural)



As principais incertezas mudam com o tempo

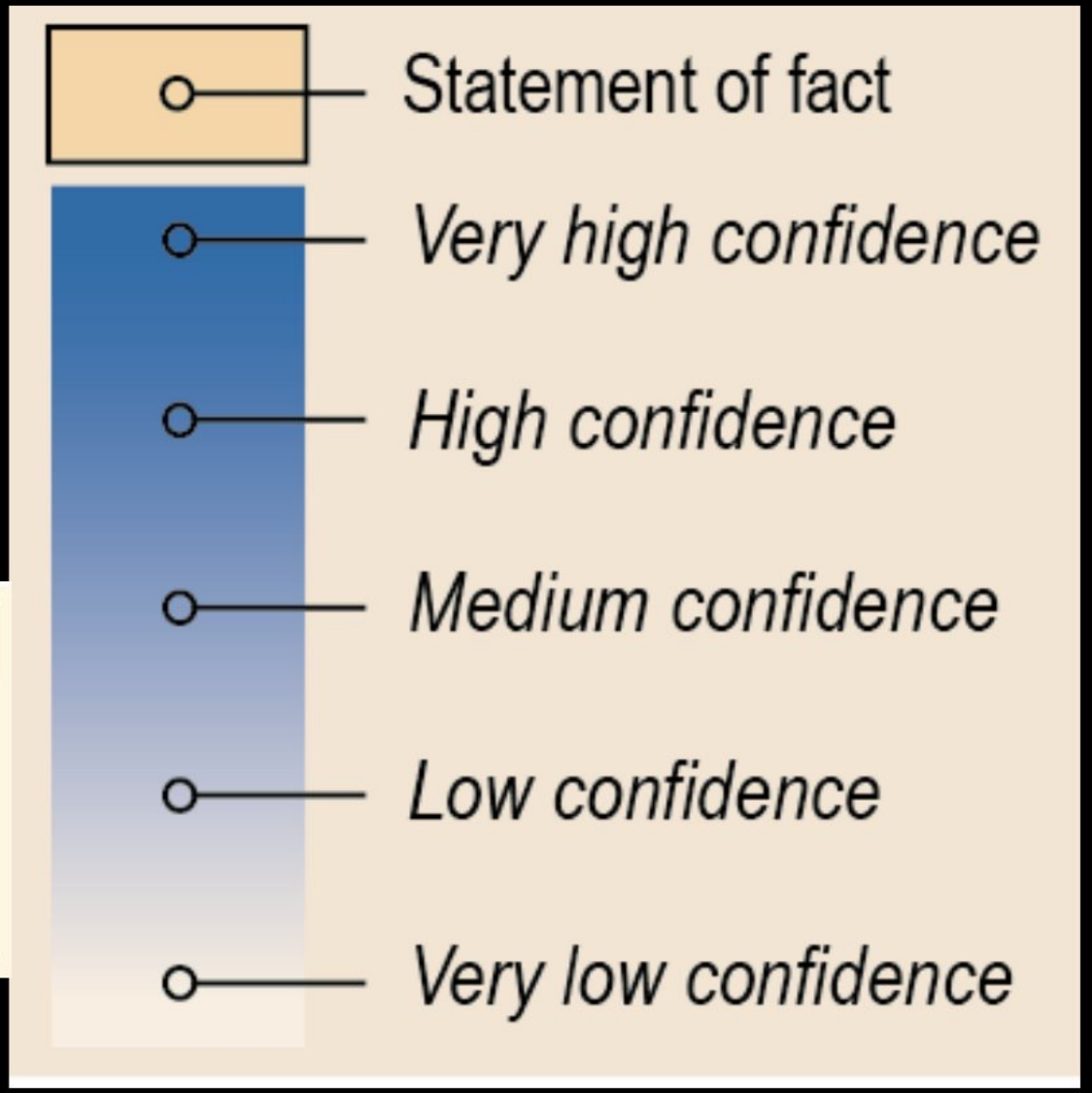
Que trajetória de emissões de GEE seguiremos (incerteza de cenário)



Confiança

"Nos relatórios do IPCC, a confiança é expressa qualitativamente e indica o grau de certeza de que os resultados científicos são válidos. Ela depende do tipo, da quantidade, da qualidade e da consistência das evidências"

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/

Probabilidade

"A certeza dos resultados científicos é então descrita por meio de probabilidades. Os resultados são avaliados de forma probabilística a partir de observações, resultados de modelos ou avaliação especializada."

Allison Crimmins:

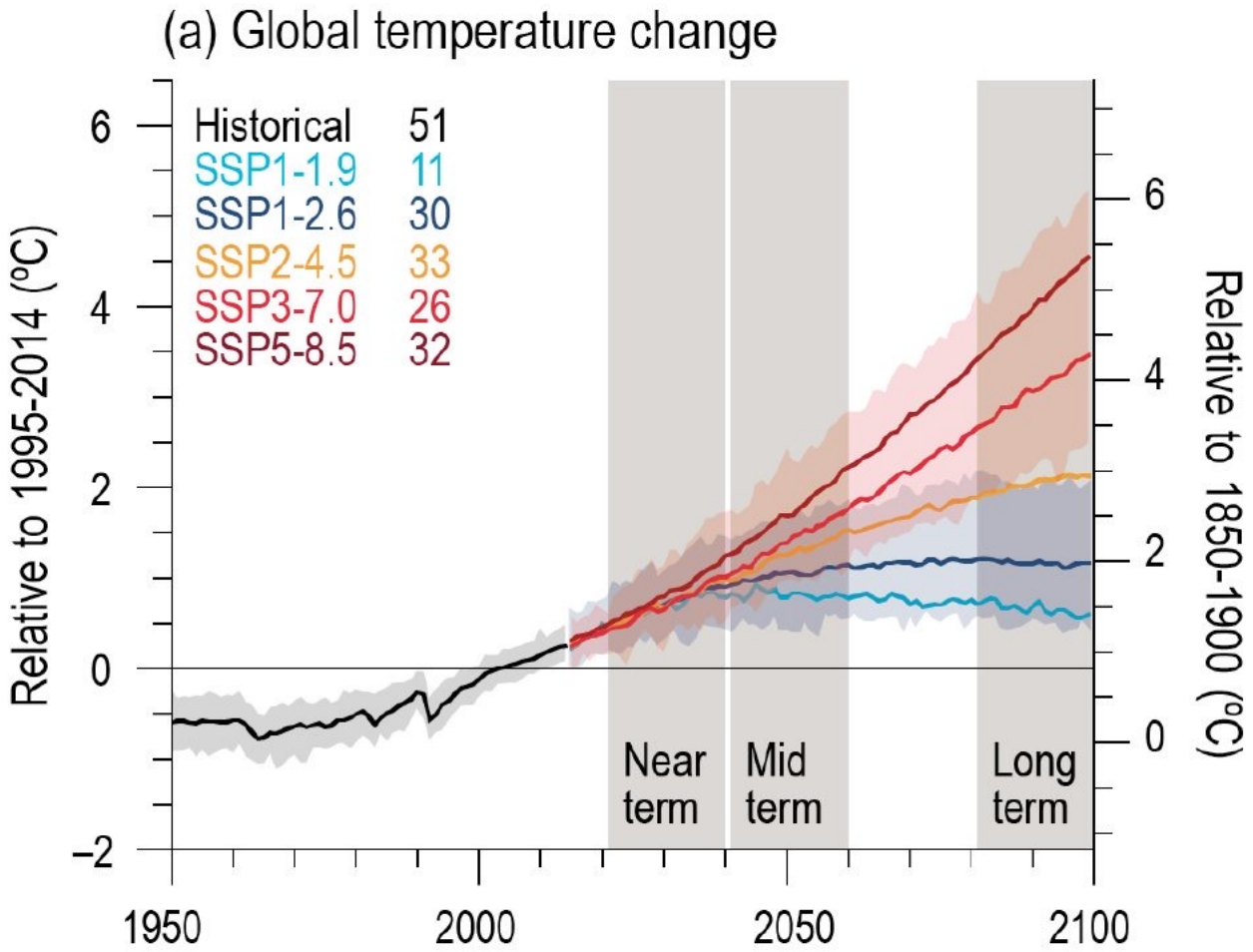
"Quando você olha um produto na Amazon, o número de estrelas é a probabilidade e o número de avaliações é a confiança."

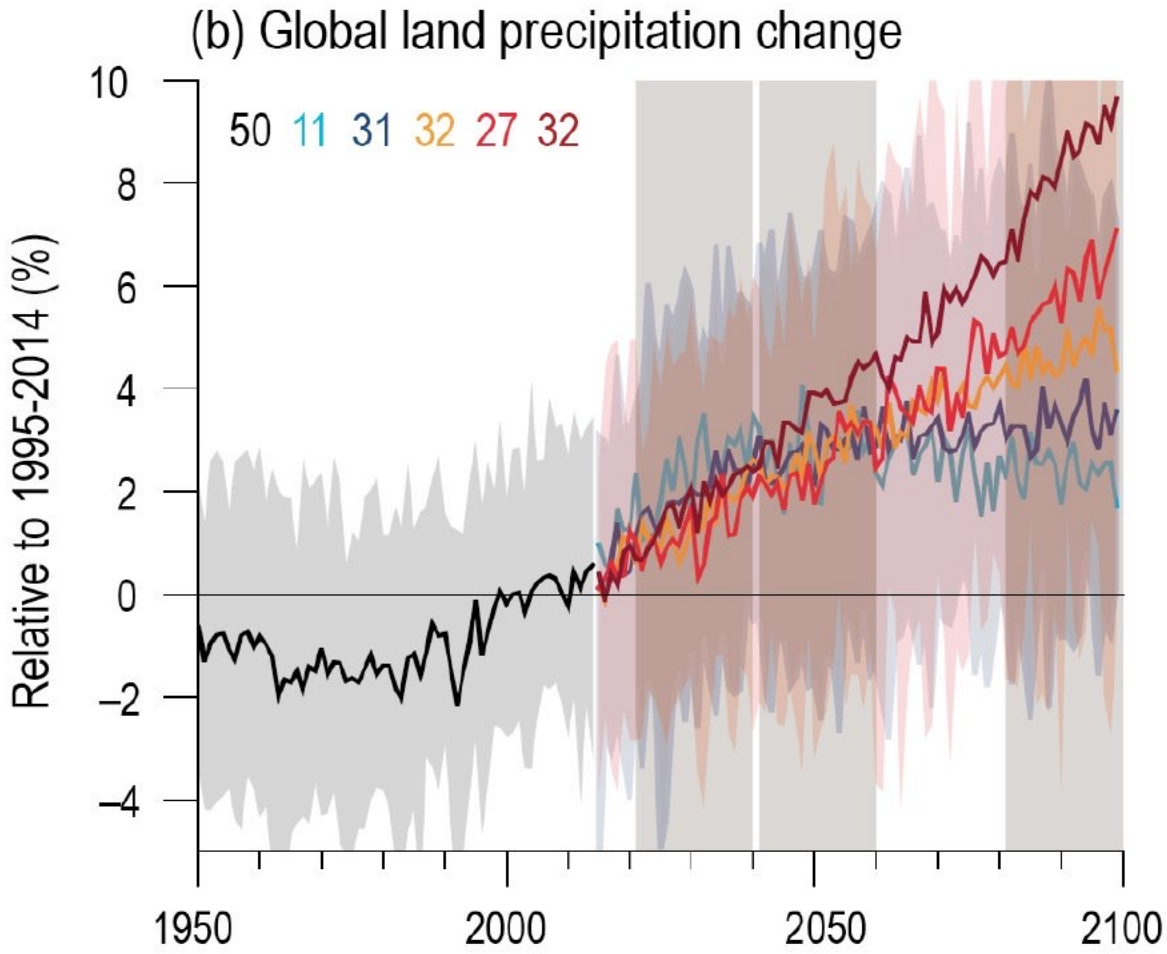
Likelihood	Outcome probability
Virtually certain	99-100%
Extremely likely	95-100%
Very likely	90-100%
Likely	66-100%
More likely than not	>50-100%
About as likely as not	33-66%
Unlikely	0-33%
Very unlikely	0-10%
Extremely unlikely	0-5%
Exceptionally unlikely	0-1%

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

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

Temperatura e precipitação (terra)





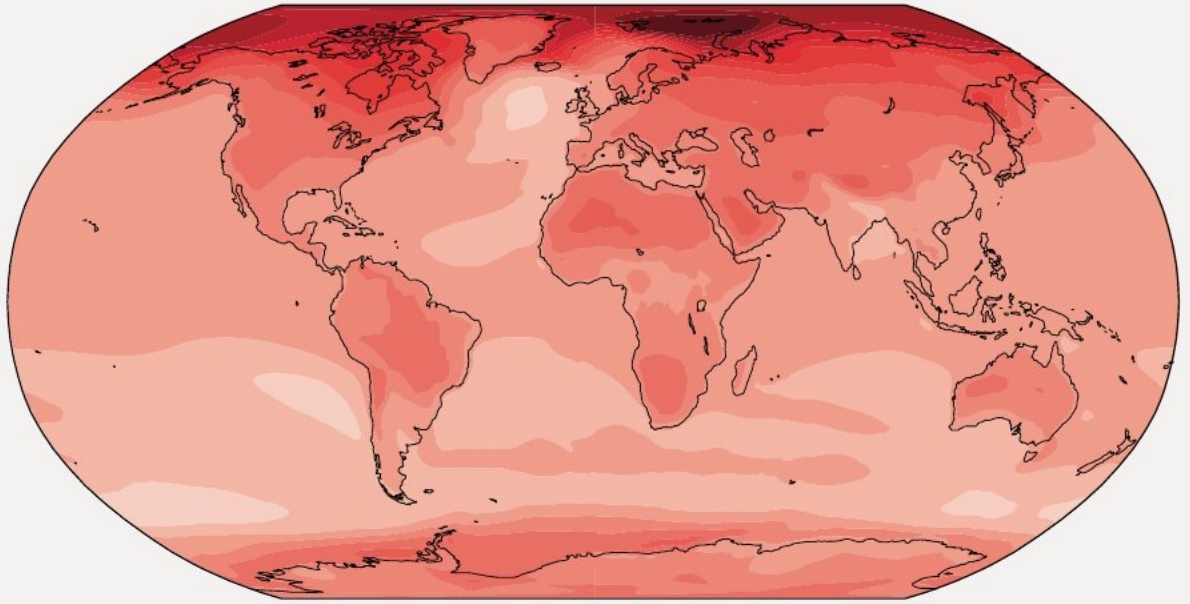
https://www.ipcc.ch/report/ar6/wg1/figures/chapter-4/figure-4-2

Temperatura

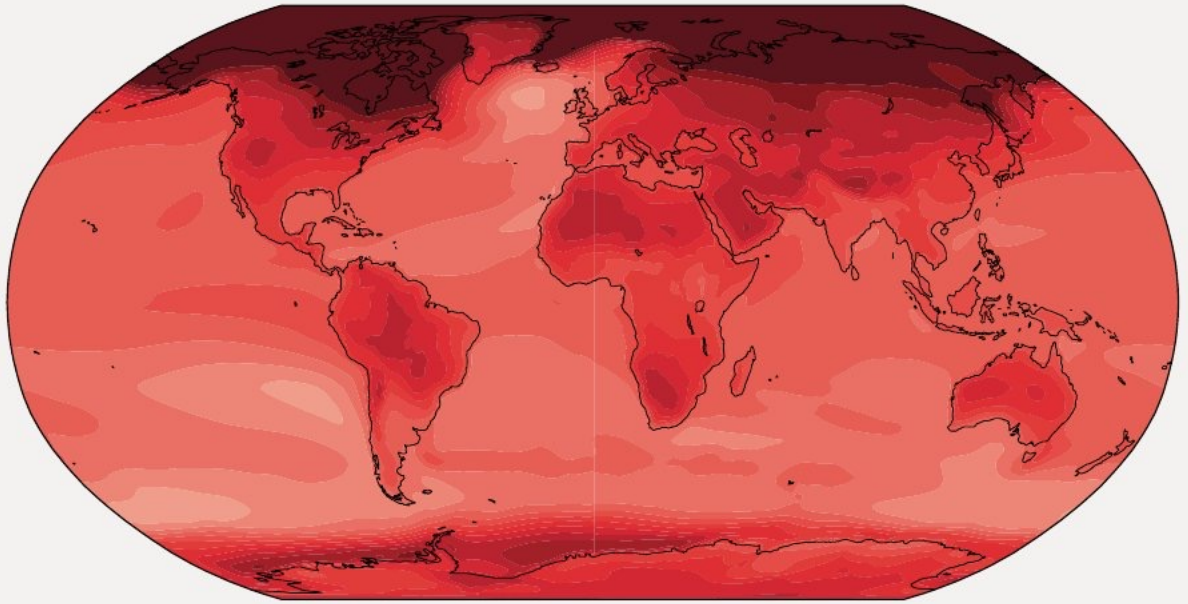
Generalizada, unidirecional;
resposta robusta dos modelos;

Coerente com os padrões observados
(p. ex. aquecimento maior sobre a terra,
amplificação polar)

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



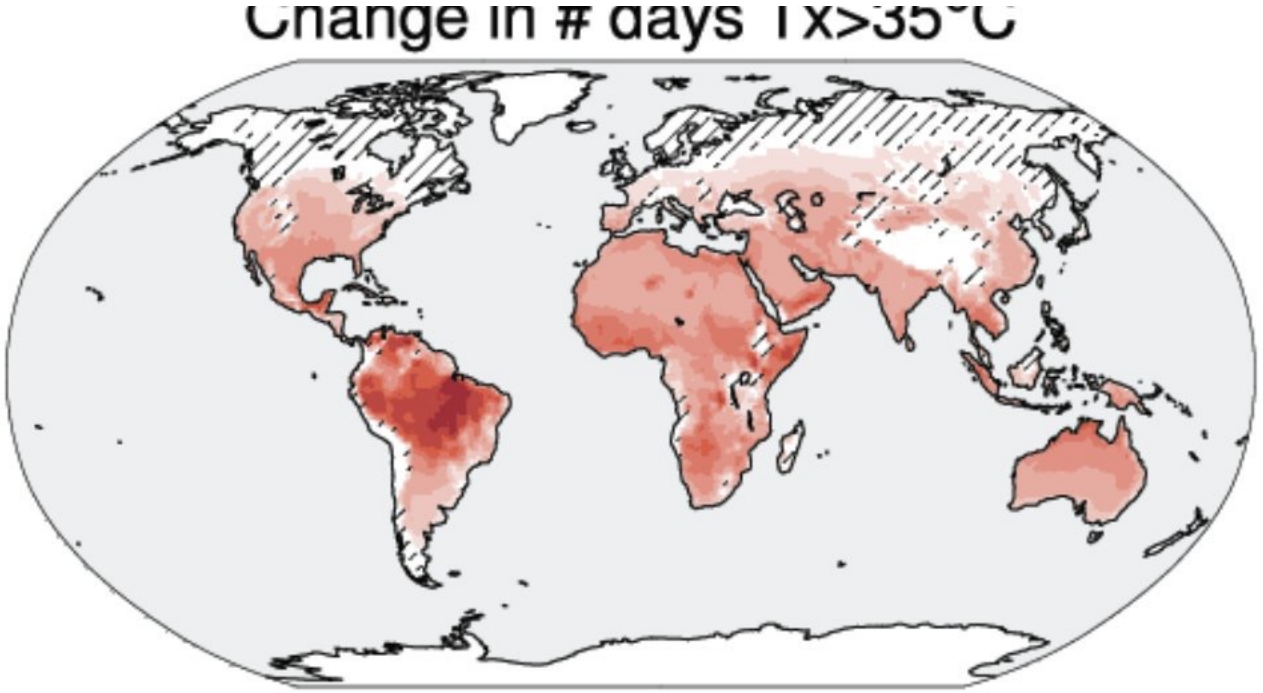
Simulated change at **4°C** global warming

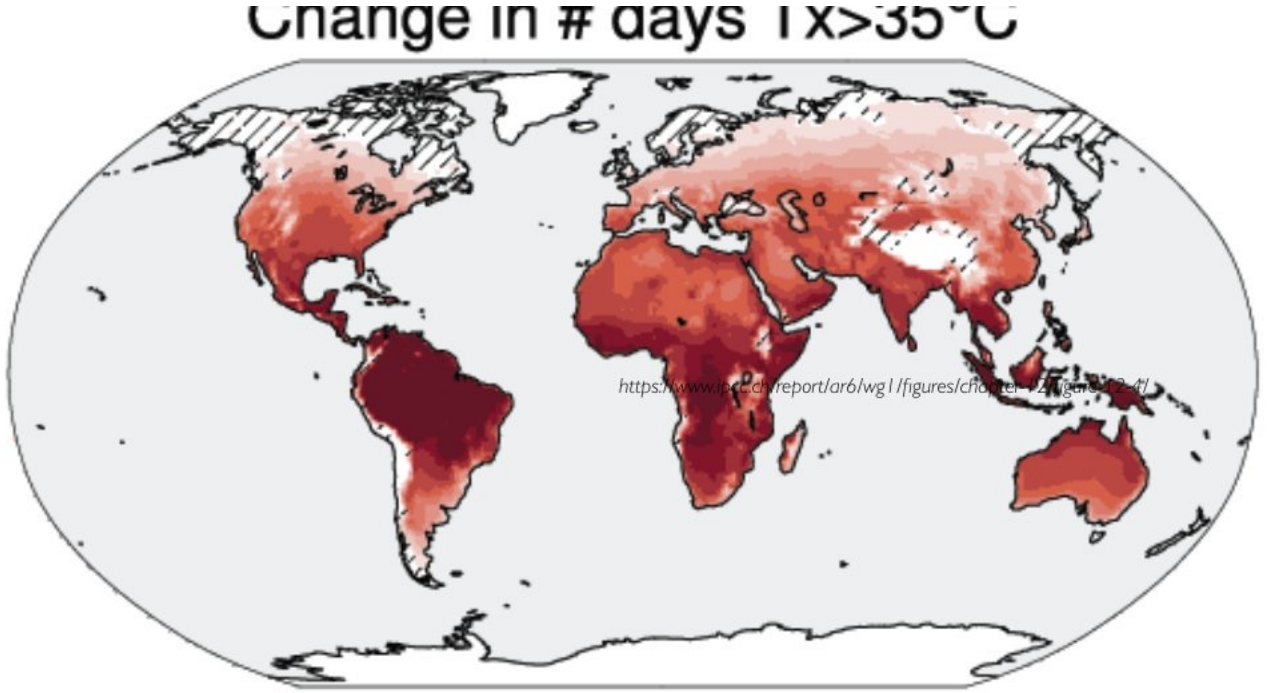


https://www.ipcc.ch/report/ar6/wg1/#SPM



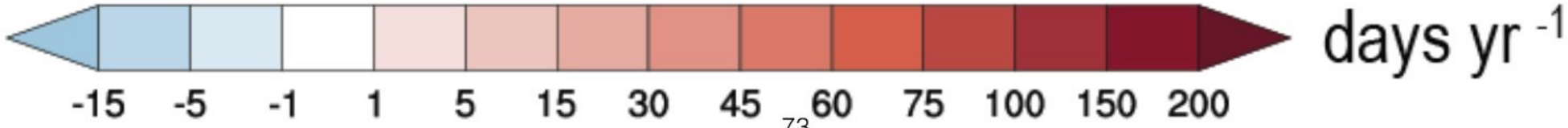
Temperaturas extremas



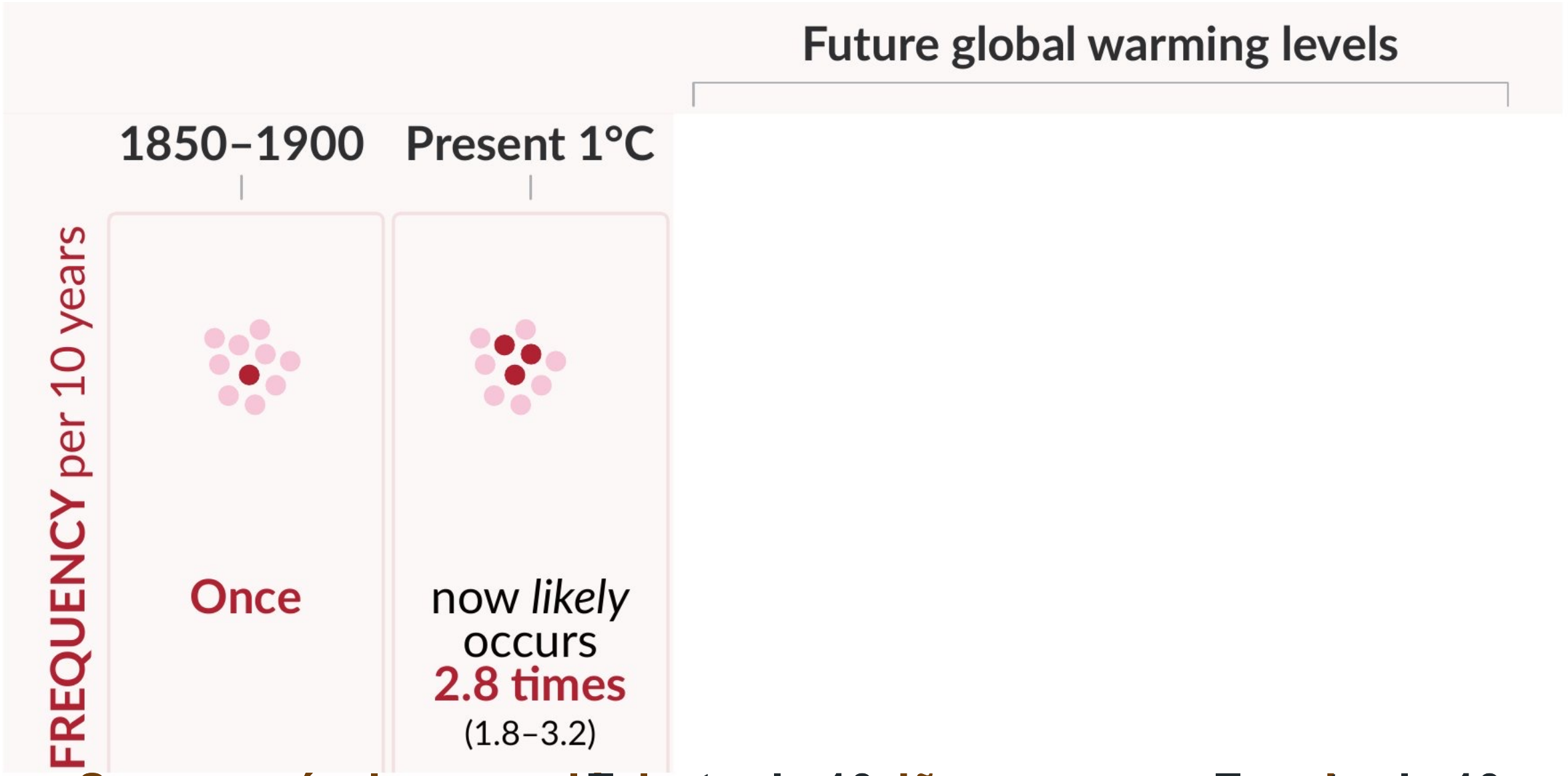


Cenário de baixo aquecimento
(2080-2100)

Cenário de alto aquecimento
(2080-2100)



Mudanças nos extremos de calor de 10 anos



Calor extremo sobre a terra

Evento de 10 anos

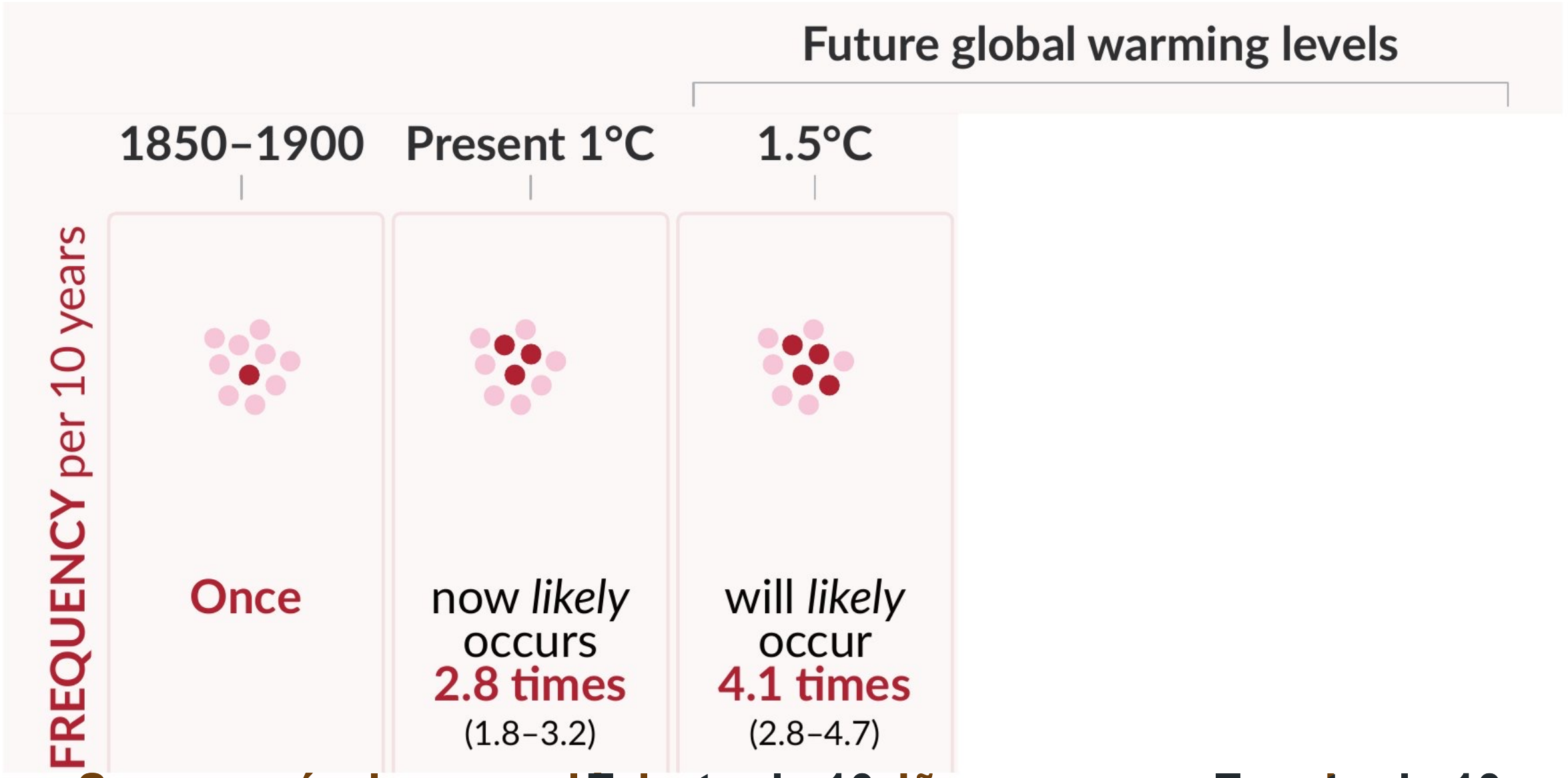
Evento de 50 anos

Secas agrícolas e ecológicas em regiões em processo de desertificação

Evento de 10 anos

Evento de 10 anos

Mudanças nos extremos de calor de 10 anos



Calor extremo sobre a terra

Evento de 10 anos

Evento de 50 anos

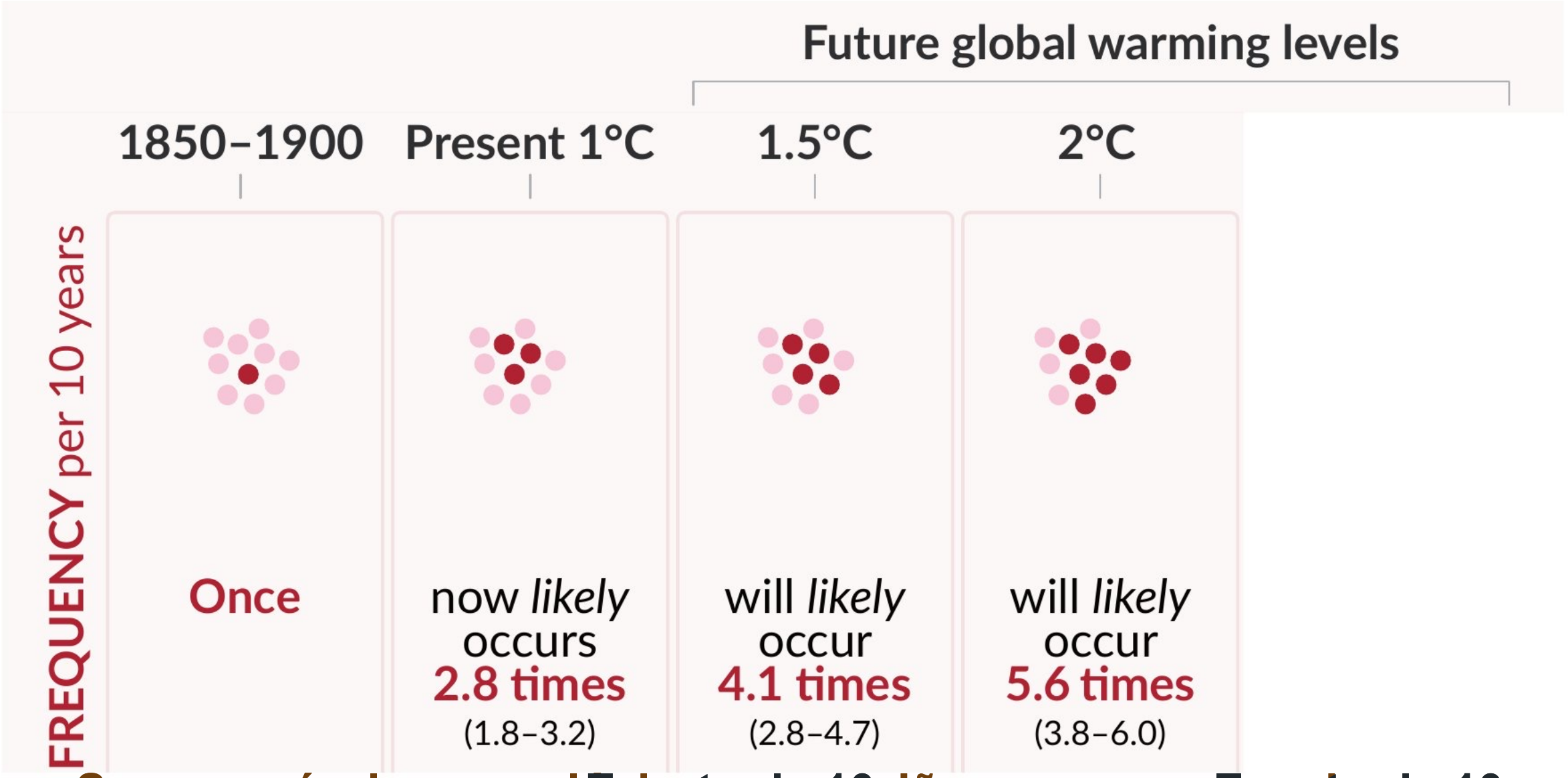
Secas agrícolas e ecológicas em regiões em processo de secagem

Evento de 10 anos

Evento de 10 anos

Calor extremo sobre a terra Evento de 10 anos Evento de 50 anos

Mudanças nos extremos de calor de 10 anos

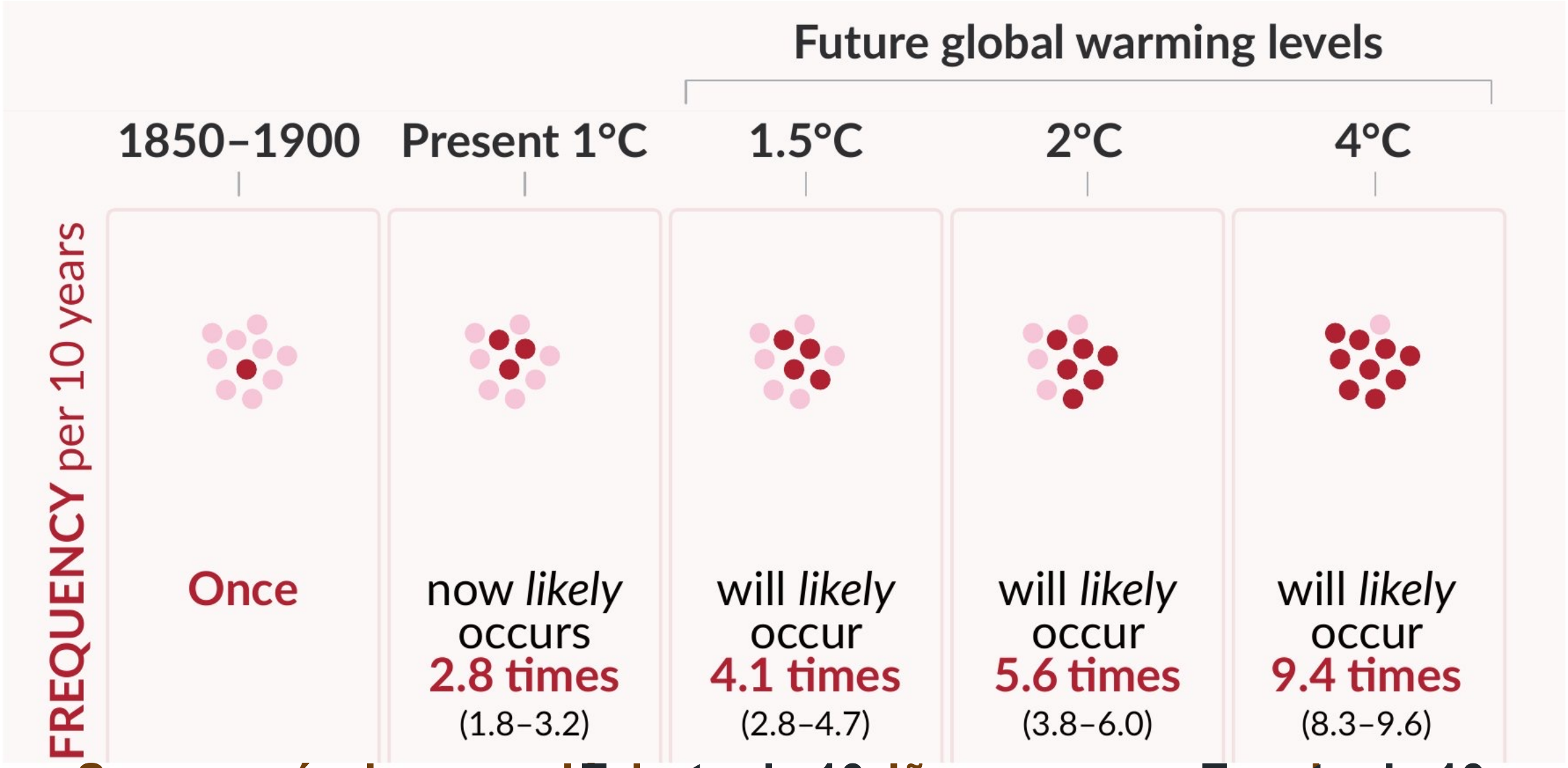


https://www.ipcc.ch/report/ar6/wg1/#SPM

Secas agrícolas e ecológicas em regiões em processo de secagem Evento de 10 anos Evento de 10 anos

Calor extremo sobre a terra Evento de 10 anos Evento de 50 anos

Mudanças nos extremos de calor de 10 anos



Secas agrícolas e ecológicas em regiões em processo de secagem

Evento de 10 anos

Evento de 10 anos

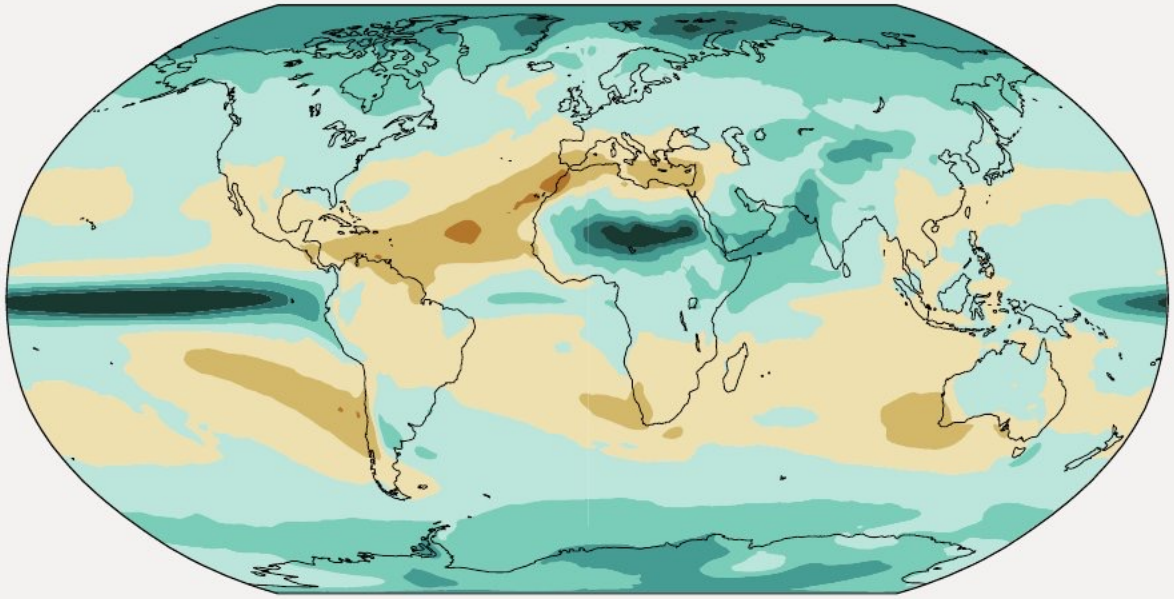
Precipitação (chuva + neve)

Resultados robustos para algumas áreas: altas latitudes mais úmidas, subtrópicos mais secos;

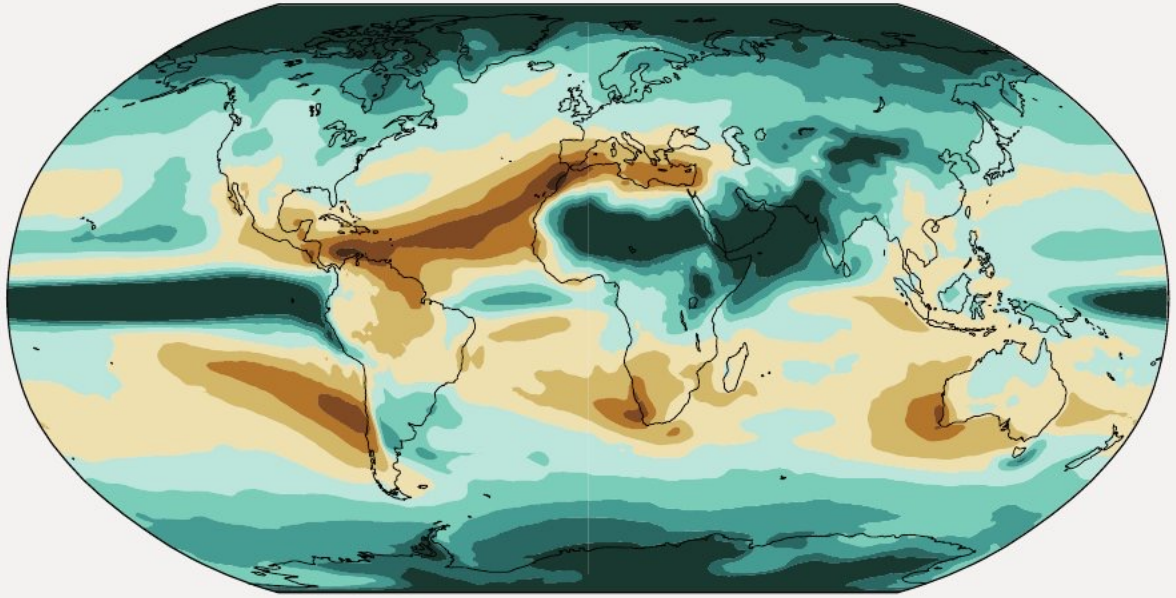
Maior incerteza por envolver mais processos (umidade, estabilidade, energia etc.)

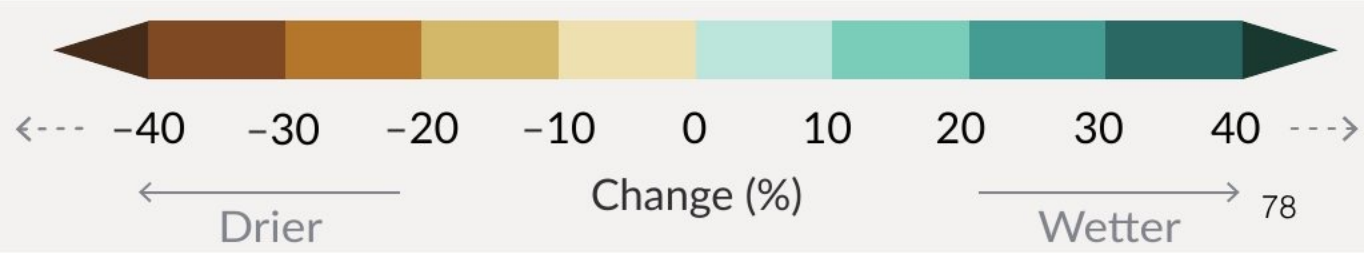
https://www.ipcc.ch/report/ar6/wg1/#SPM

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



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



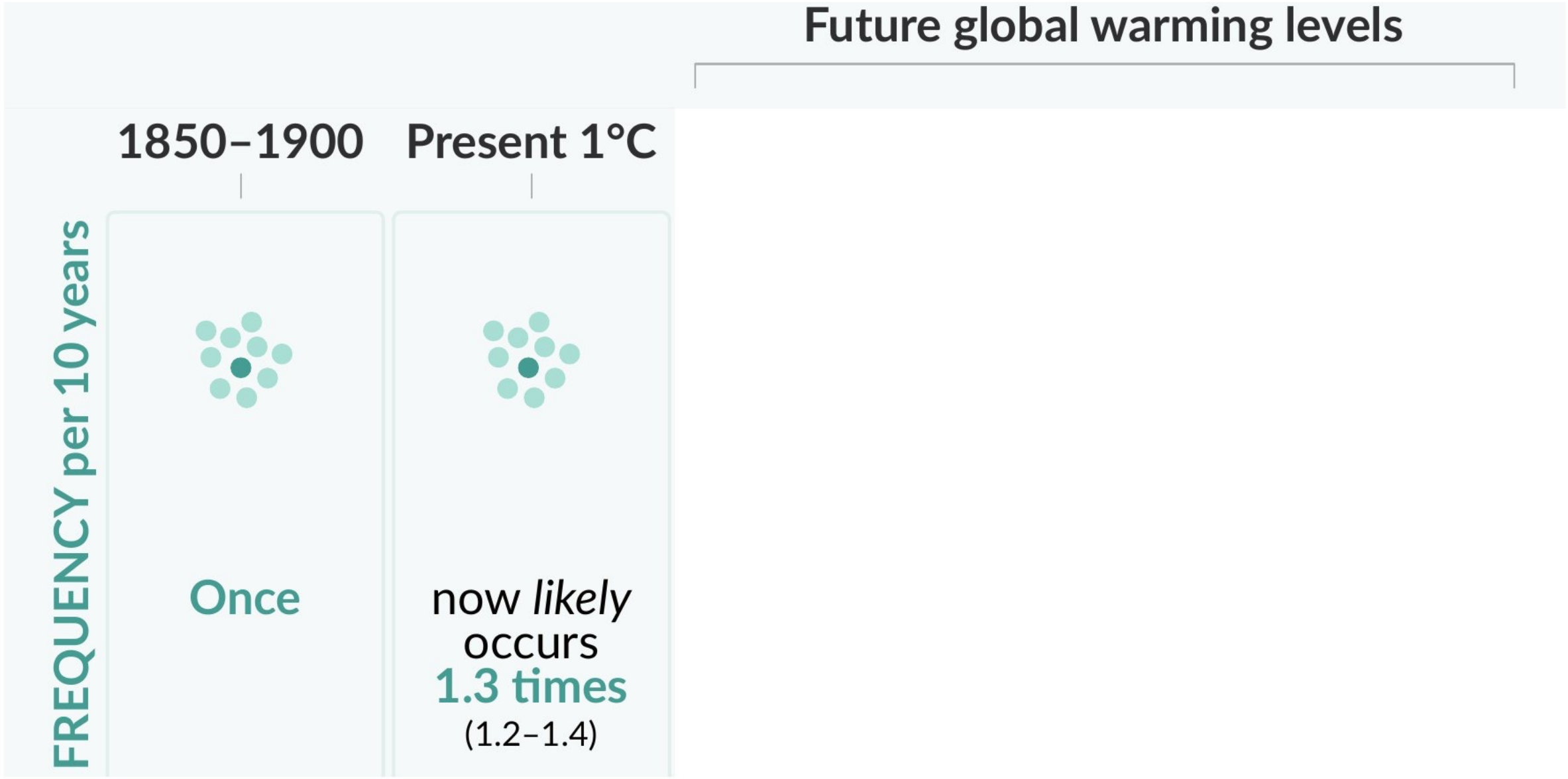


Secas agrícolas e ecológicas em regiões extremo

Evento de 10 anos

Evento de 50 anos

Mudanças nas chuvas intensas de 10 anos



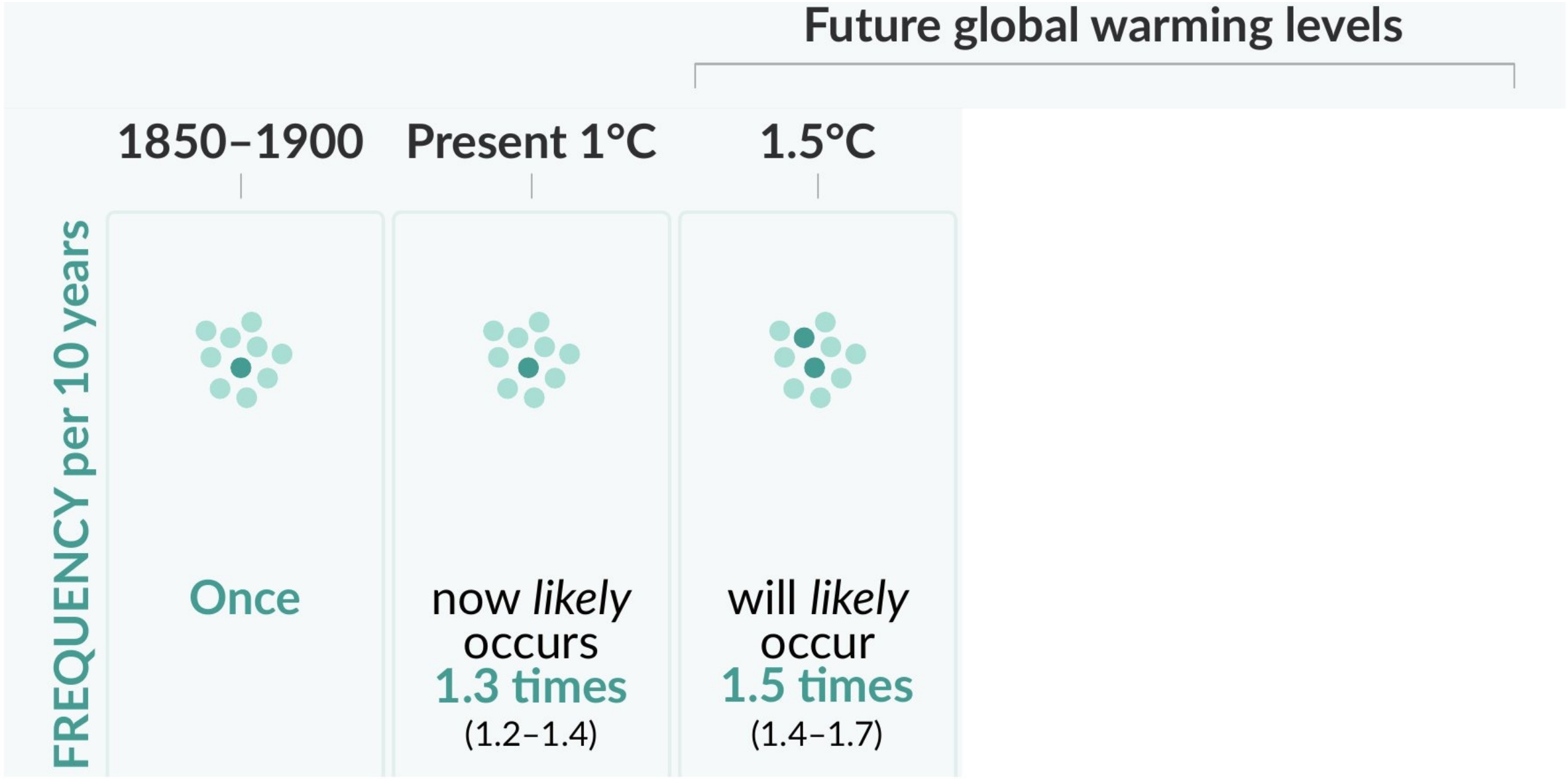
https://www.ipcc.ch/report/ar6/wg1/#SPM

Secas agrícolas e ecológicas em regiões extremo

Evento de 10 anos

Evento de 50 anos

Mudanças nas chuvas intensas de 10 anos



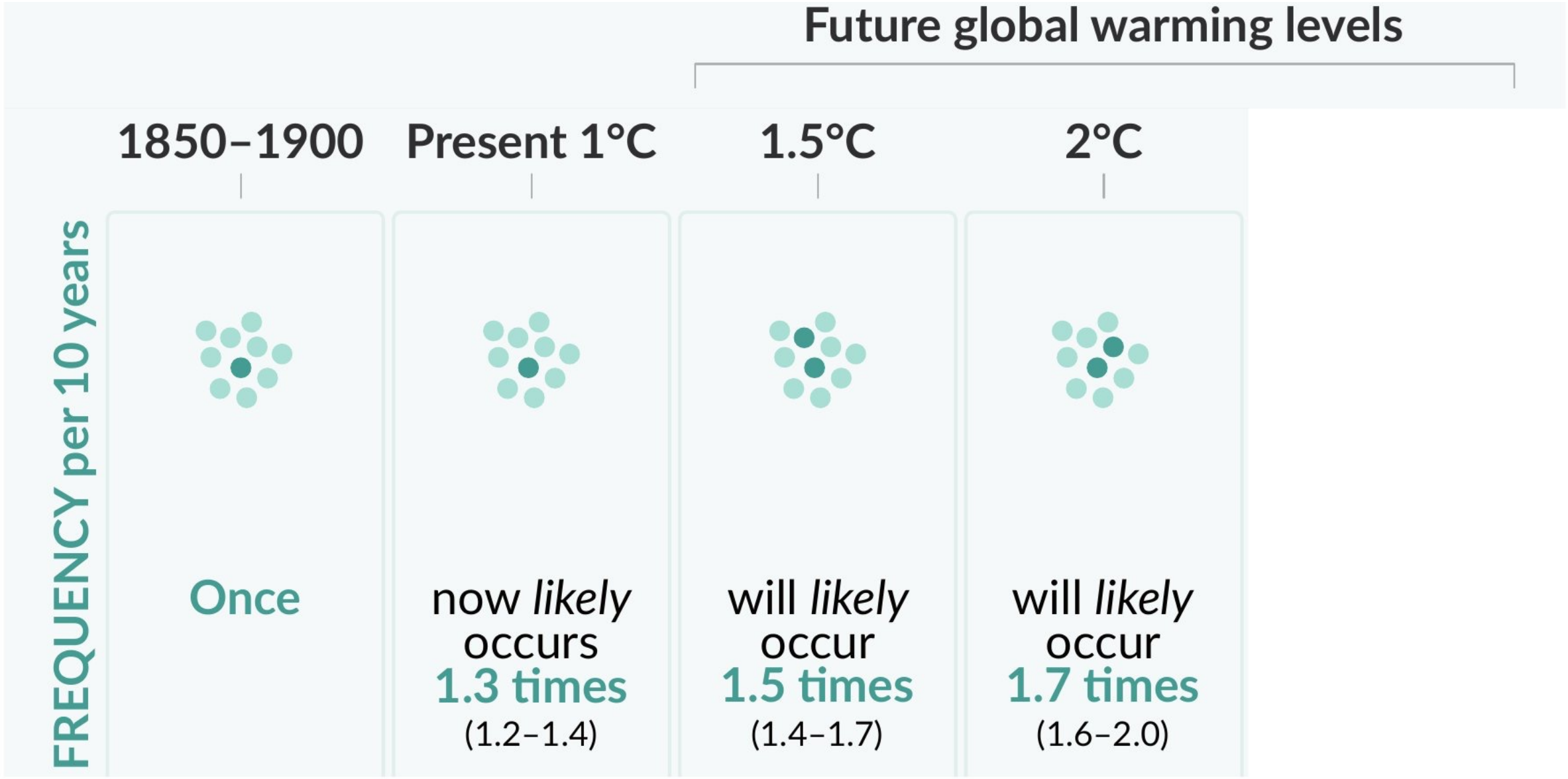
https://www.ipcc.ch/report/ar6/wg1/#SPM

Secas agrícolas e ecológicas em regiões extremo

Evento de 10 anos

Evento de 50 anos

Mudanças nas chuvas intensas de 10 anos



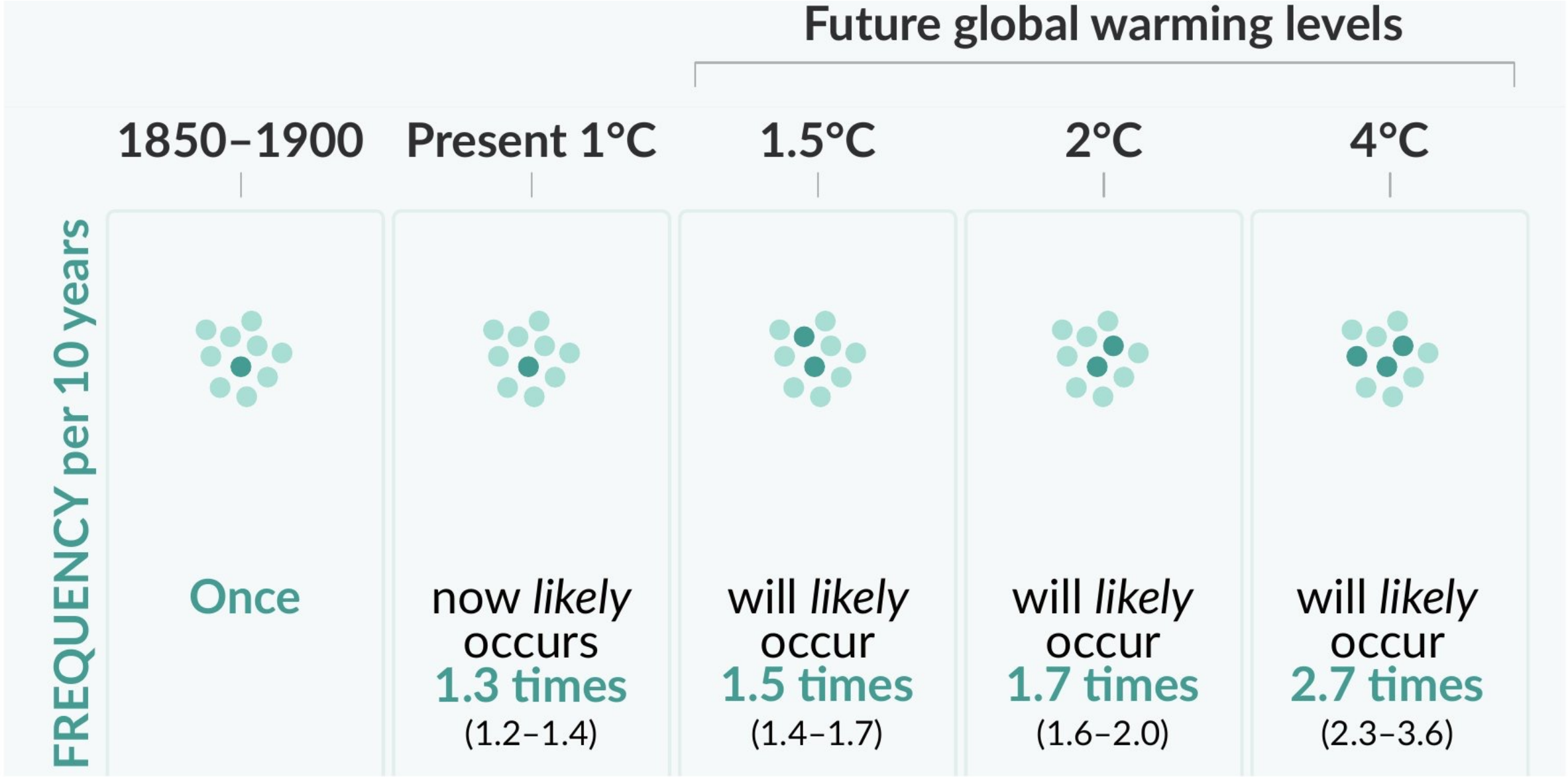
https://www.ipcc.ch/report/ar6/wg1/#SPM

Secas agrícolas e ecológicas em regiões extremo

Evento de 10 anos

Evento de 50 anos

Mudanças nas chuvas intensas de 10 anos



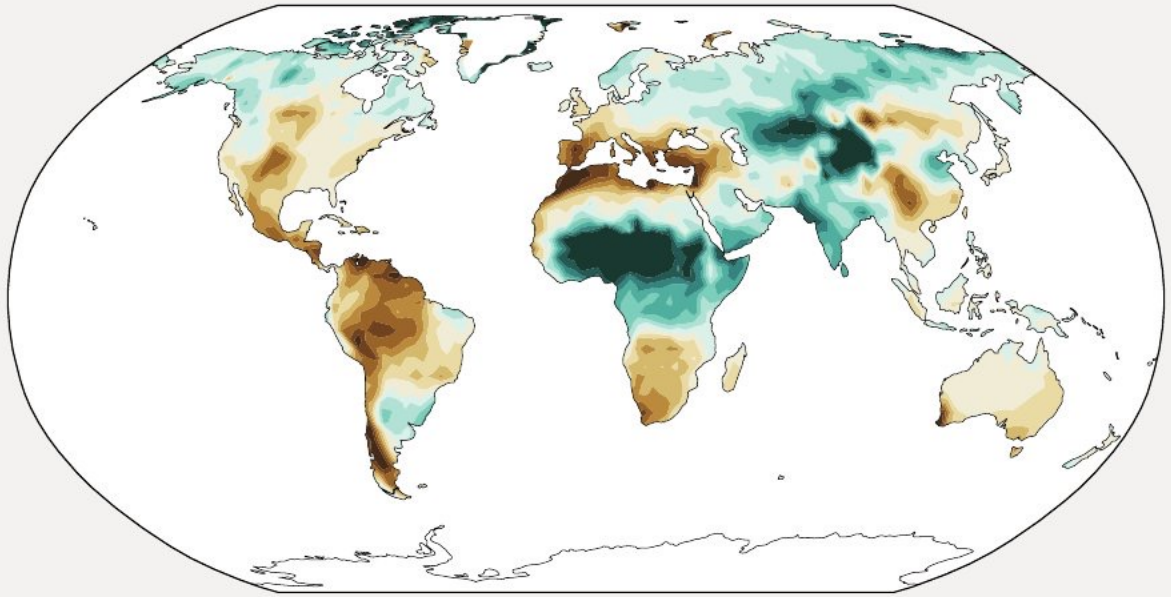
https://www.ipcc.ch/report/ar6/wg1/#SPM

Umidade do solo e seca

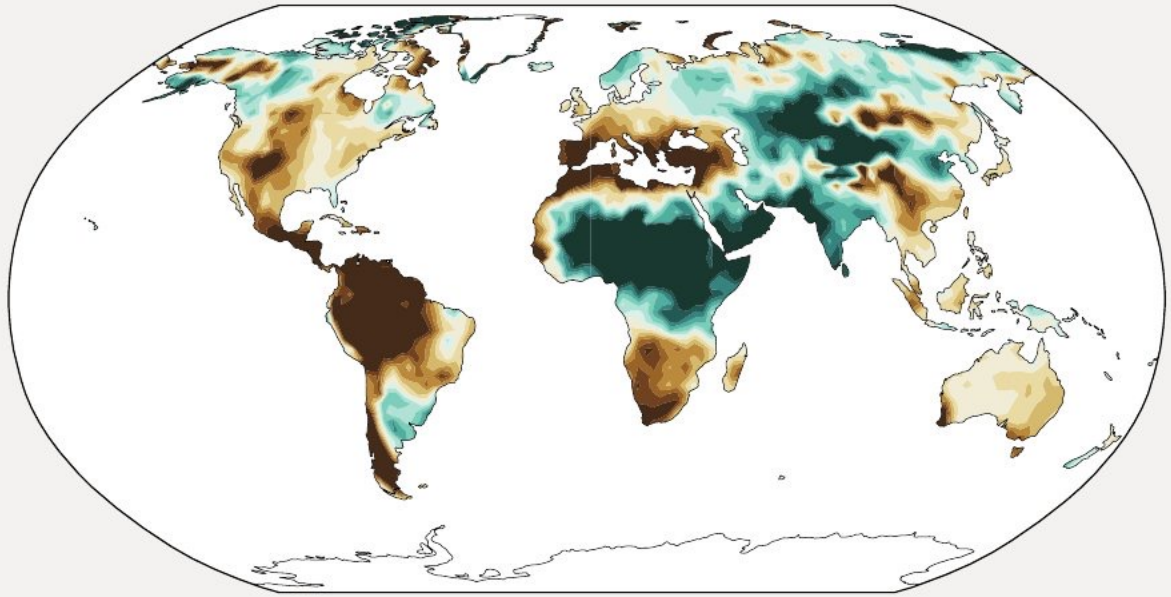
Resultados robustos para algumas áreas: altas latitudes mais úmidas, subtrópicos mais secos;

Maior incerteza por envolver mais processos (umidade, estabilidade, energia etc.)

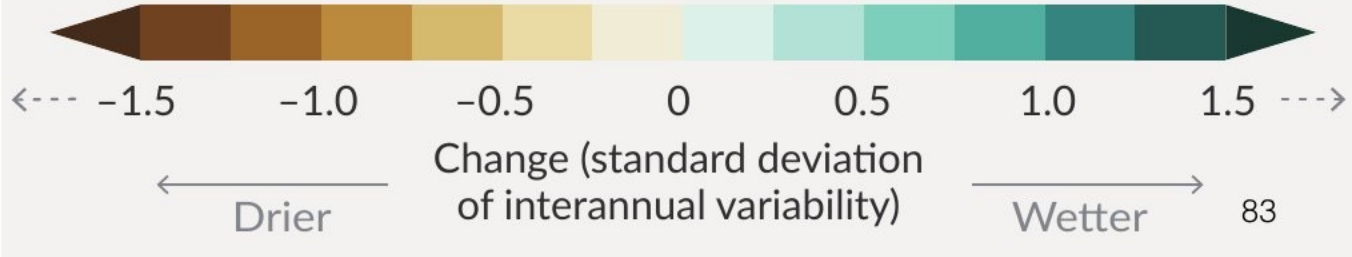
Simulated change at **2°C** global warming



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



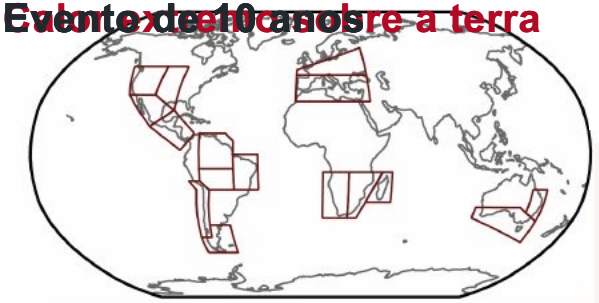
https://www.ipcc.ch/report/ar6/wg1/#SPM



Evento de 10 anos sobre a terra

Secas agrícolas e ecológicas: Evento de 10 anos em processo de secagem

Mudanças nas secas de umidade do solo de 10 anos

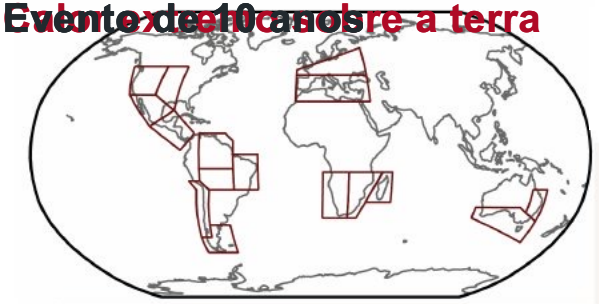


https://www.ipcc.ch/report/ar6/wg1/#SPM

Evento de 10 anos sobre a terra

Secas agrícolas e ecológicas também sem processo de secagem

Mudanças nas secas de umidade do solo de 10 anos

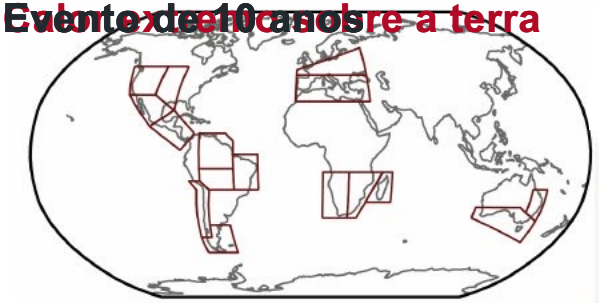


https://www.ipcc.ch/report/ar6/wg1/#SPM

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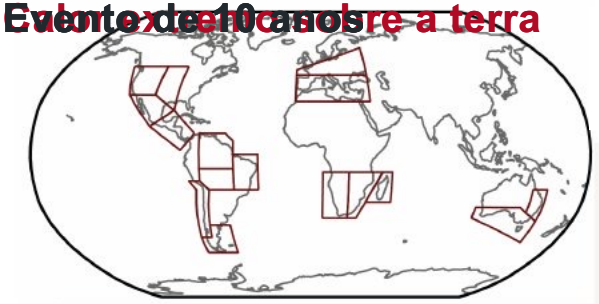


https://www.ipcc.ch/report/ar6/wg1/#SPM

Evento de 10 anos sobre a terra

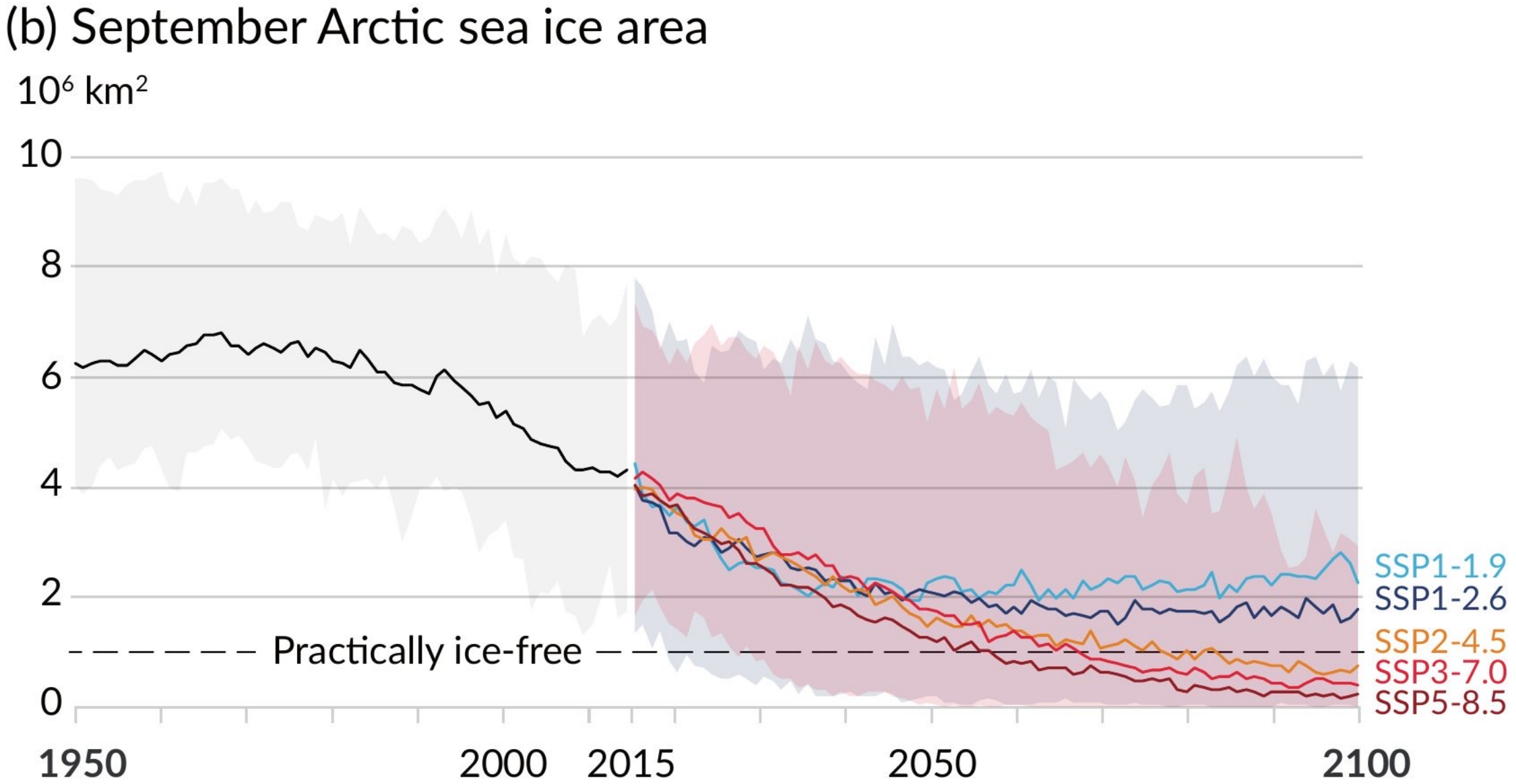
Secas agrícolas e ecológicas também sem processo de secagem

Mudanças nas secas de umidade do solo de 10 anos



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

Gelo marinho do Ártico



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

Elevação do nível do mar e inundações costeiras

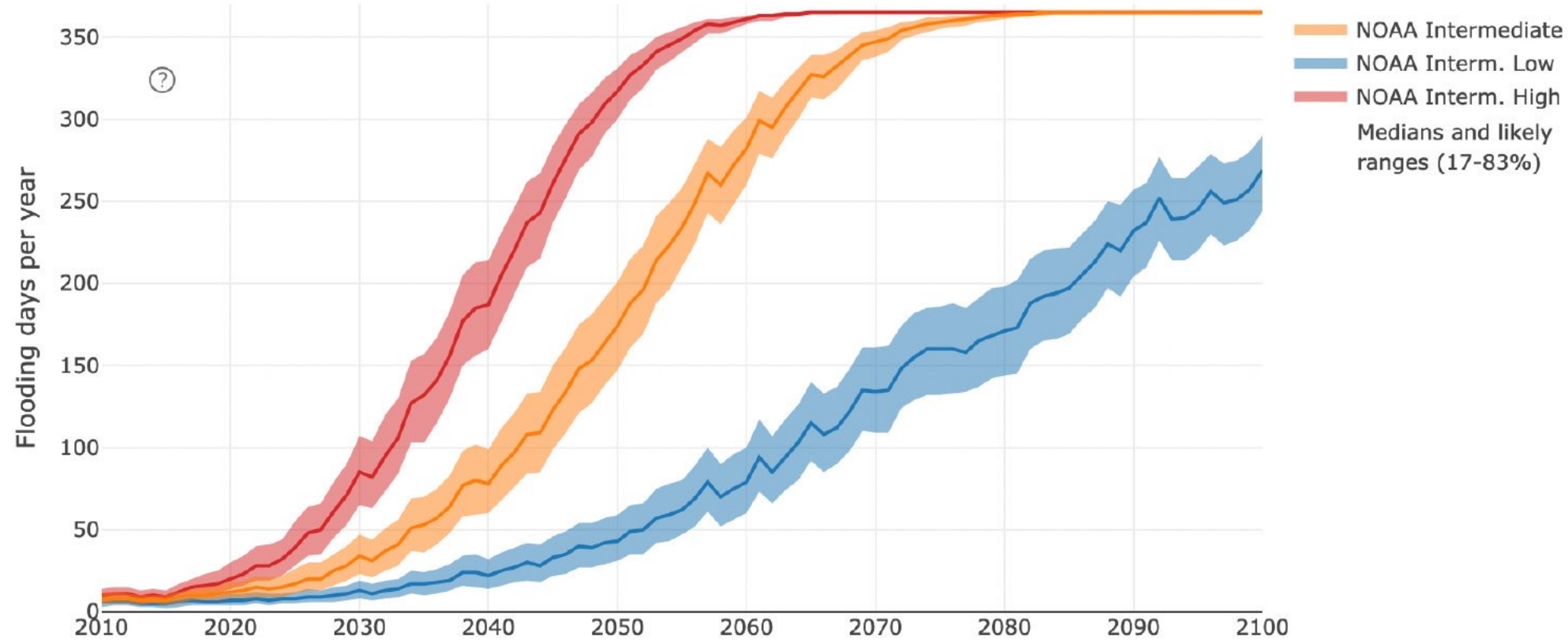
MHHW stands for *Mean Higher High Water*, which is defined as the average of the highest observed water level at the selected location on each tidal day during the period 1983-2001

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.

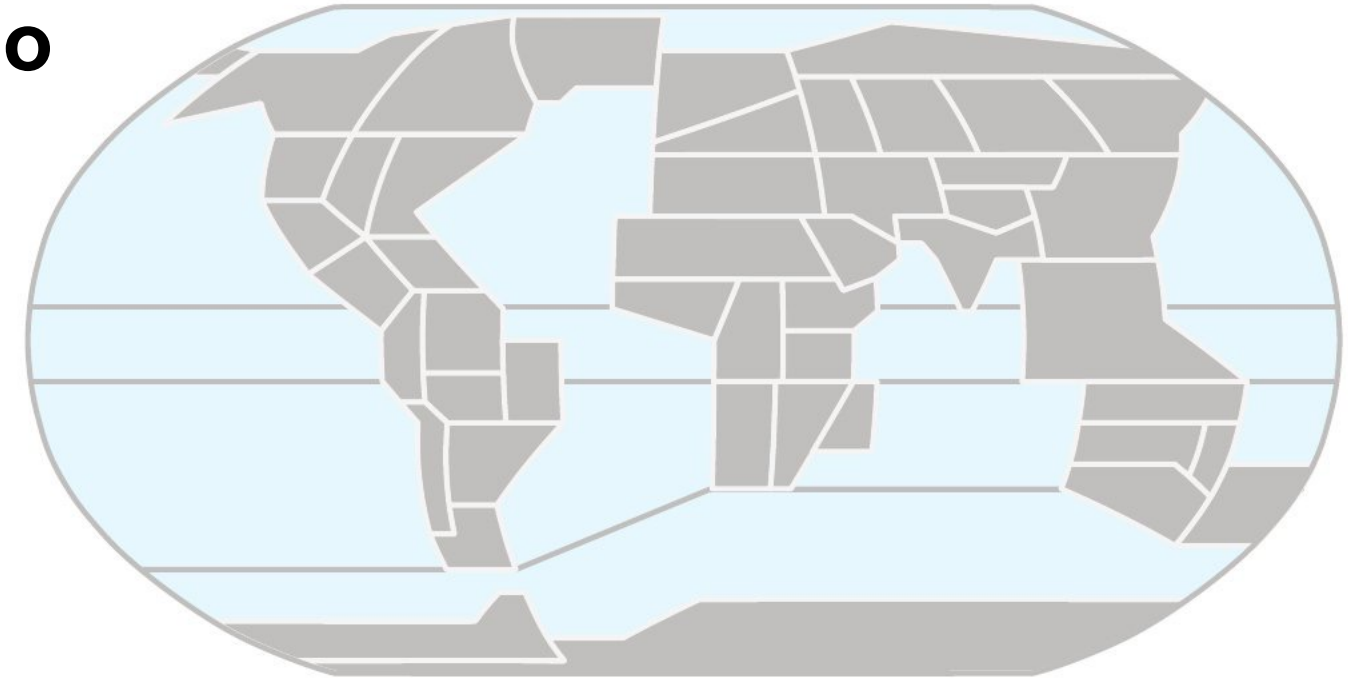
▸ **Read more**

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

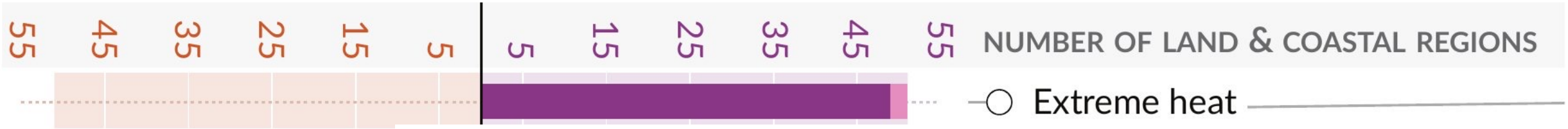


https://sealevel.nasa.gov/flooding-days-projection/

Fatores de impacto climático



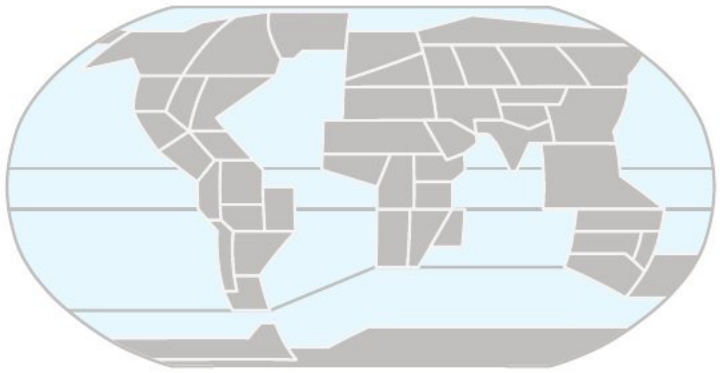




Exemplo: calor extremo

- 50/55: regiões vulneráveis
- 49/50: alta confiança em aumento do risco
- 1/50: confiança média em aumento do risco

Fatores climático de impacto



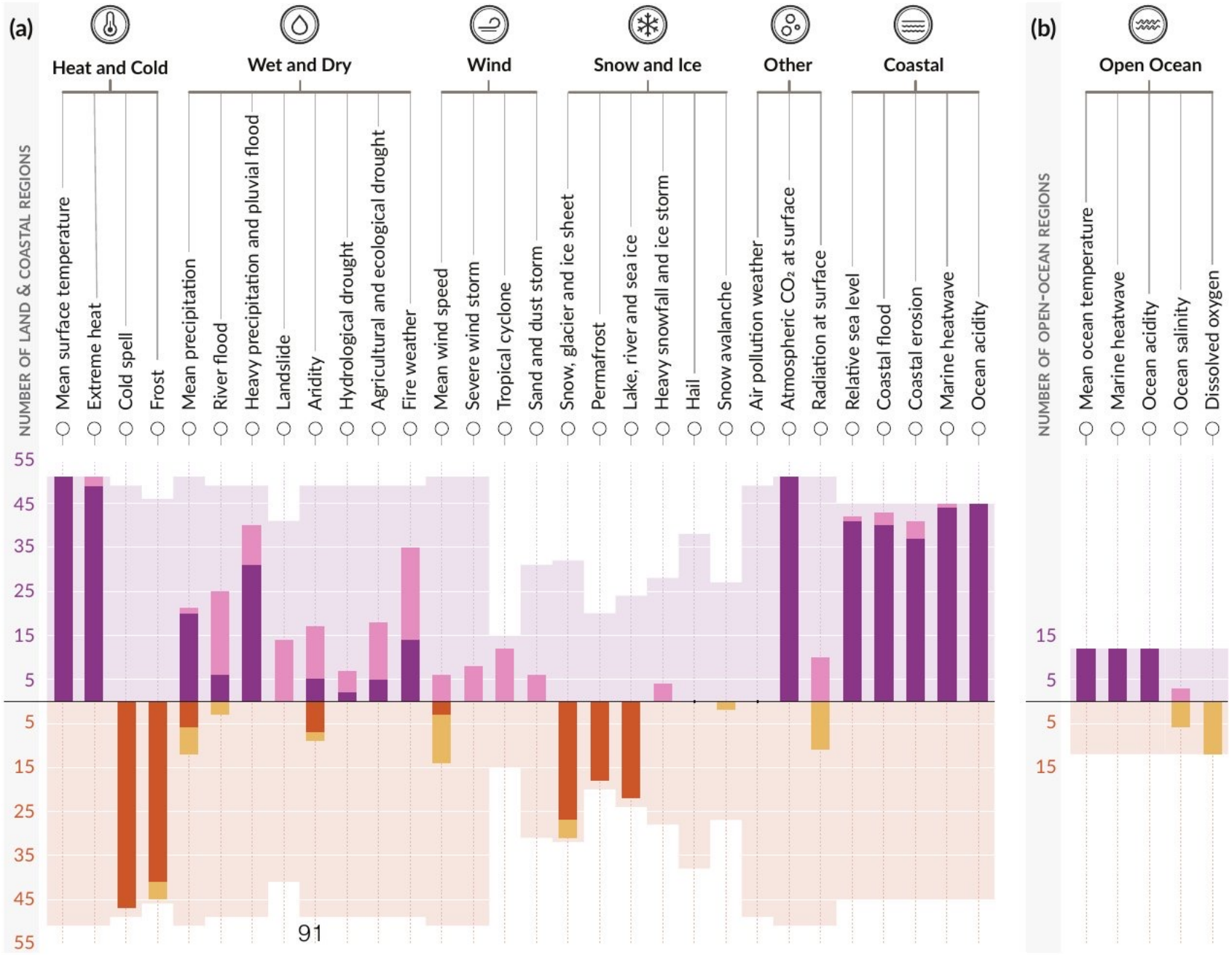
https://interactive-atlas.ipcc.ch/

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

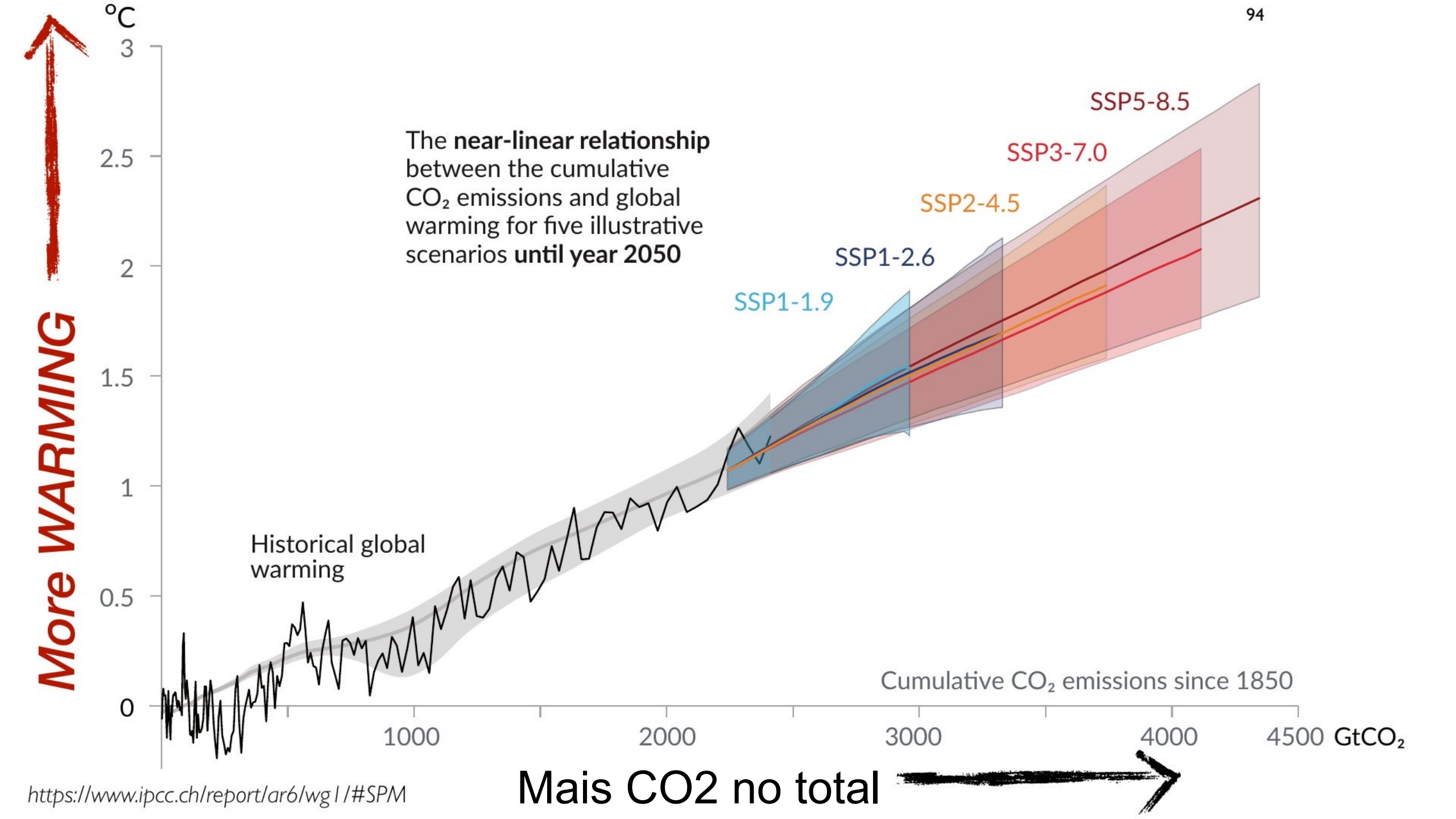
Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to increase or decrease with ***high*** *confidence* (dark shade) or ***medium*** *confidence* (light shade)



REFLEXÃO

QUAL É O PONTO MAIS CONFUSO ATÉ AQUI? OU SEJA, O QUE FICOU MENOS CLARO PARA VOCÊ?

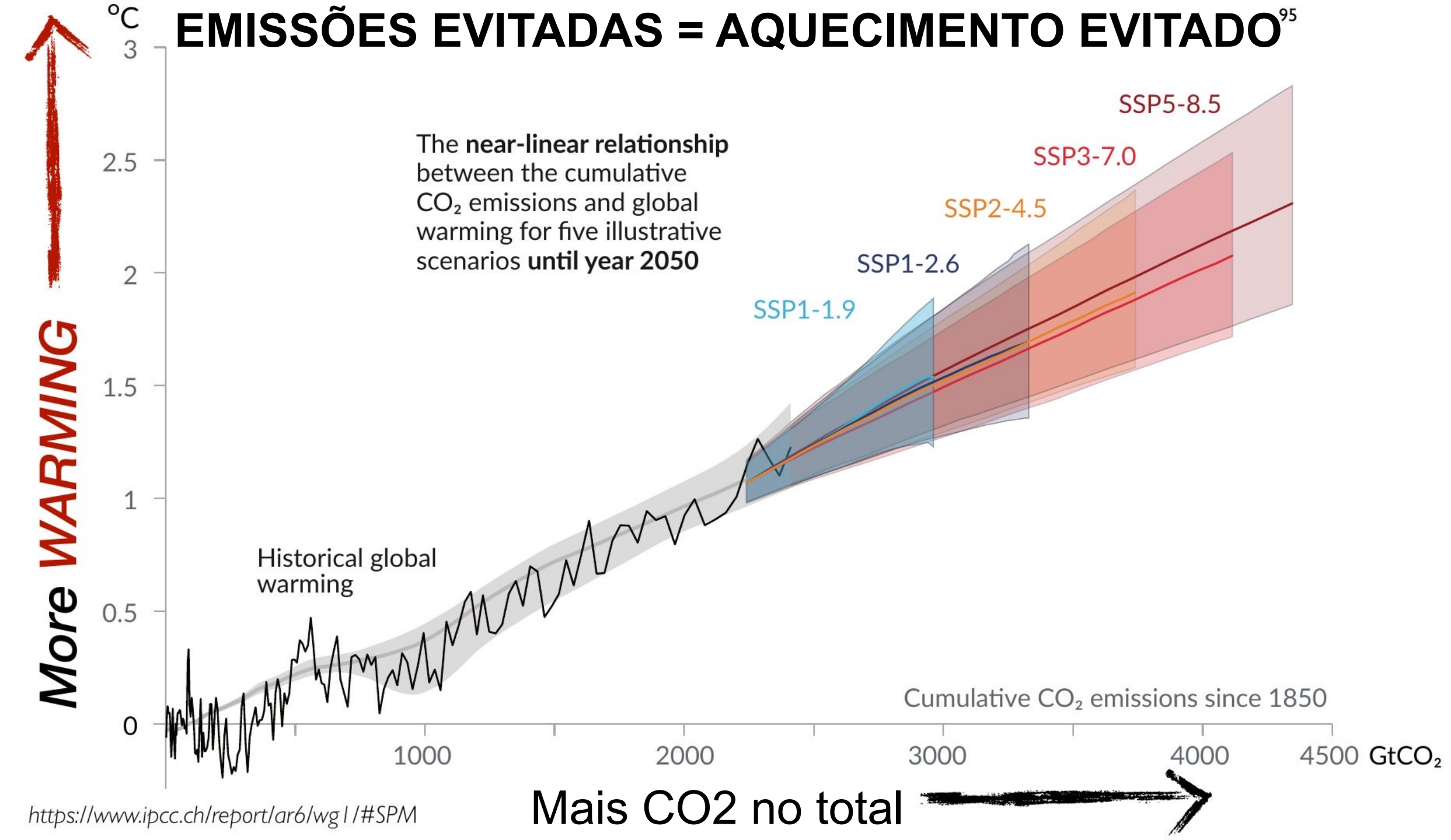
MITIGAÇÃO DA MUDANÇA CLIMÁTICA



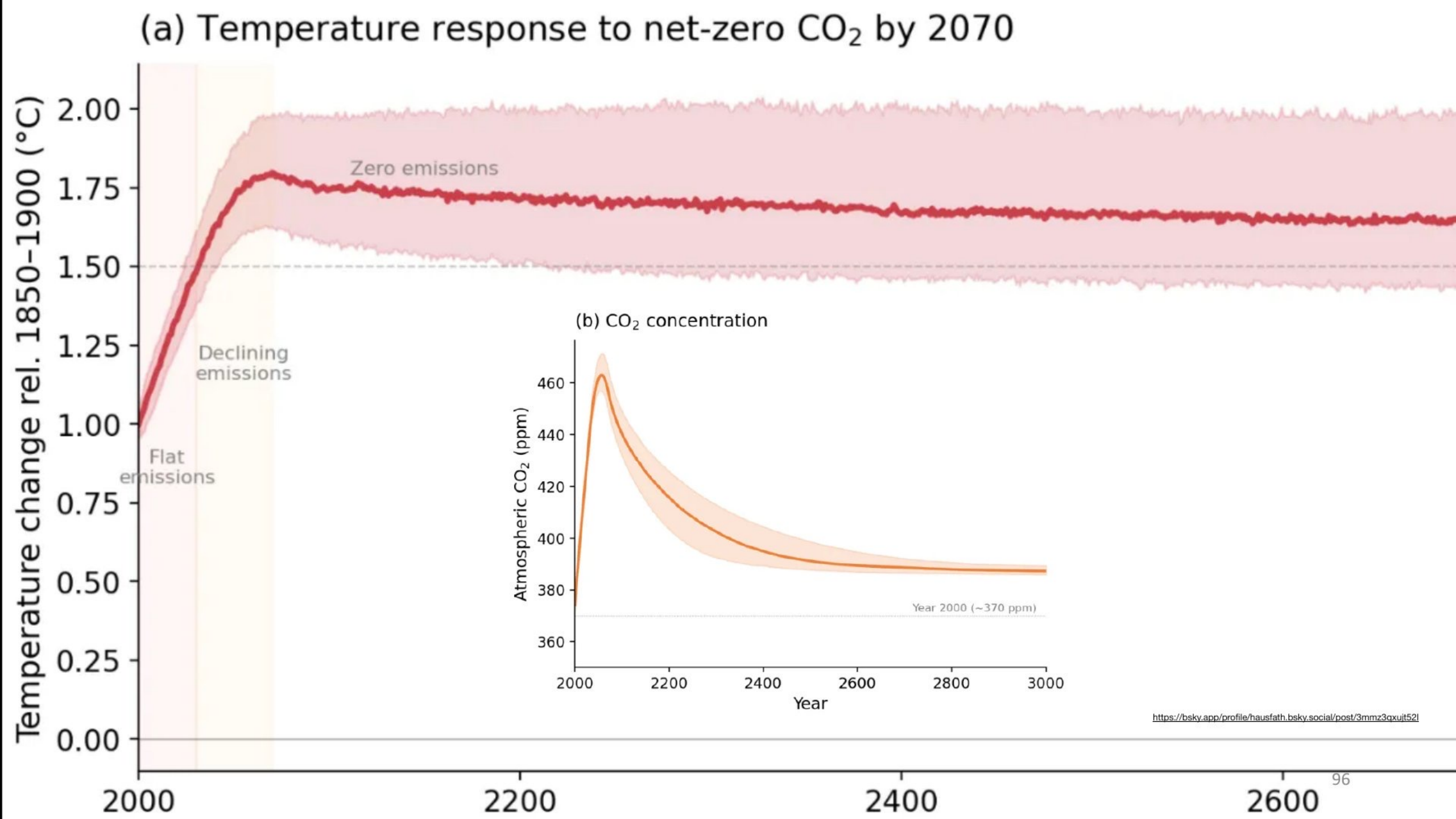
https://www.ipcc.ch/report/ar6/wg1/#SPM

Mais CO2 no total

EMISSÕES EVITADAS = AQUECIMENTO EVITADO[95]



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



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

IDENTIDADE DE KAYA

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

P = população mundial
G = PIB mundial
E = consumo mundial de energia
F = emissões de GEE de origem humana (combustíveis fósseis)

IDENTIDADE DE KAYA

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

PIB per capita
(consumo econômico)

IDENTIDADE DE KAYA

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

intensidade energética

(Quanta energia por unidade de produção econômica)

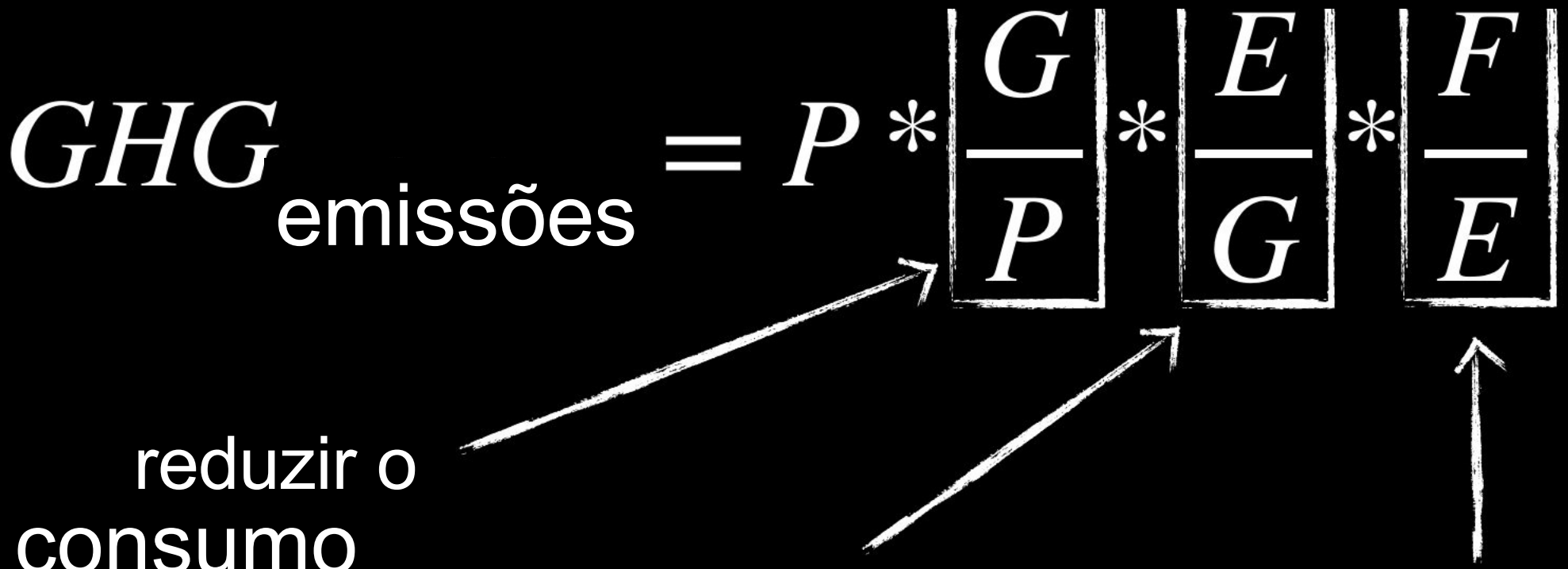
IDENTIDADE DE KAYA

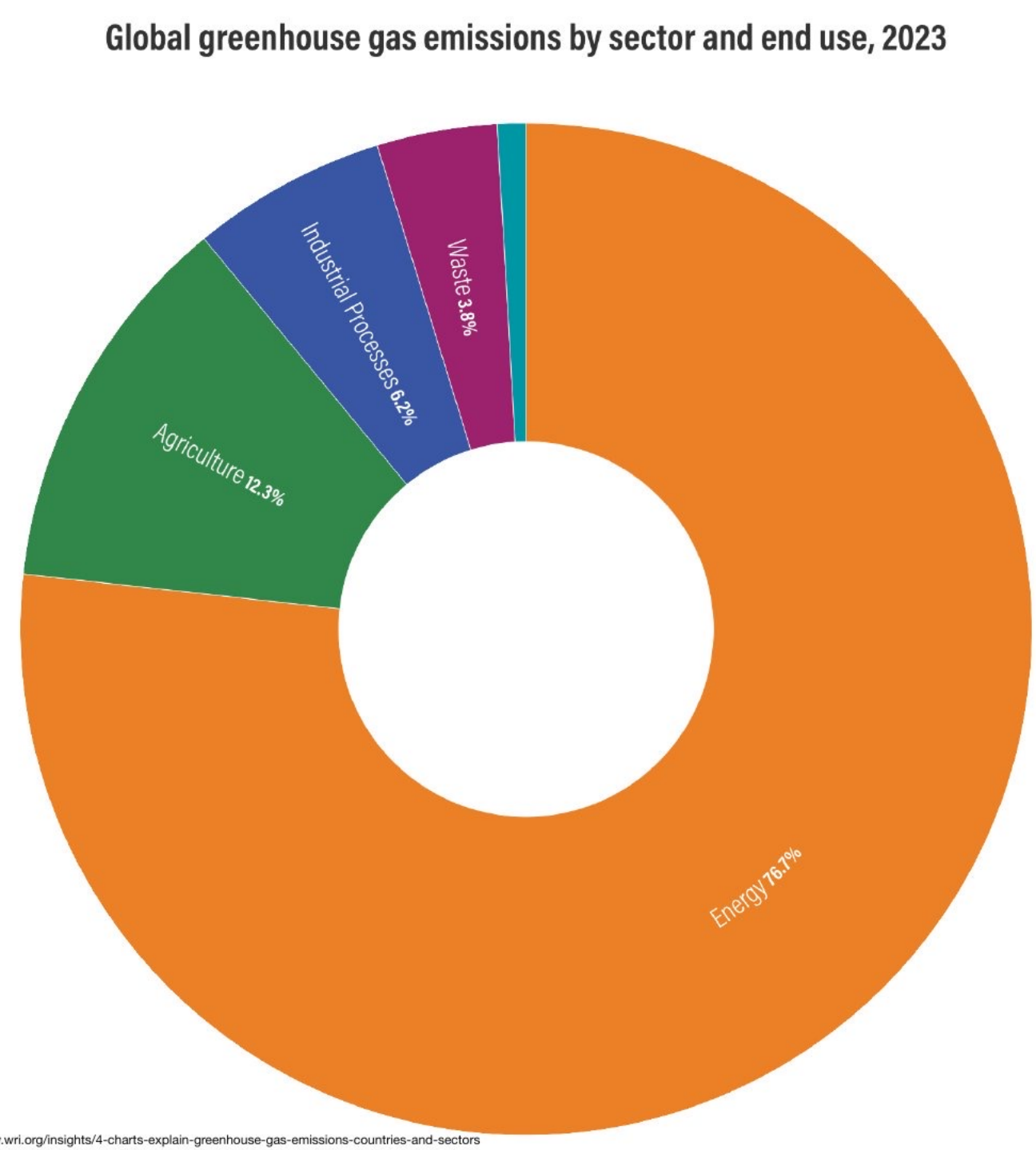
$$GHG_{\text{emissões}} = P * \frac{G}{P} * \frac{E}{G} * \boxed{\frac{F}{E}}$$

intensidade de emissões da energia

(uso de combustíveis fósseis)

IDENTIDADE DE KAYA

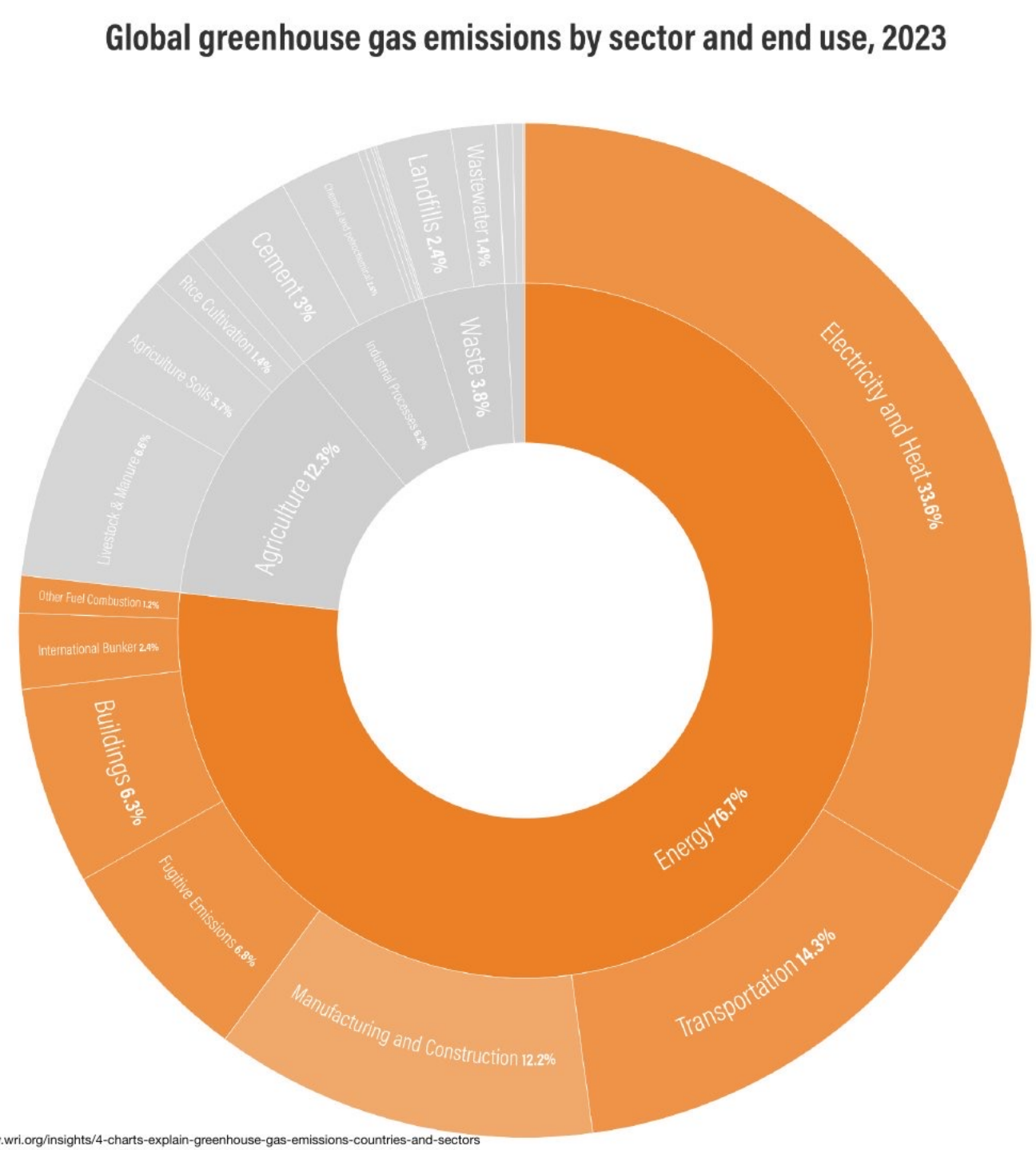




https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

>76% das emissões de GEE vêm do uso final de energia

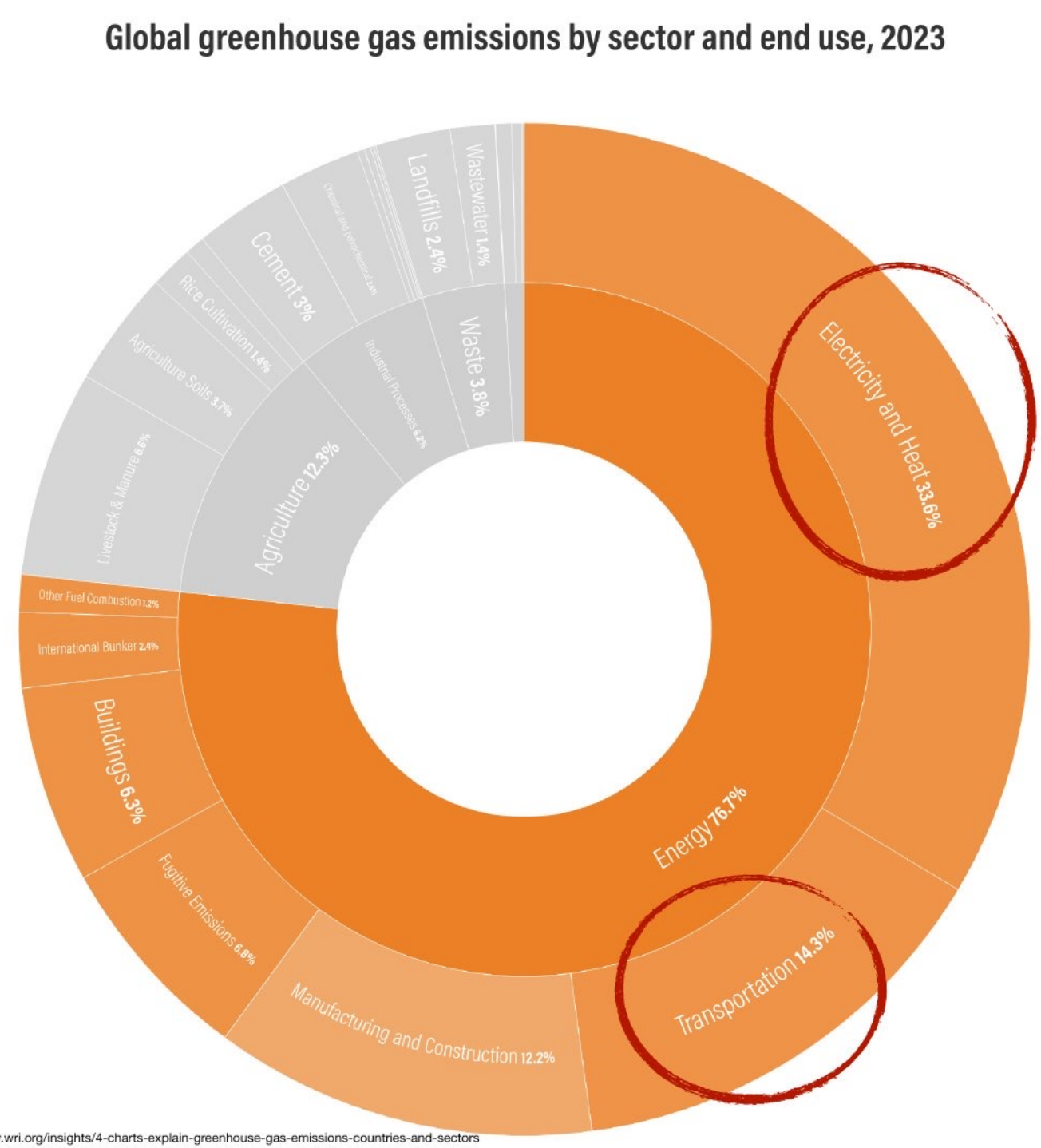
WORLD RESOURCES INSTITUTE



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

>76% das emissões de GEE vêm da energia

WORLD RESOURCES INSTITUTE



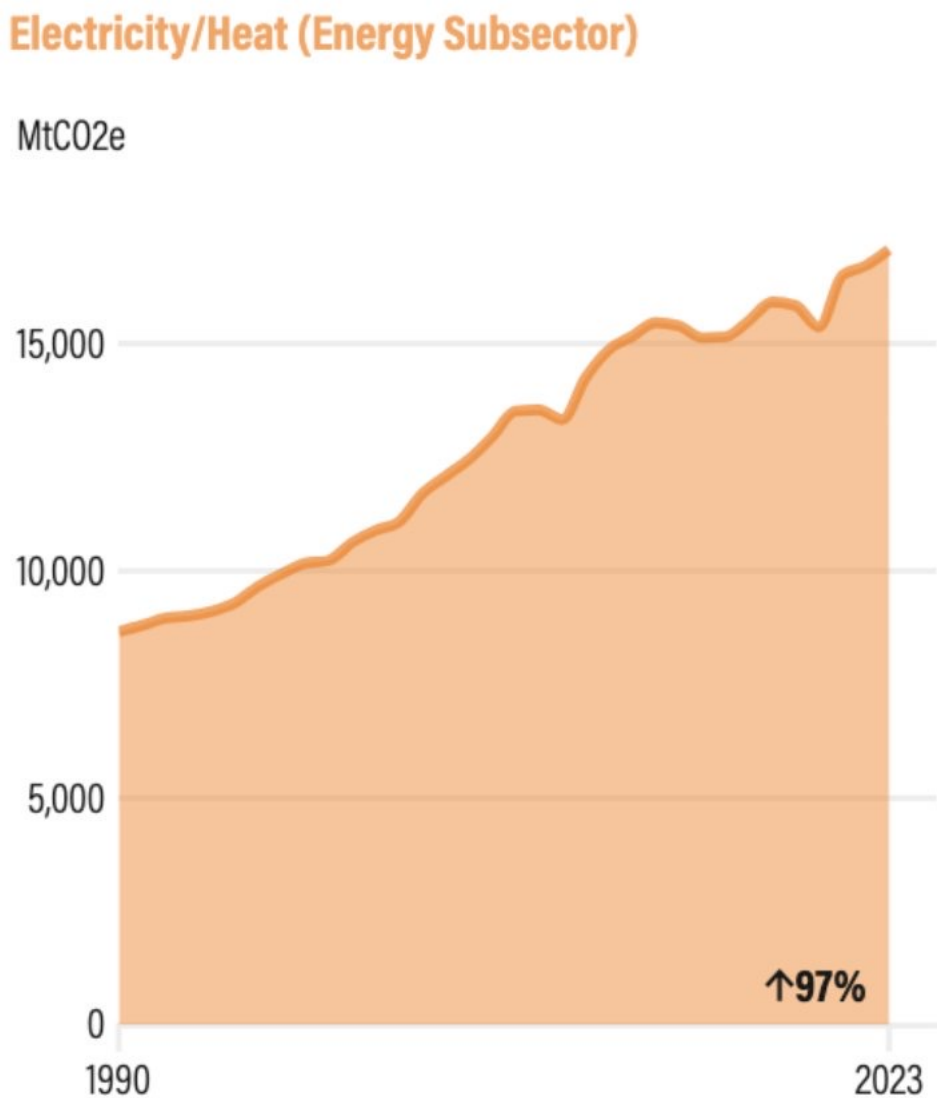
https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

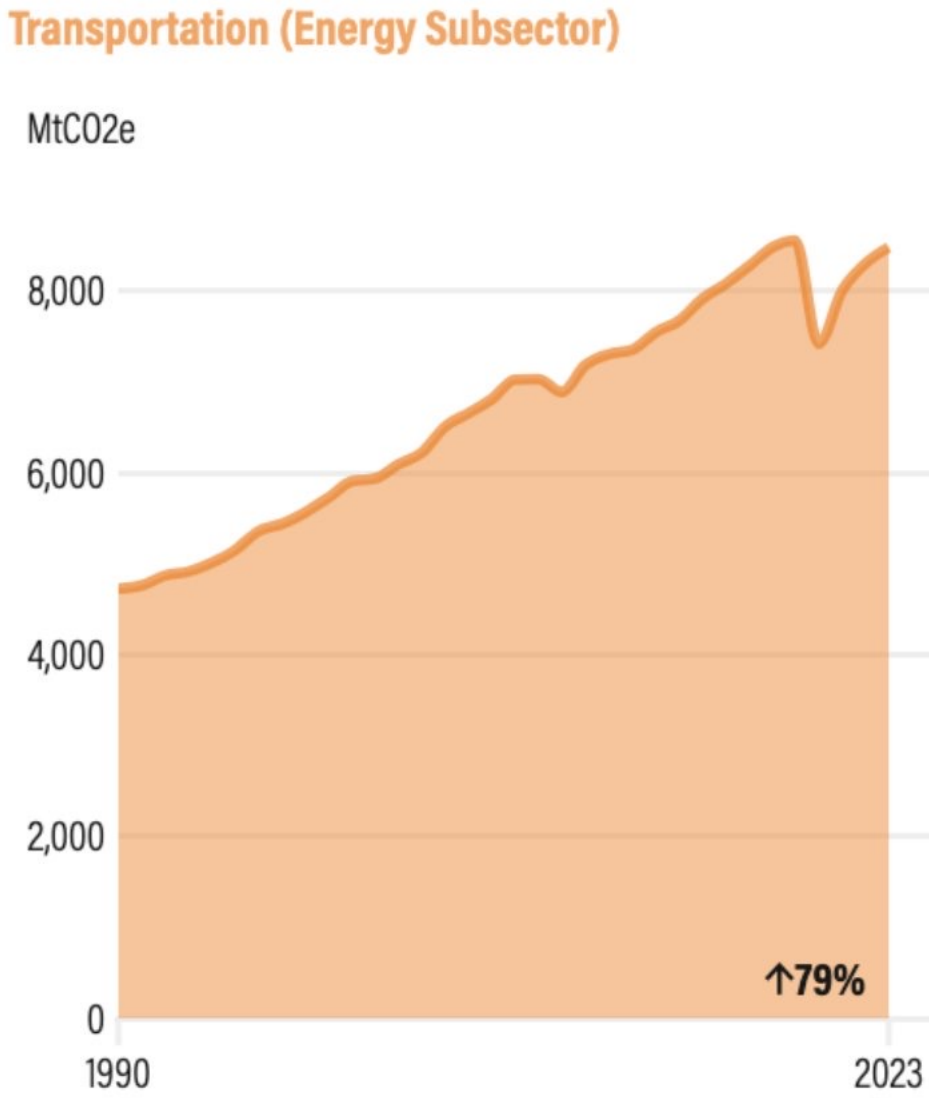
Eletricidade + calor e transportes: maior componente das emissões de energia

WORLD RESOURCES INSTITUTE

Trends in sectoral emissions, 1990-2023

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



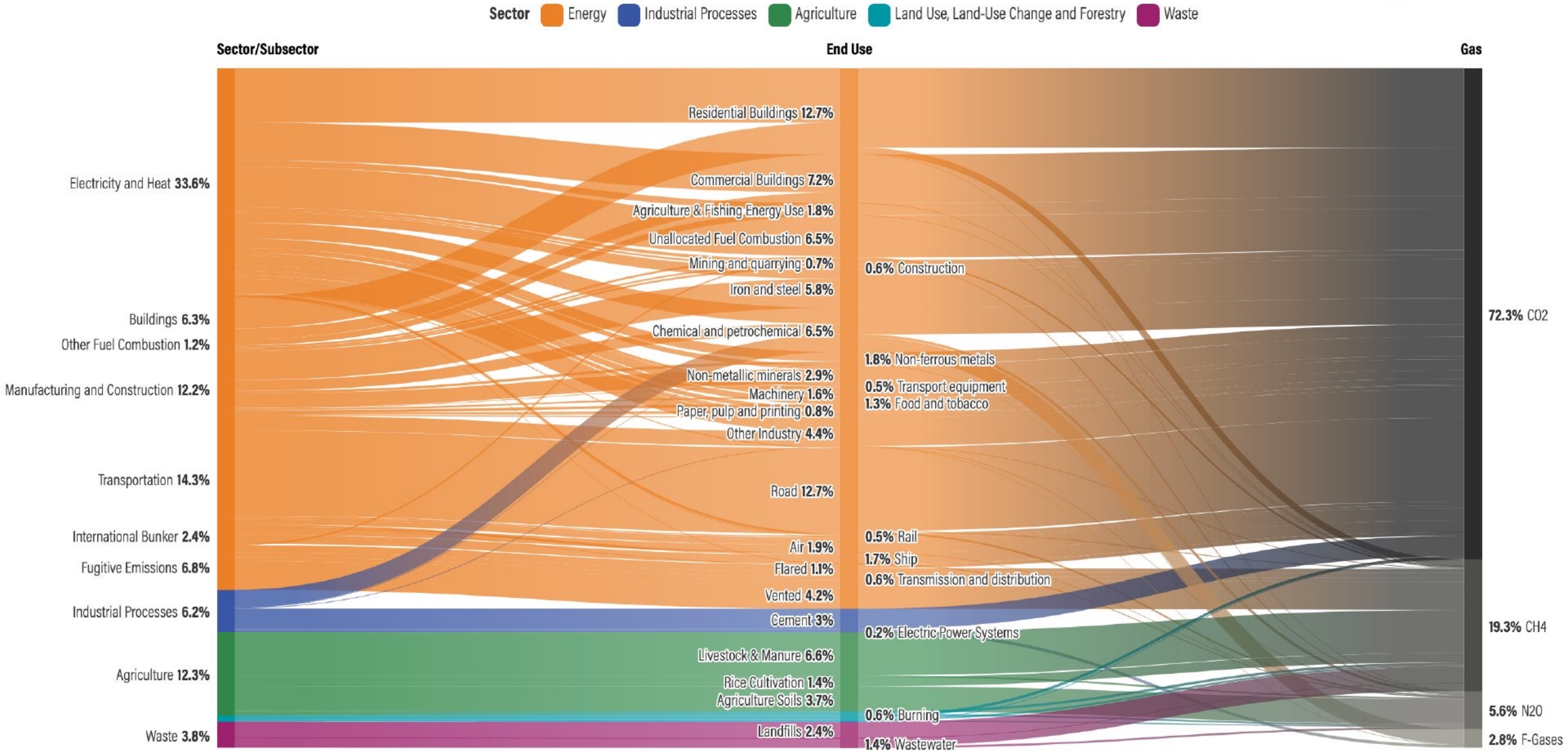


WORLD RESOURCES INSTITUTE

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

Agricultura, florestas e outros usos da terra (AFOLU)

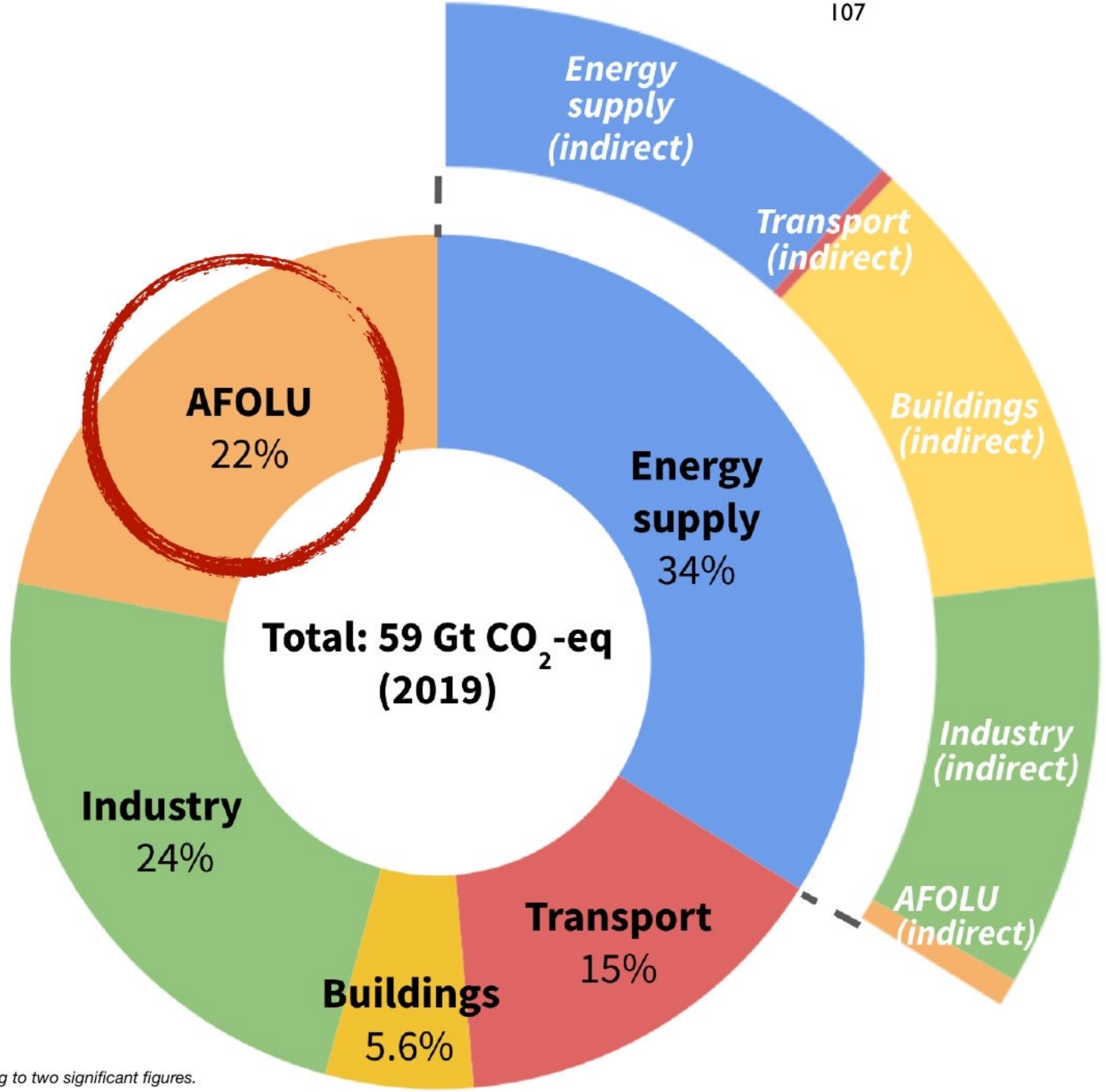
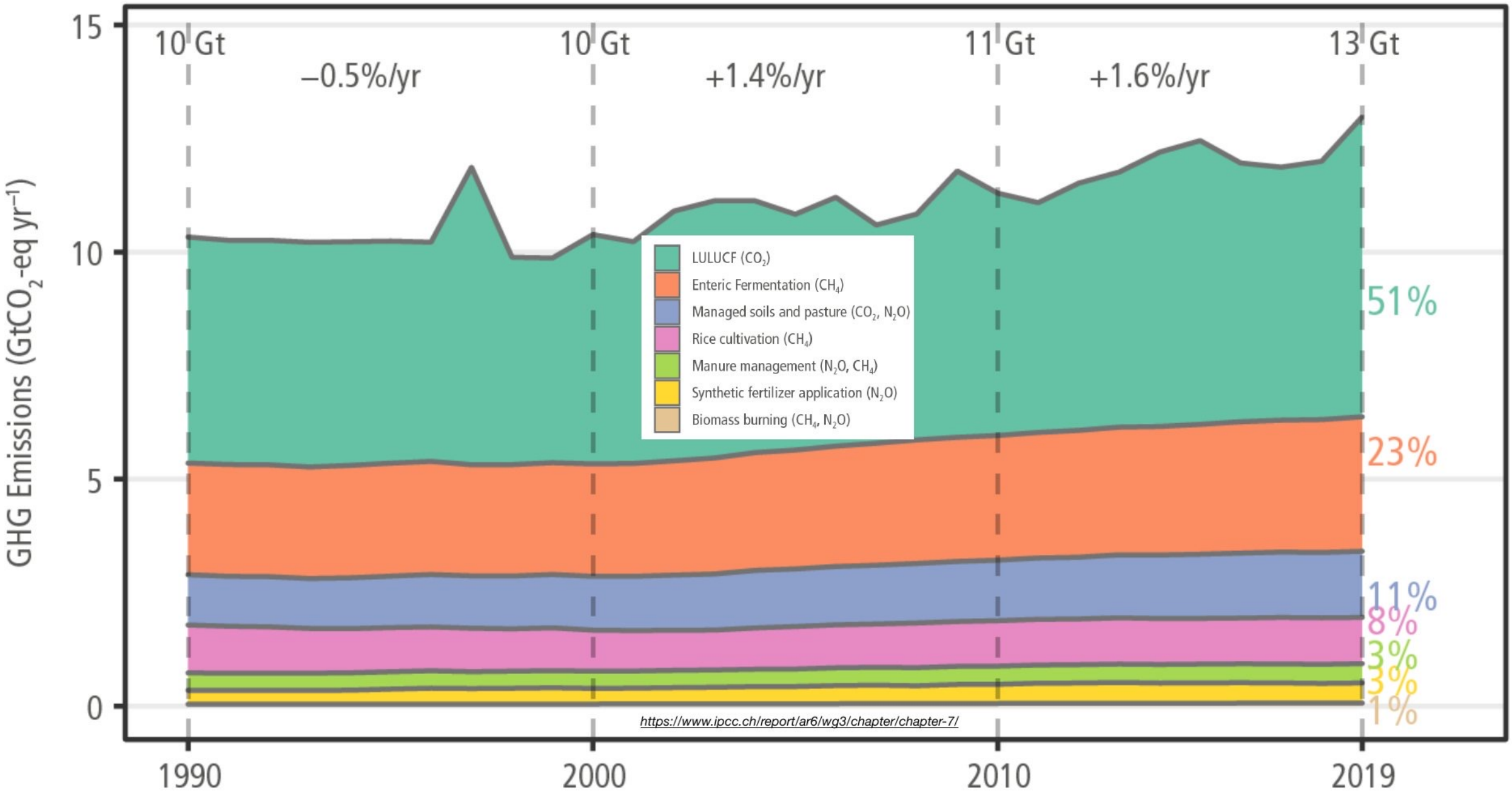


Figure data based on IPCC AR6 WG3 Report (2022). Percentages shown do not add to exactly 100% due to rounding to two significant figures.
Credit: Dr. Priya Donti

a. AFOLU global trends in GHG emissions and removals

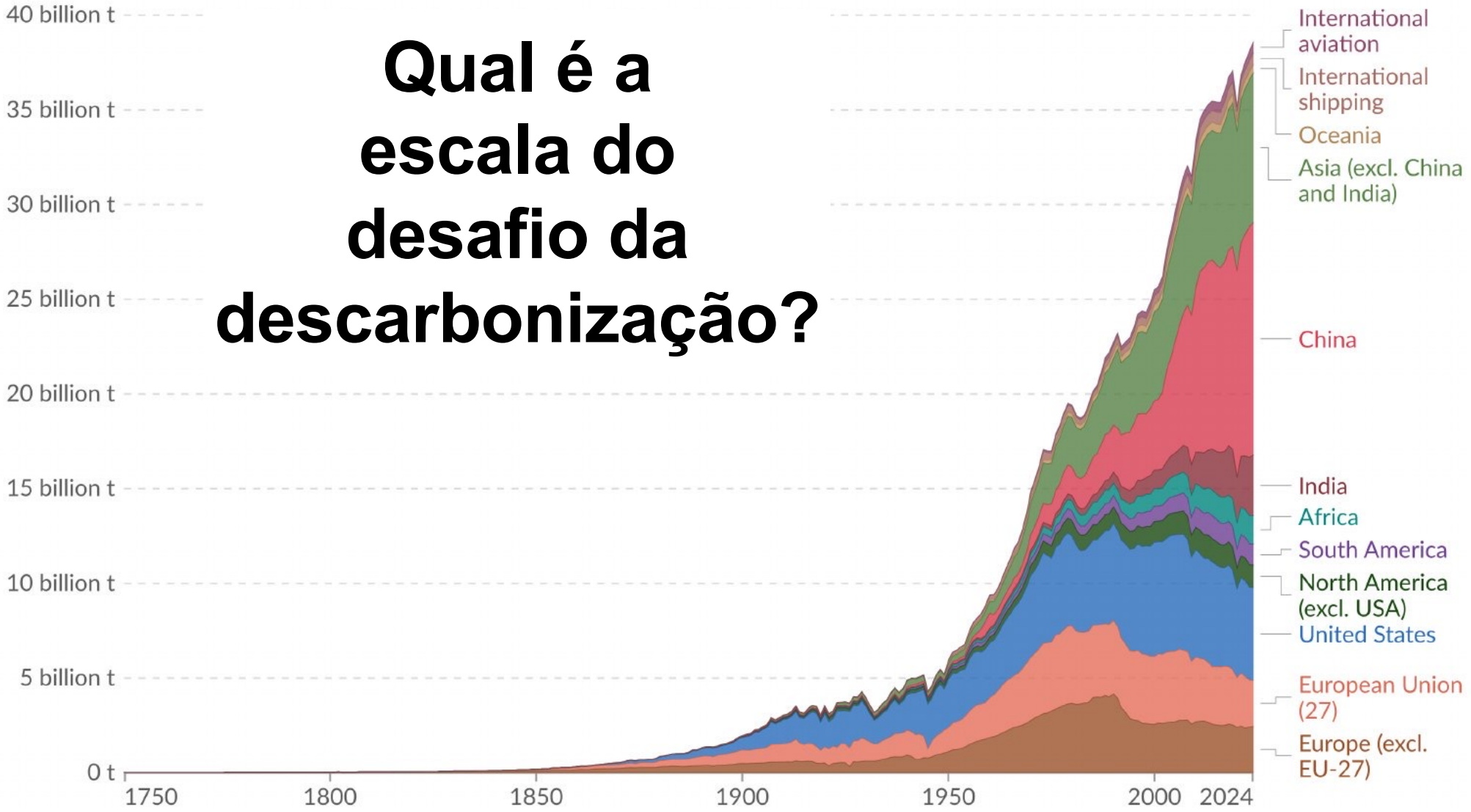


Our World in Data

Annual CO_2 emissions by world region

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.

Qual é a escala do desafio da descarbonização?

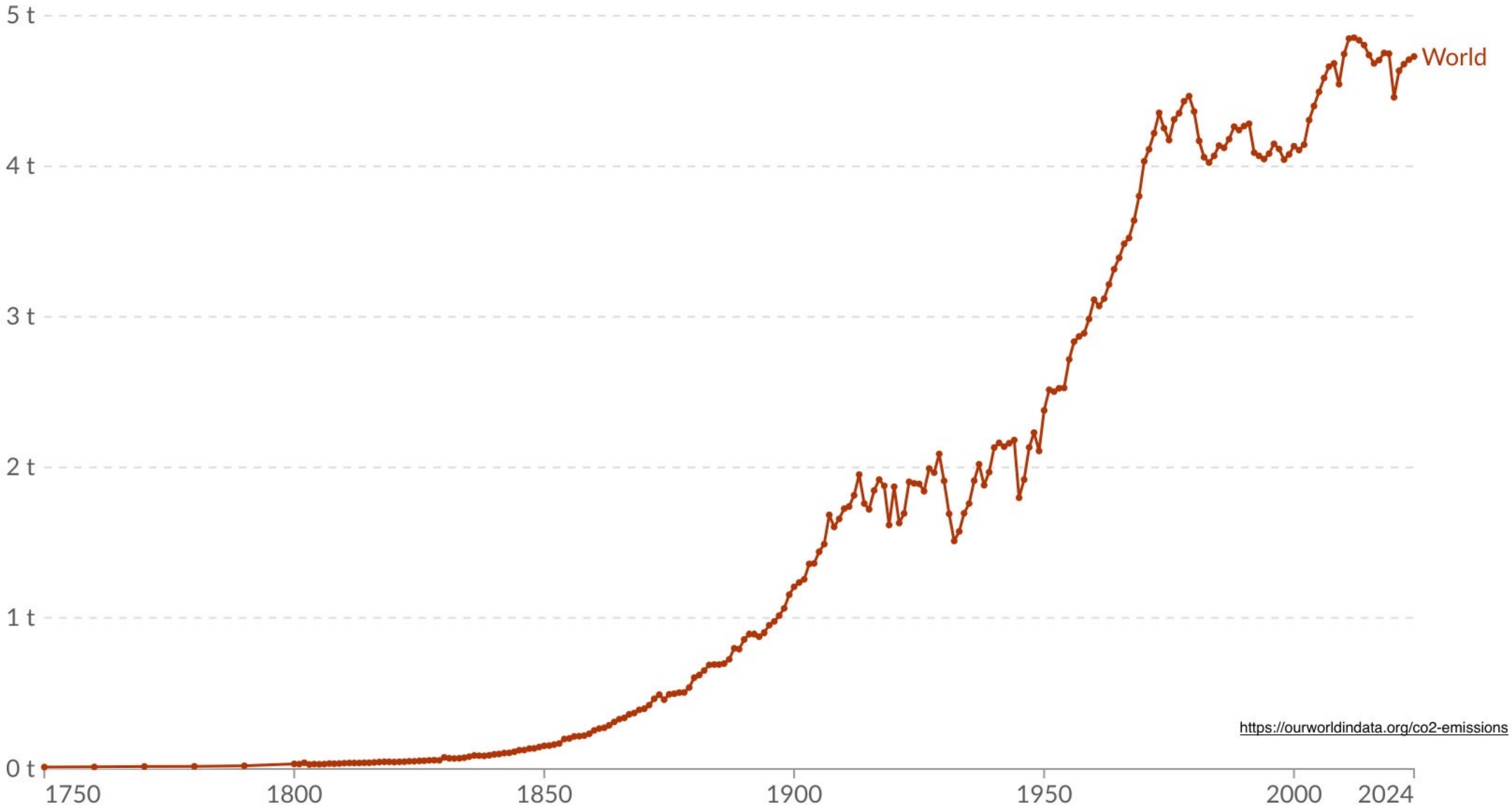


Data source: Global Carbon Budget (2025) https://ourworldindata.org/co2-emissions OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

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].

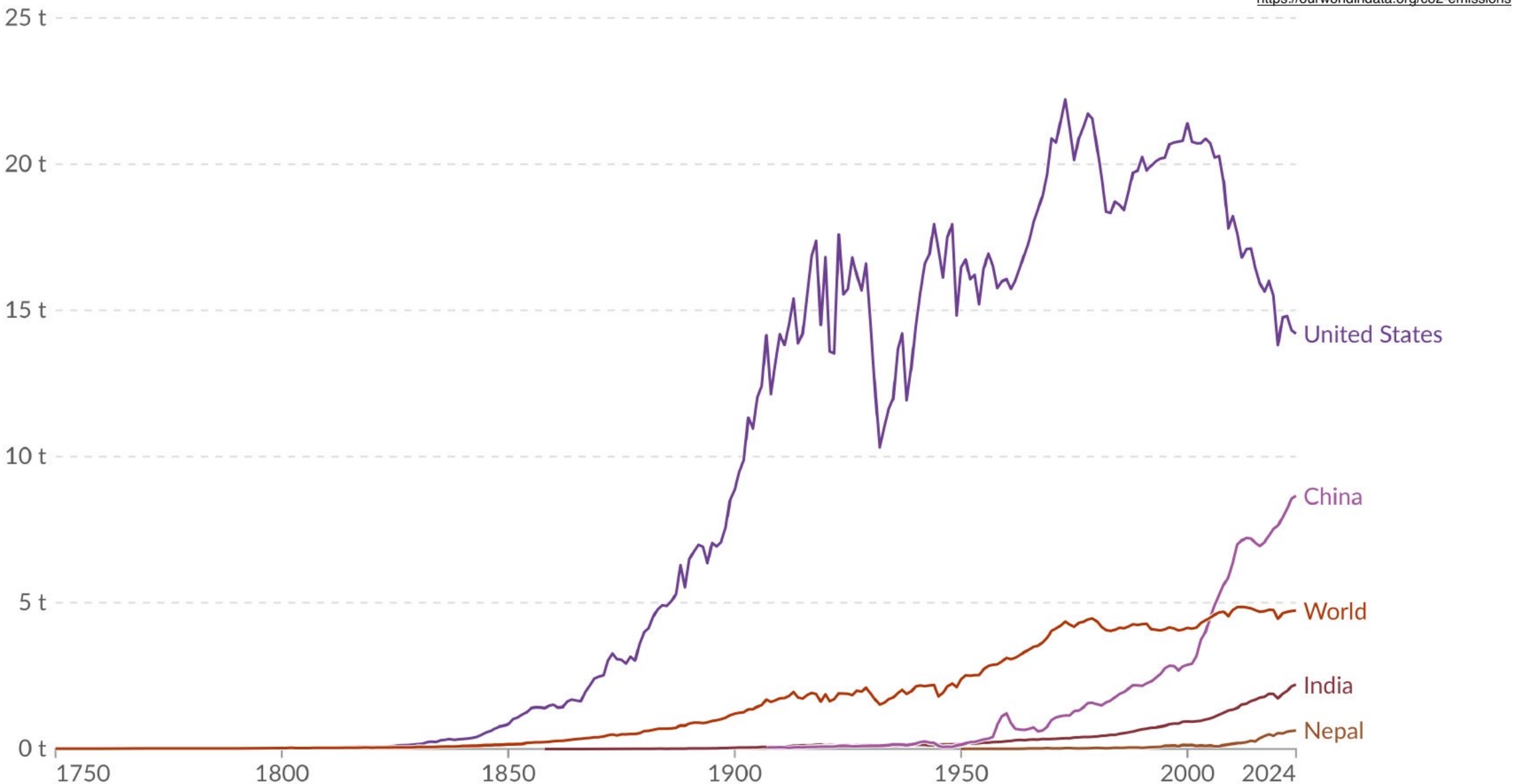


CO_2 emissions per capita

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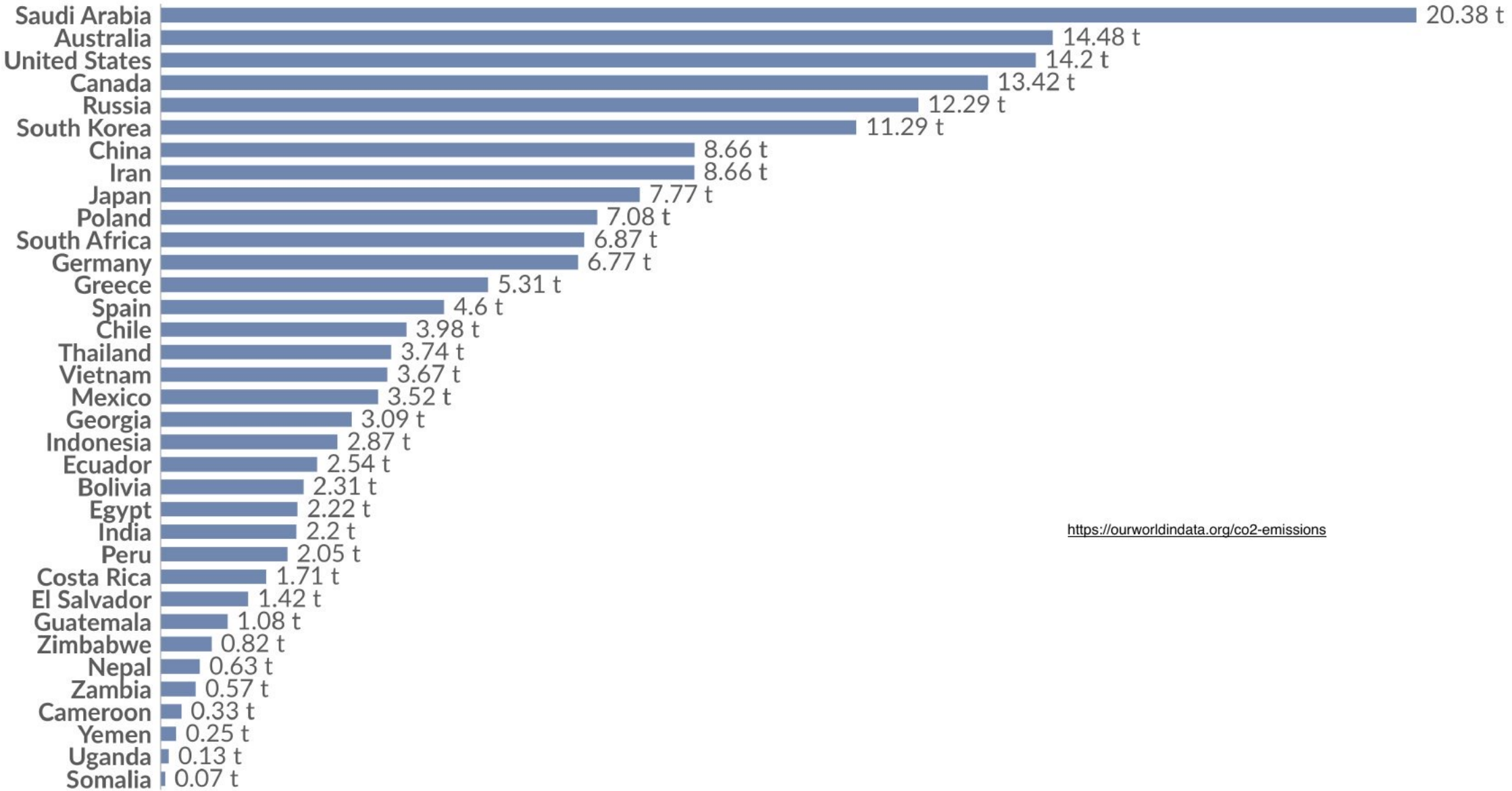
Our World in Data

https://ourworldindata.org/co2-emissions



CO_2 emissions per capita, 2024

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

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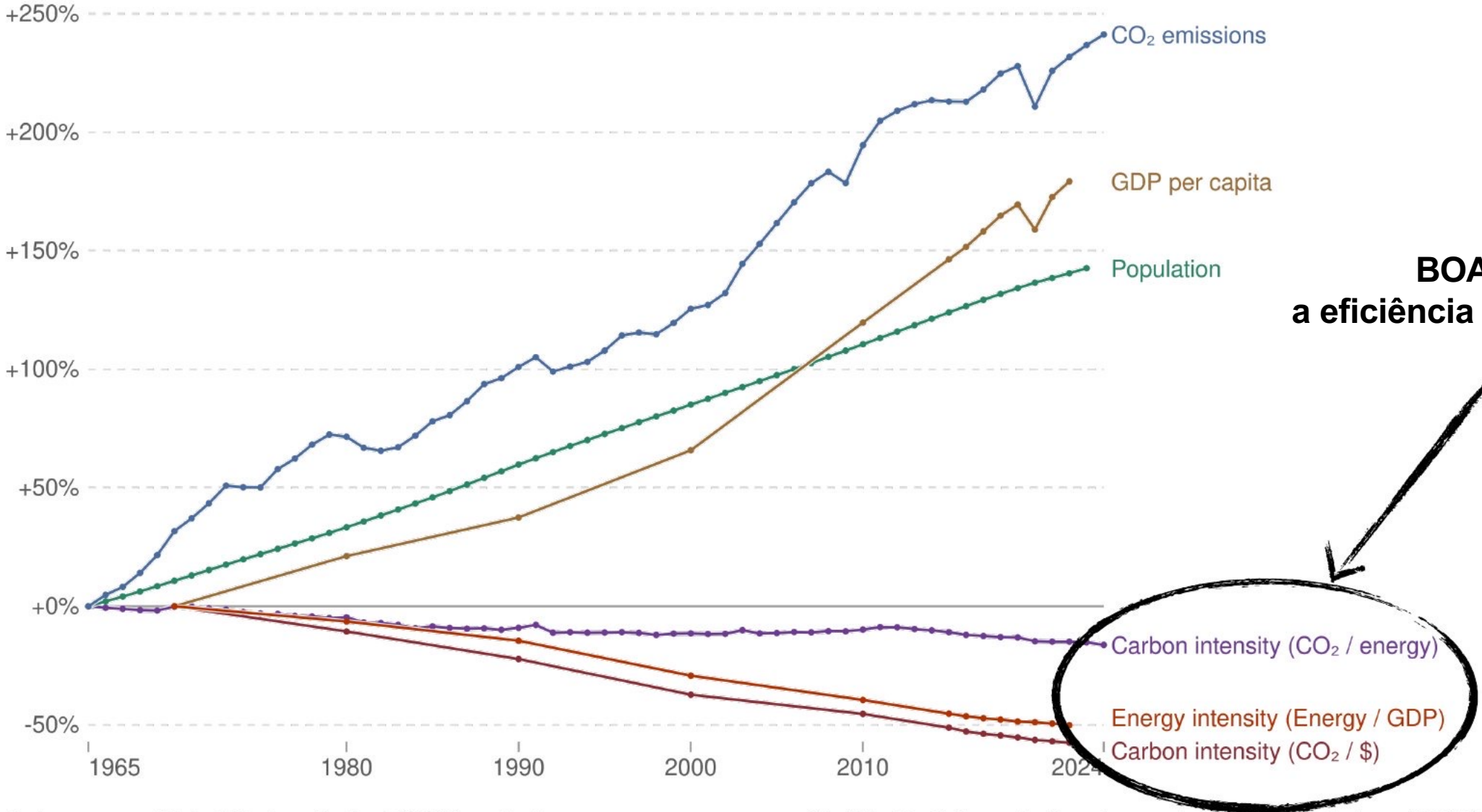
https://ourworldindata.org/co2-emissions

Equidade/justiça climática: reconhecer que a mudança climática é uma questão social, ética e política, e que enfrentar suas raízes exige encarar a responsabilidade histórica, os legados coloniais e as injustiças sistêmicas.

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.



BOA NOTÍCIA
a eficiência está aumentando

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

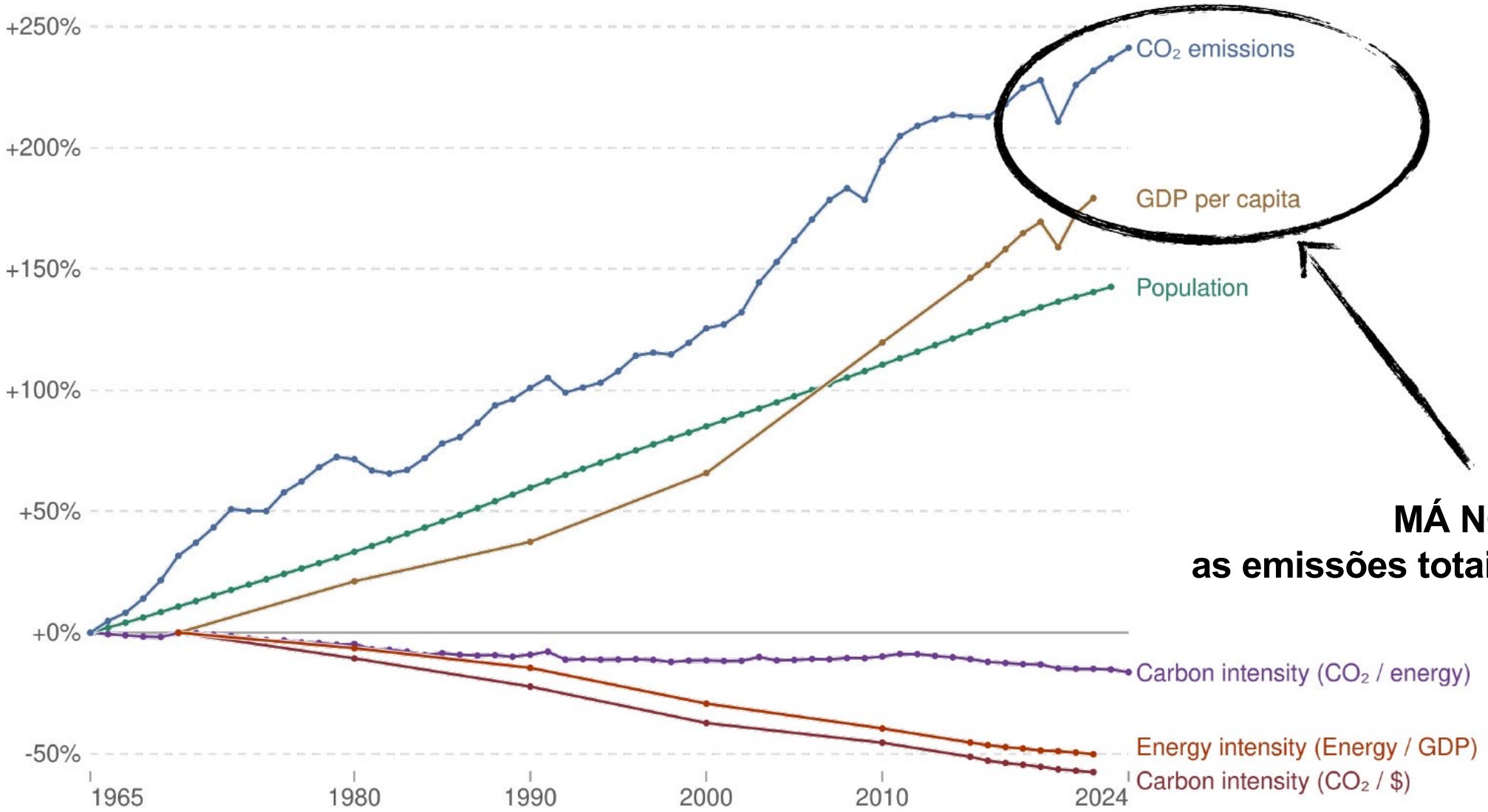
OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

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.



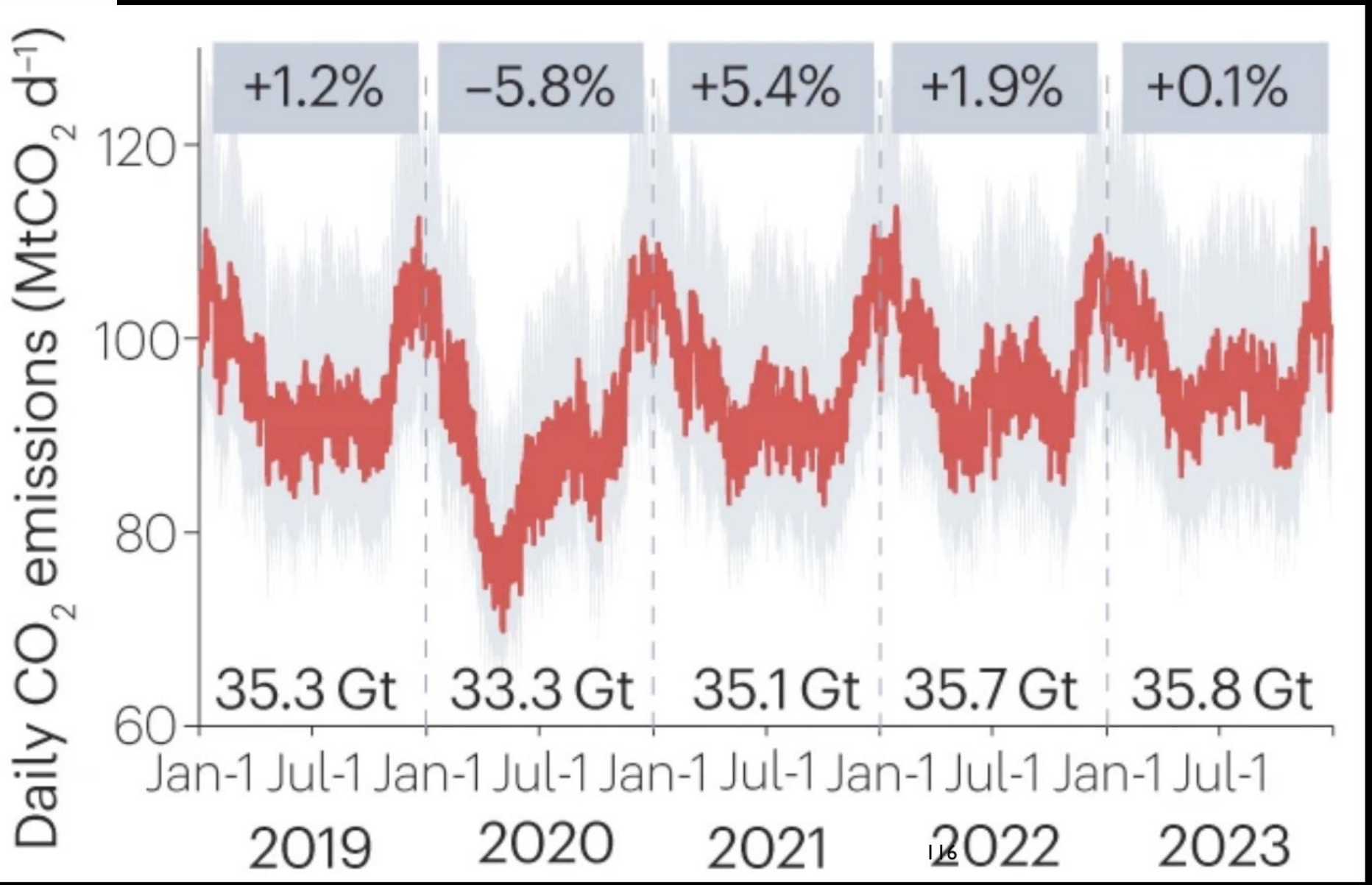
MÁ NOTÍCIA
as emissões totais ainda aumentam

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.

A escala do desafio



COVID

Queda de só 5,8% nas emissões em um ano

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

O Acordo de Paris (COP 21, dez. 2015)

"O objetivo central do Acordo de Paris é fortalecer a resposta global à ameaça da mudança climática, mantendo o aumento da temperatura global neste século bem abaixo de 2 graus Celsius acima dos níveis pré-industriais e envidando esforços para limitá-lo ainda mais, a 1,5 grau Celsius."

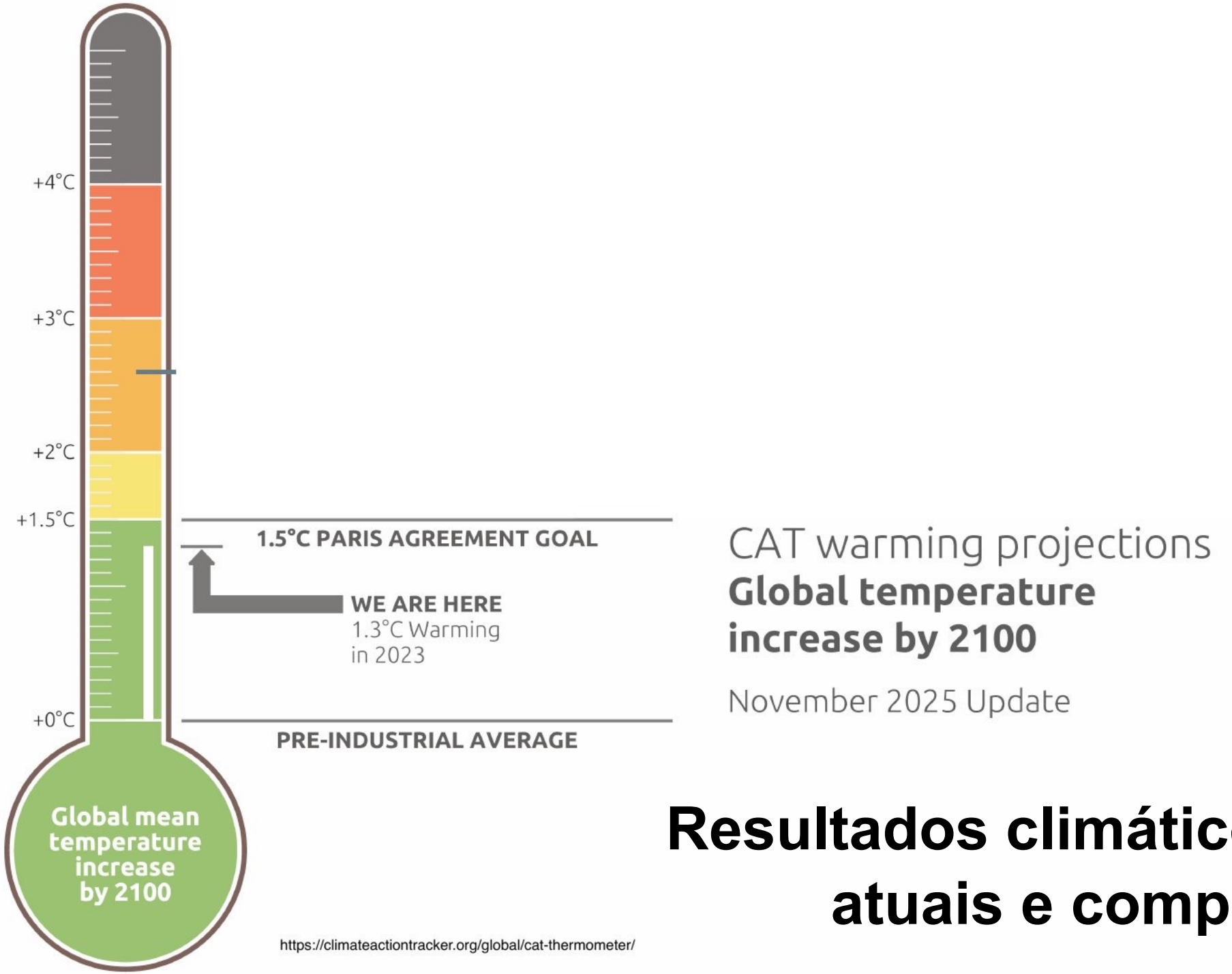
O limite de 2° vem do economista de Yale William Nordhaus em seu artigo de 1975: "Can We Control Carbon Dioxide?"

Baseado na ideia de que seria razoável tentar manter a mudança climática dentro dos limites da "variação normal"

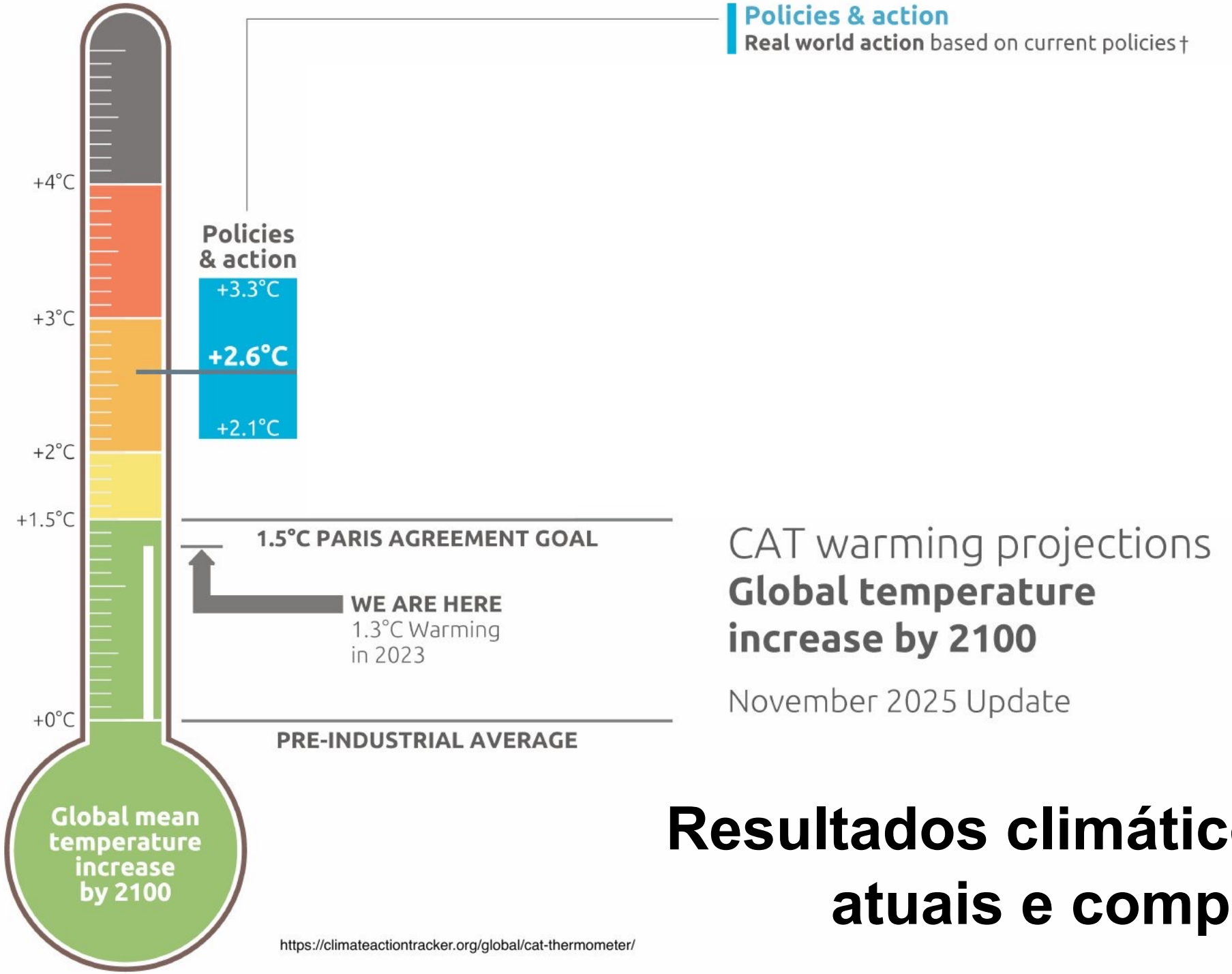
Nordhaus ressaltou que seu raciocínio era "profundamente insatisfatório"

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

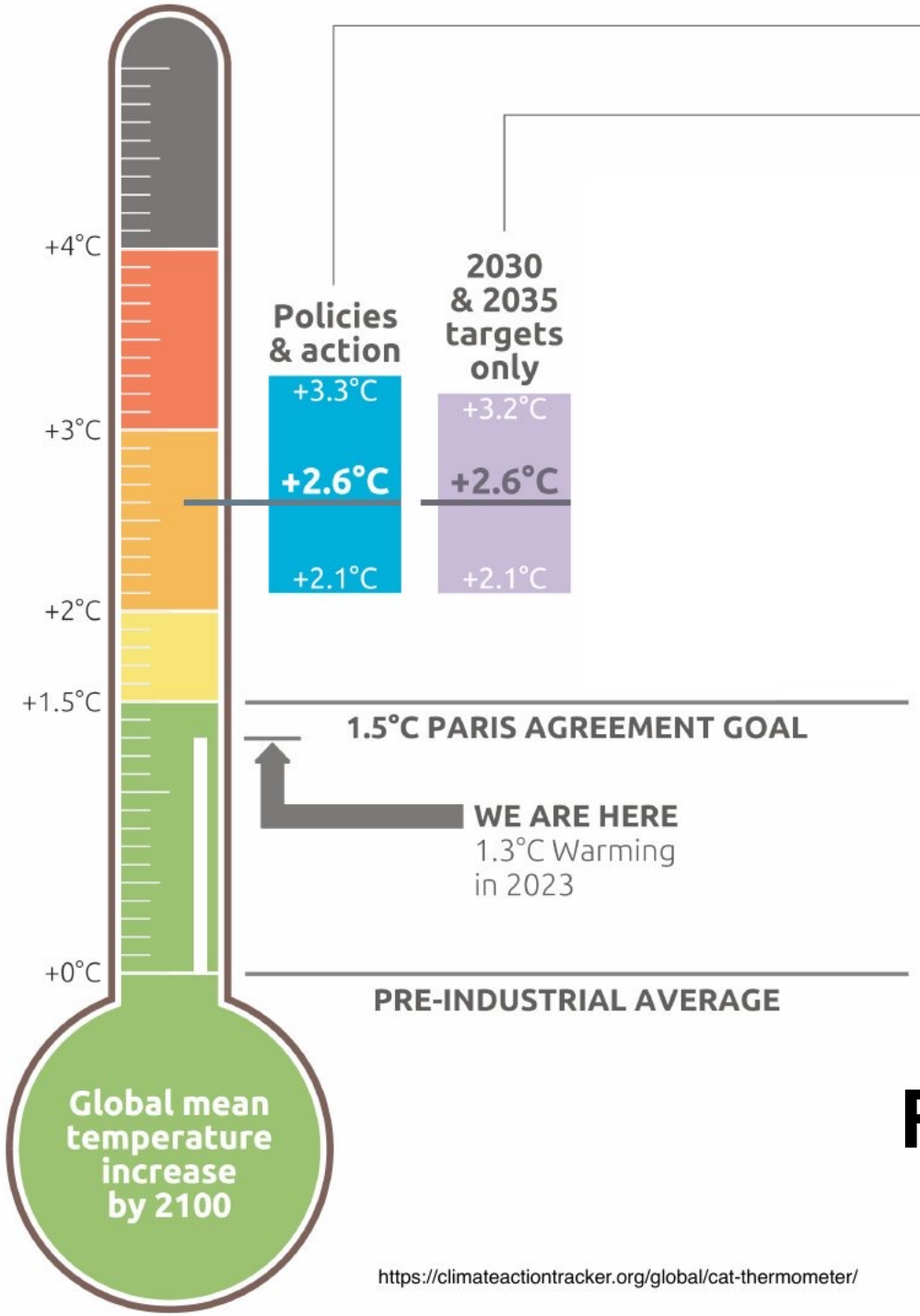
http://theconversation.com/why-is-climate-changes-2-degrees-celsius-of-warming-limit-so-important-82058



Resultados climáticos dos cenários atuais e comprometidos



Resultados climáticos dos cenários atuais e comprometidos

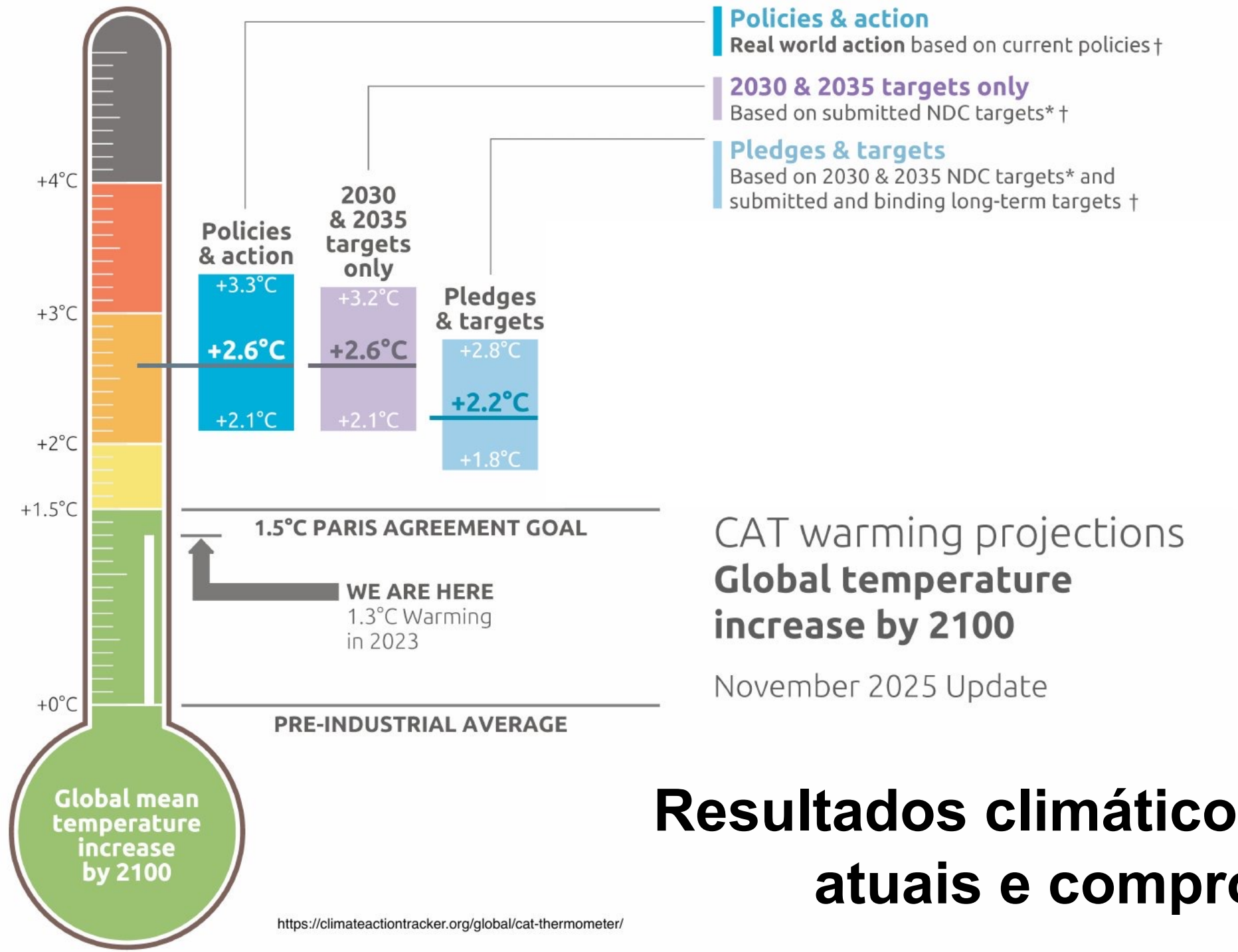


CAT warming projections
Global temperature increase by 2100

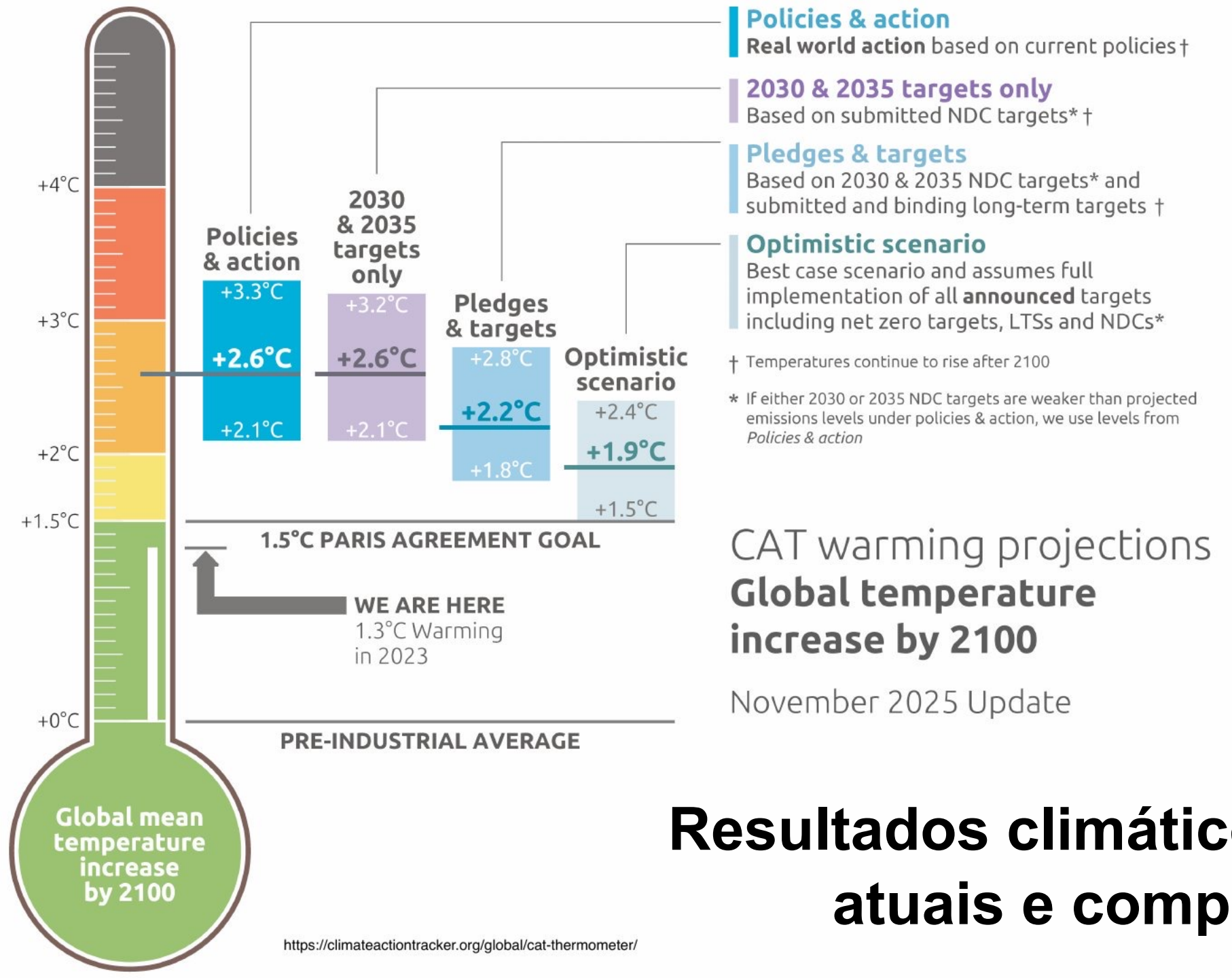
November 2025 Update

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

Resultados climáticos dos cenários atuais e comprometidos

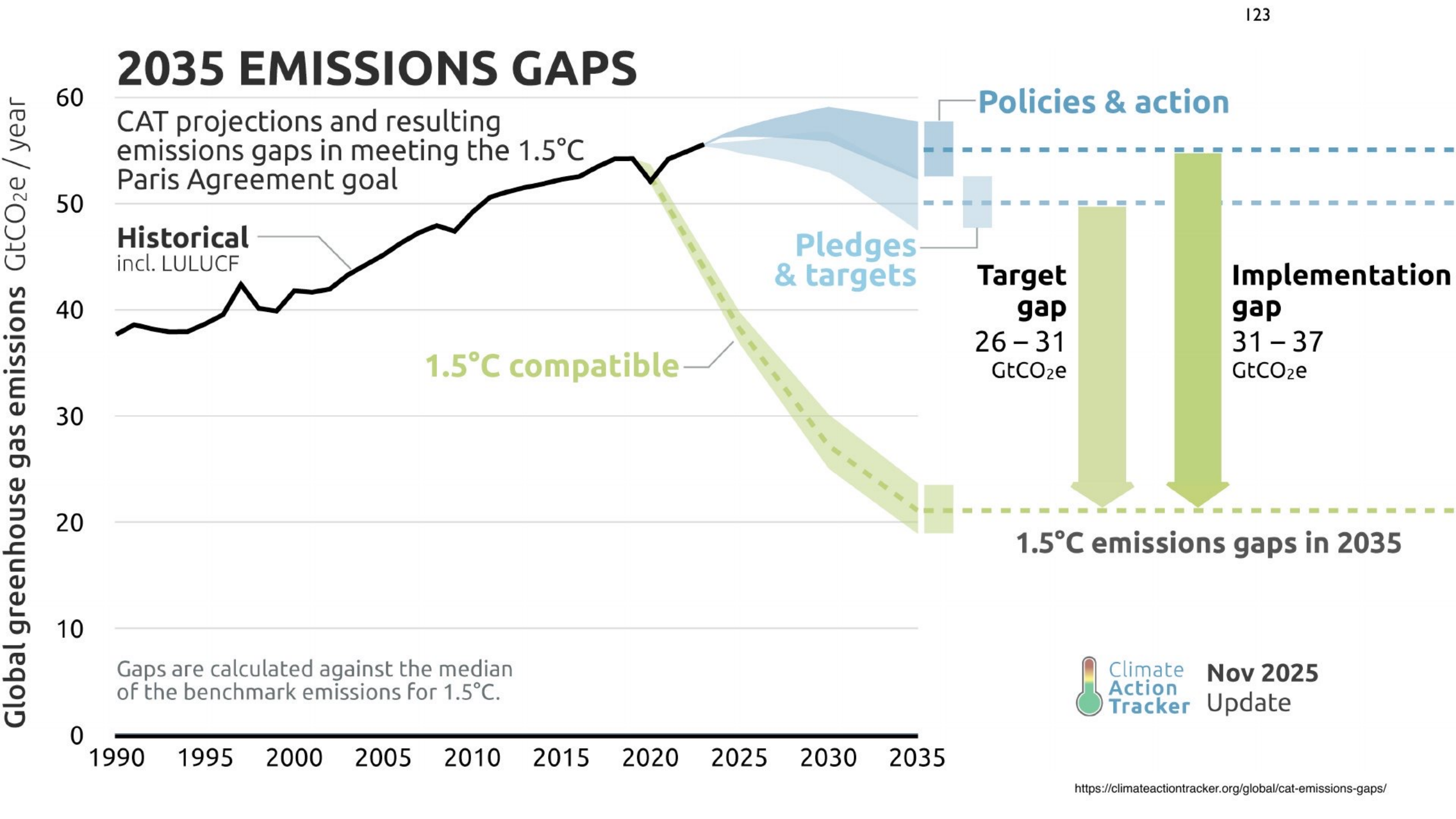


Resultados climáticos dos cenários atuais e comprometidos



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

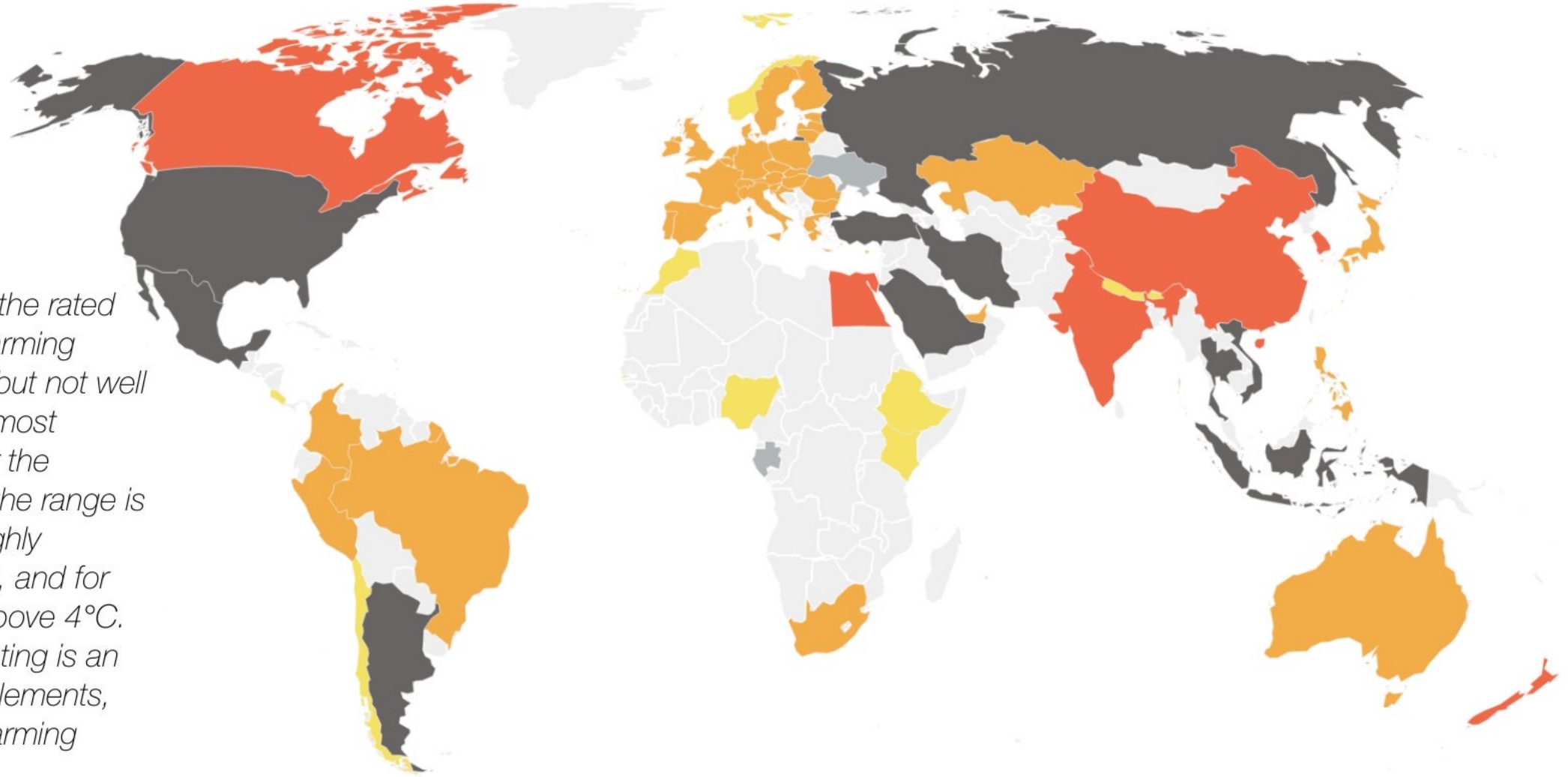
Resultados climáticos dos cenários atuais e comprometidos



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

Países: contribuições propostas

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

ADAPTAÇÃO À MUDANÇA CLIMÁTICA

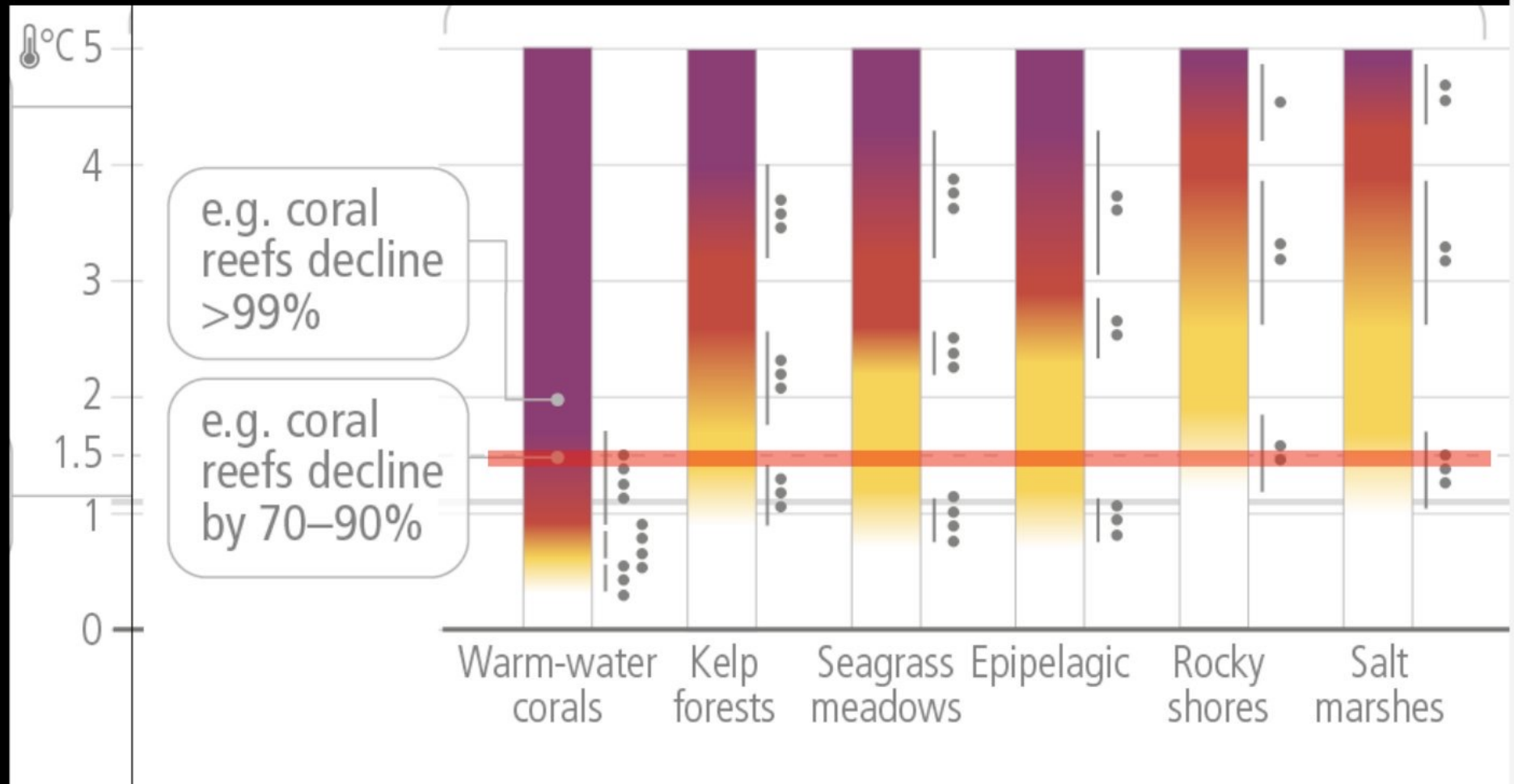
ADAPTAÇÃO À MUDANÇA CLIMÁTICA

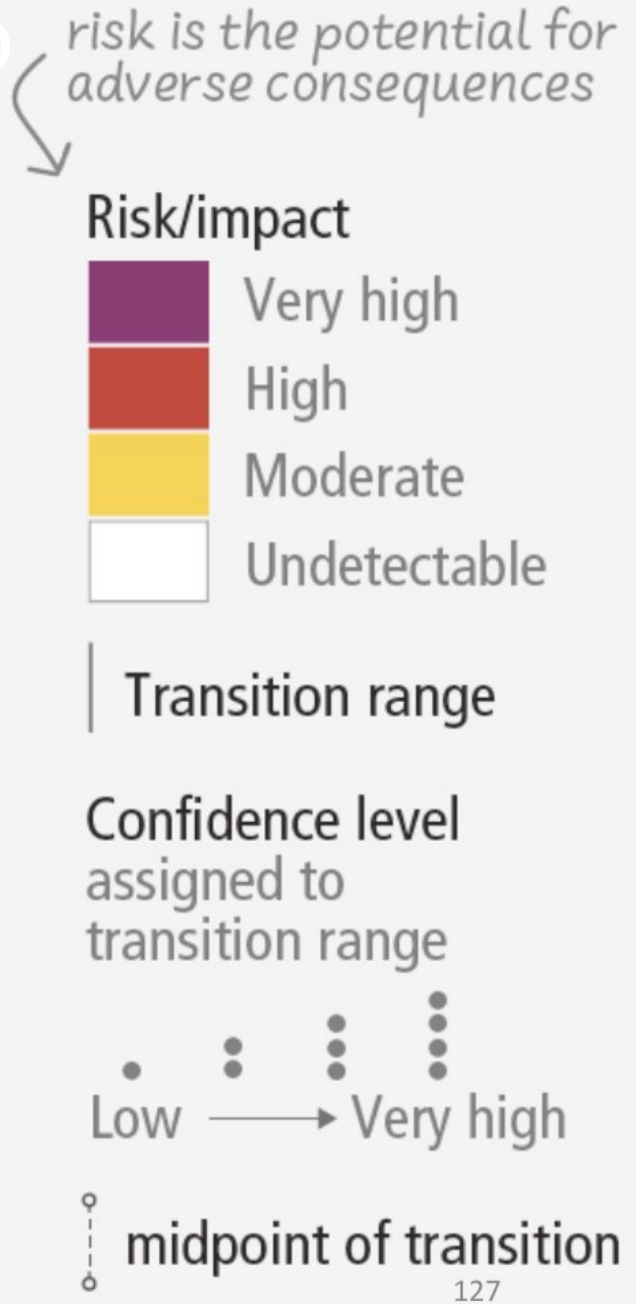
Robustez: resistir a uma série de cenários sem impacto ou com impacto mínimo

Resiliência: recuperar-se rápido após um impacto

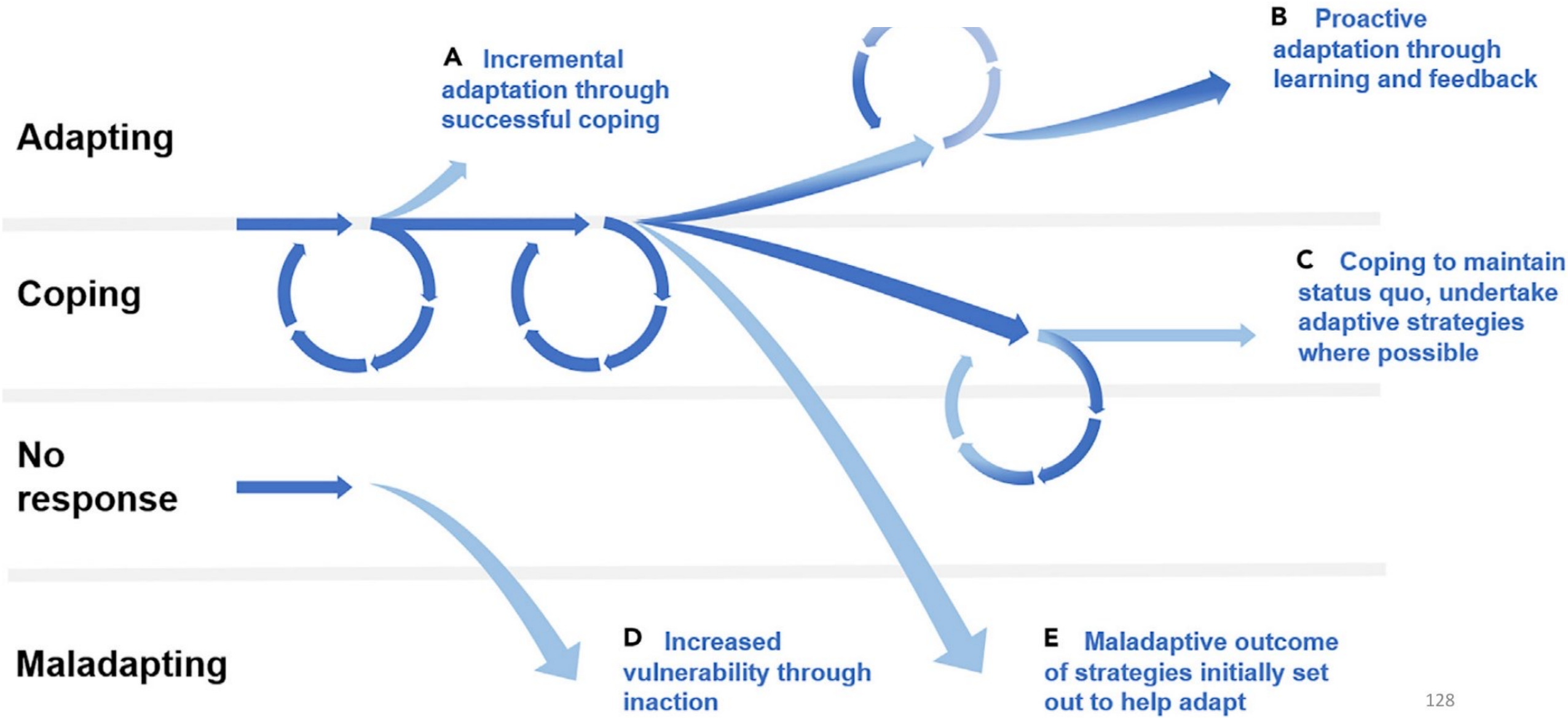
TODO aquecimento evitado é aquecimento

ao qual não teremos de nos adaptar (mesmo sem cumprir as metas de Paris)

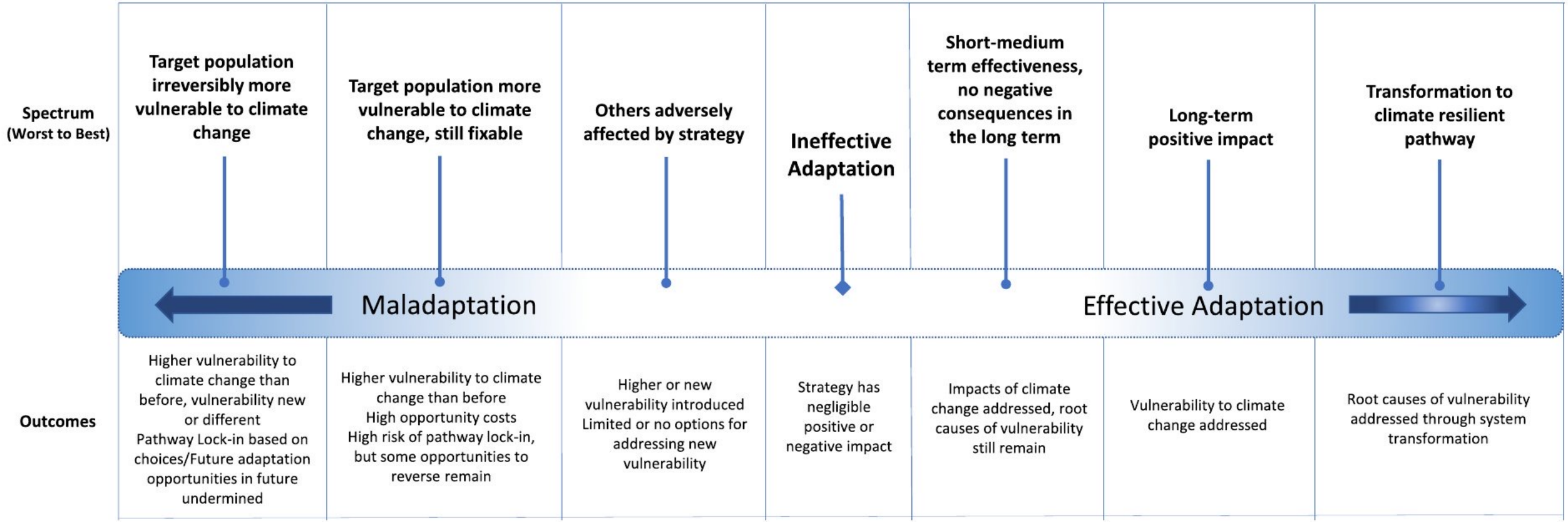




ADAPTAÇÃO

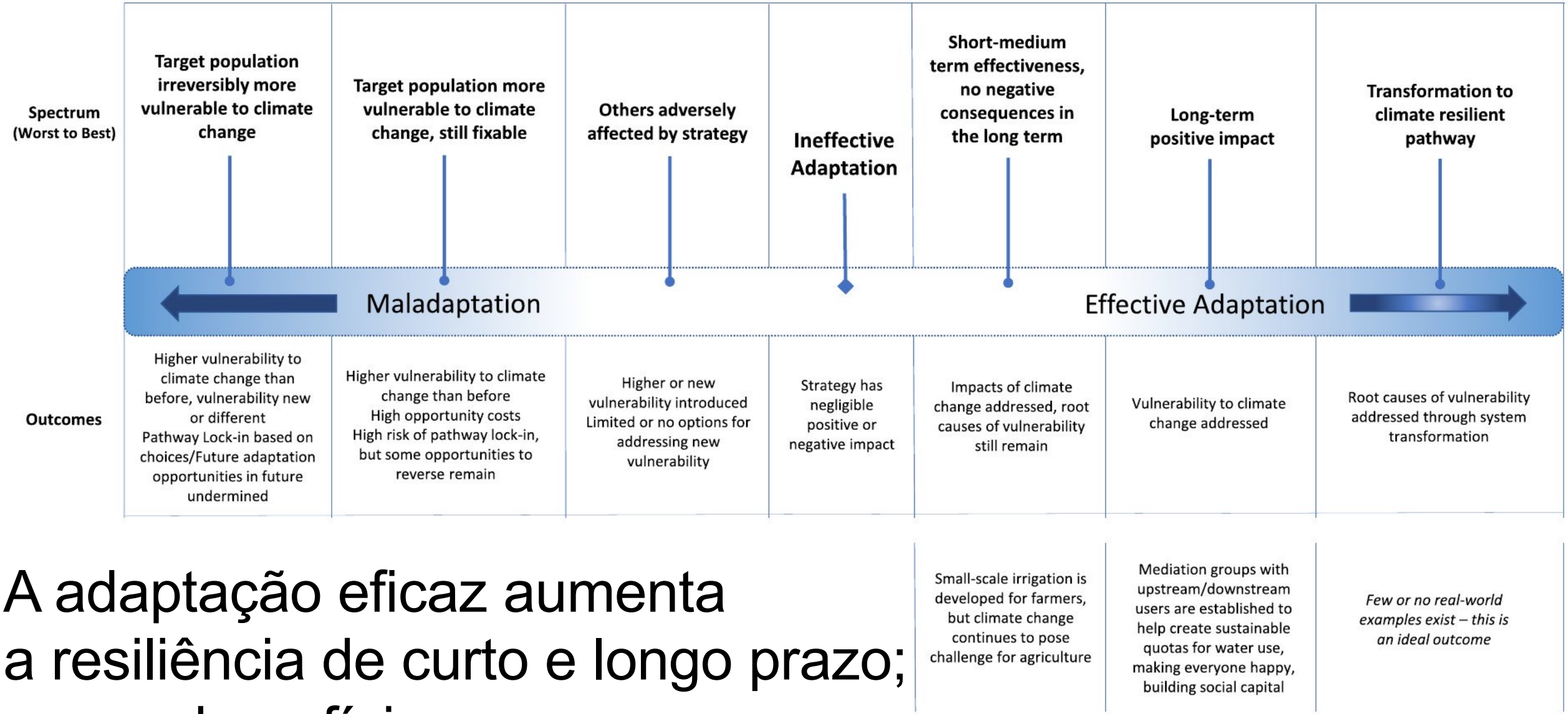


https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2



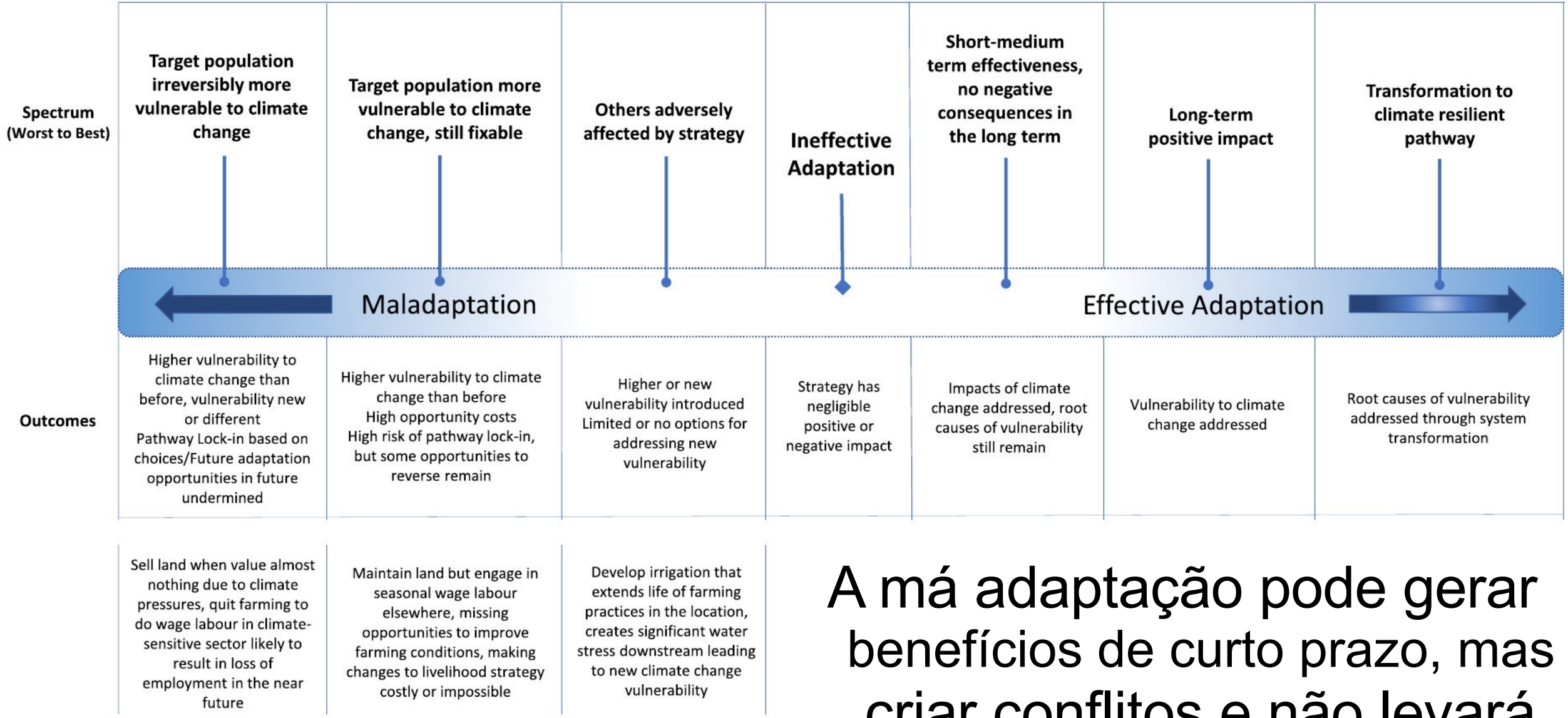
Espectro de resultados possíveis das estratégias de (má) adaptação

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



A adaptação eficaz aumenta a resiliência de curto e longo prazo; gera cobenefícios e exige cooperação

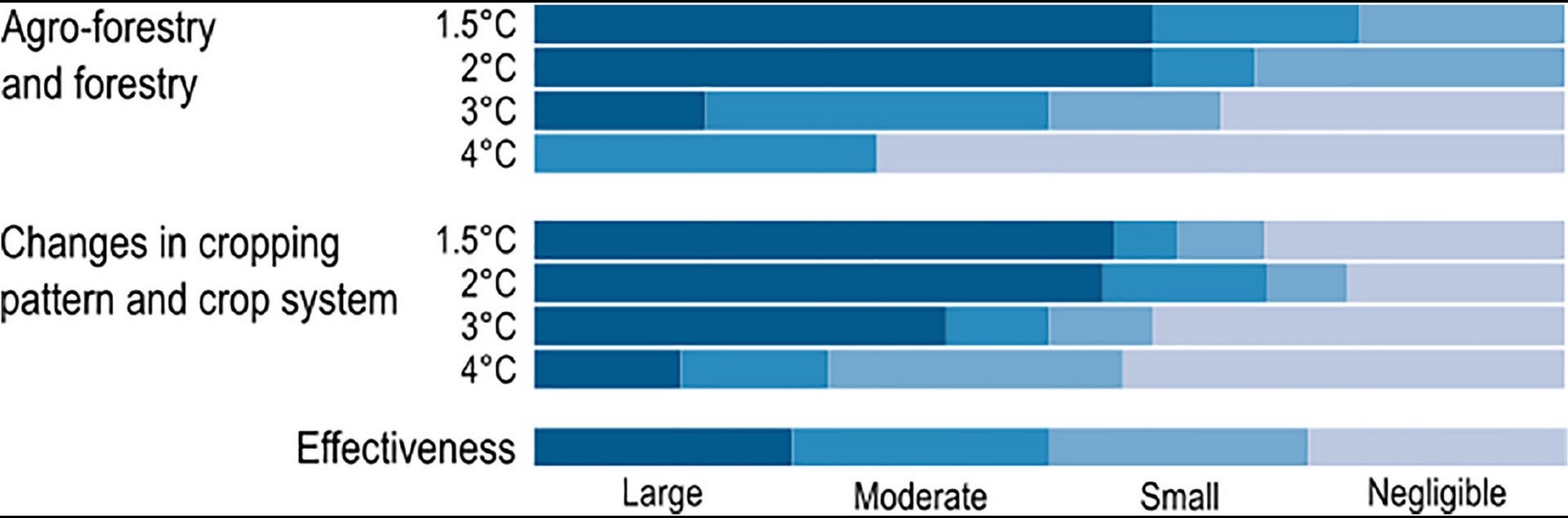
https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2



A má adaptação pode gerar benefícios de curto prazo, mas criar conflitos e não levará à sustentabilidade de longo prazo

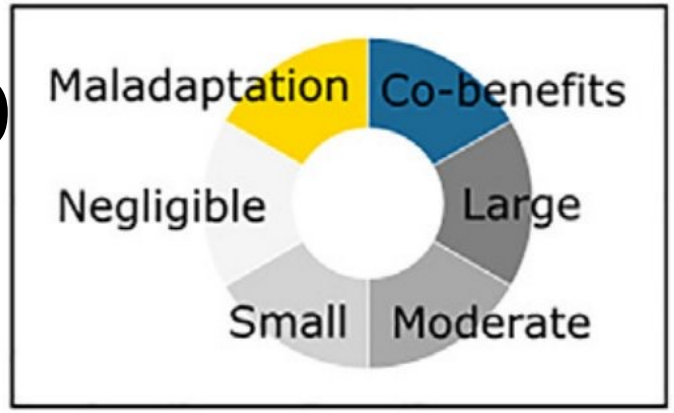
https://www.sciencedirect.com/science/article/pii/S2590332220304838#fig2

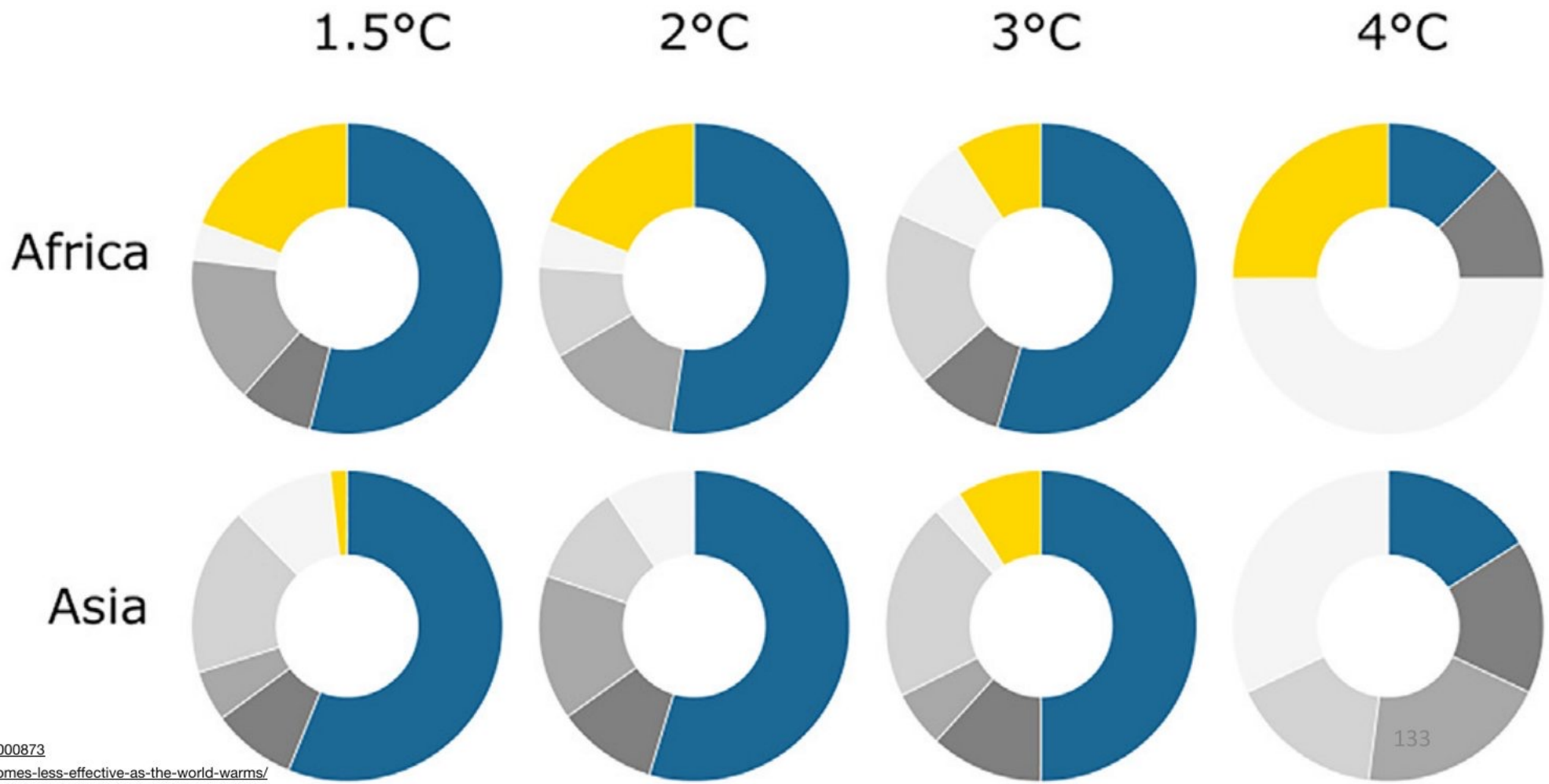
ALÉM DISSO, a adaptação é mais fácil e eficaz com níveis menores de aquecimento



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

Cobenefícios, má adaptação e eficácia





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

Cobenefícios e trade-offs da ação climática

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

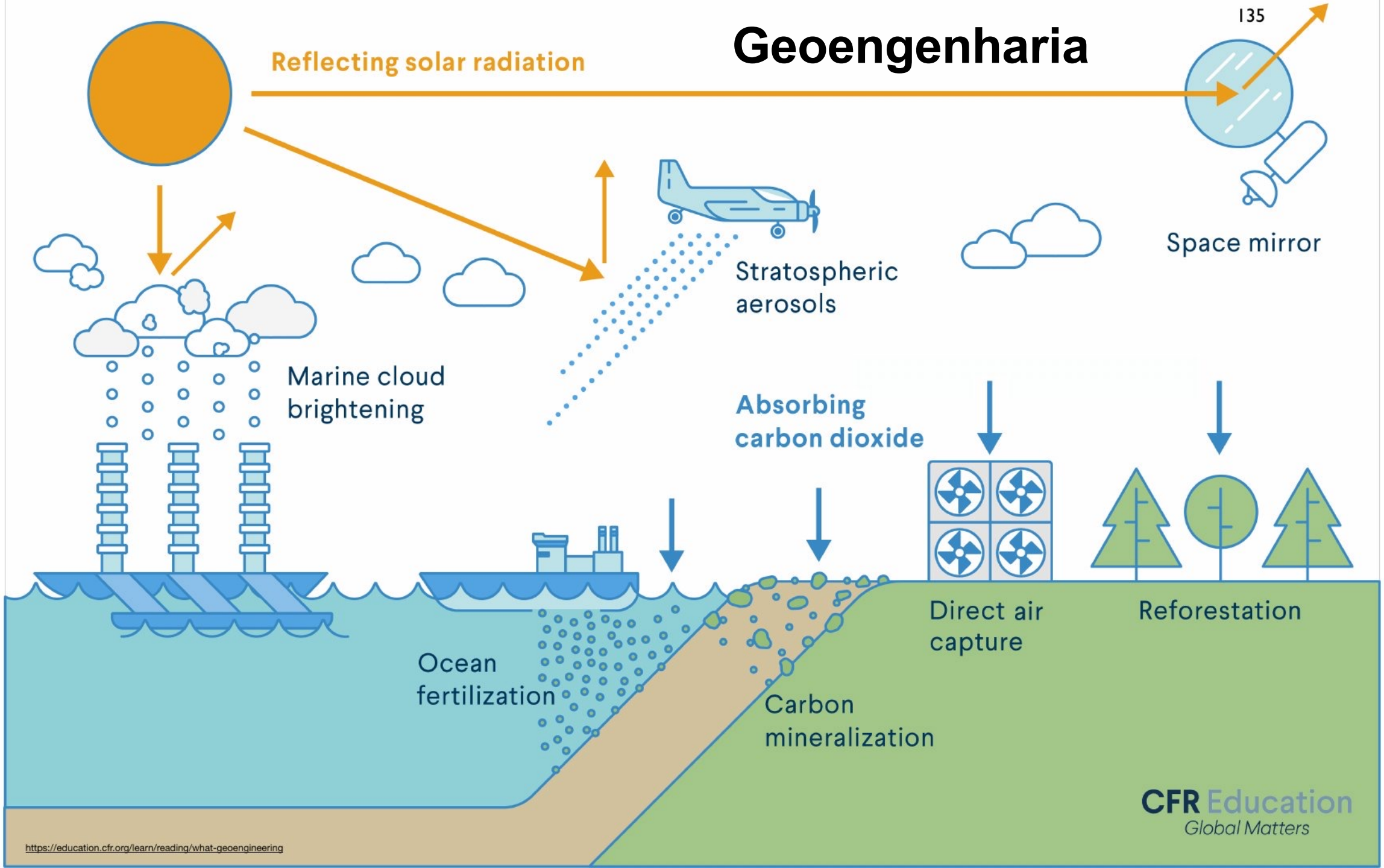
- Significantly positive, strong scientific evidence
- Potentially positive, incomplete evidence & quantification
- Unresolved, lack of evidence, system-dependent, tradeoffs
- Indirect positive
- Loose or non-existent link
- Negative, strong scientific evidence

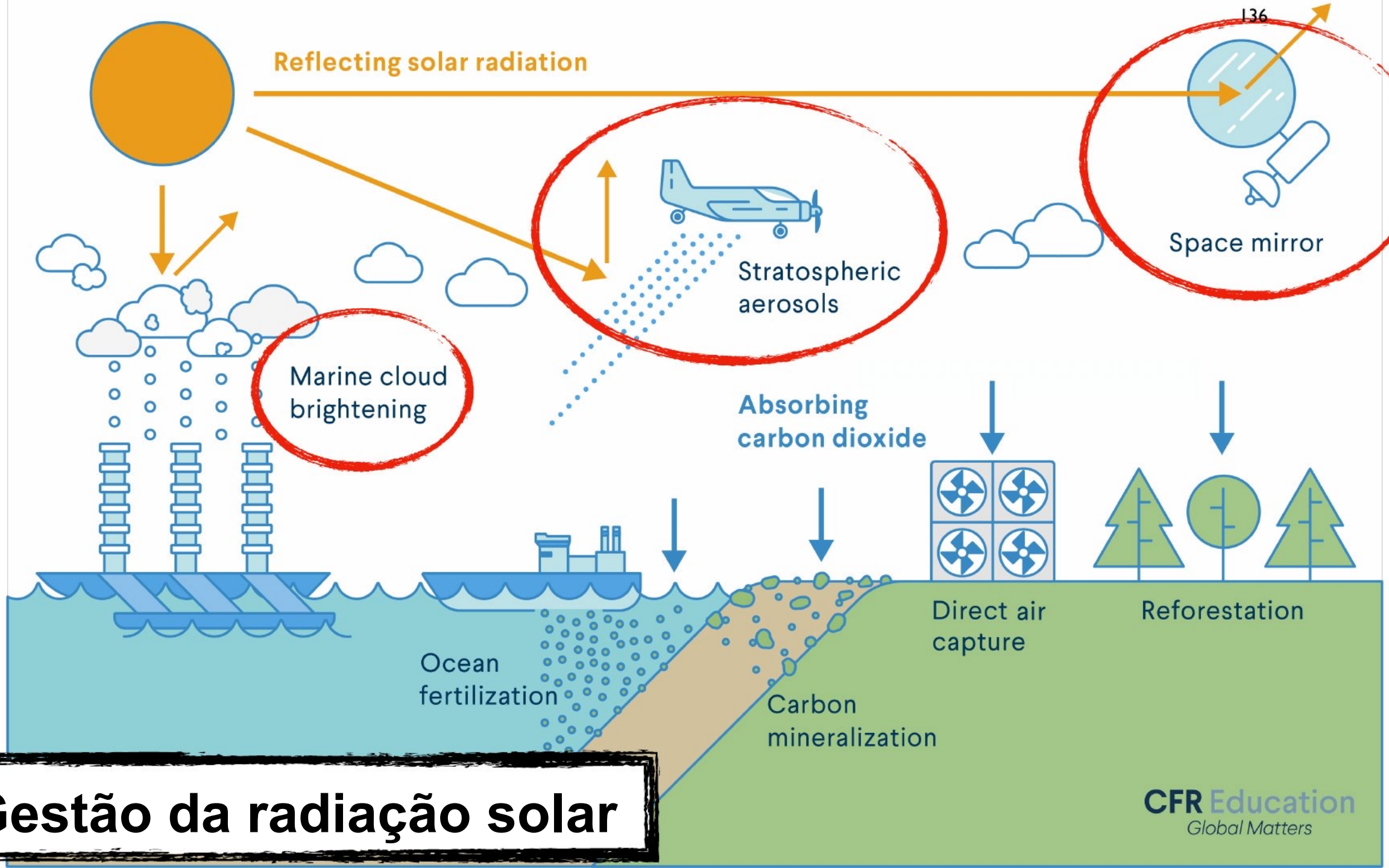
Reliability of the mitigation outcome

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

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

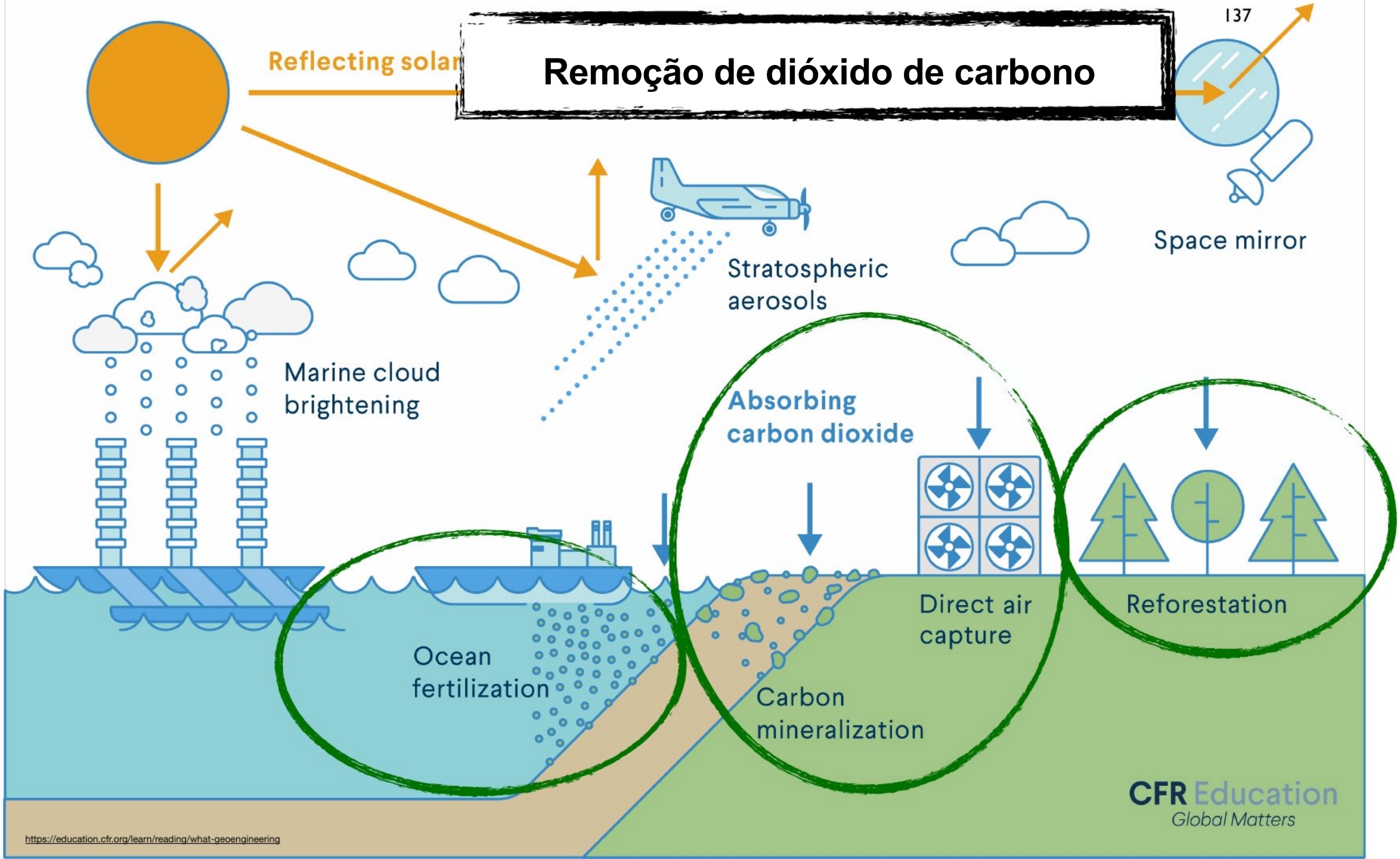
Geoengenharia





Gestão da radiação solar

Remoção de dióxido de carbono



Não é teórico…

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

ClimeWorks (usina Mammoth)

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

- Empresa: ClimeWorks, local: Islândia
- Movida 100% a energia renovável (geotérmica); capacidade máxima prevista de 36.000 t de CO_2 por ano (na prática, um pouco menor)
- Emissões humanas globais anuais de CO_2: ~38,6 BILHÕES de toneladas (2024)
- Para neutralizar essas emissões de CO_2, seriam necessárias ~1.072.222 usinas como esta com capacidade equivalente (p. ex. movidas totalmente a energia renovável).



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

Desvantagens da RDC

Pode ser cara de implementar em grande escala

Os benefícios climáticos podem demorar a aparecer

Pode ter outras consequências imprevistas para os ecossistemas (p. ex., fertilização dos oceanos)

Desvantagens da GRS

Exige manutenção contínua, o que pode ser caro

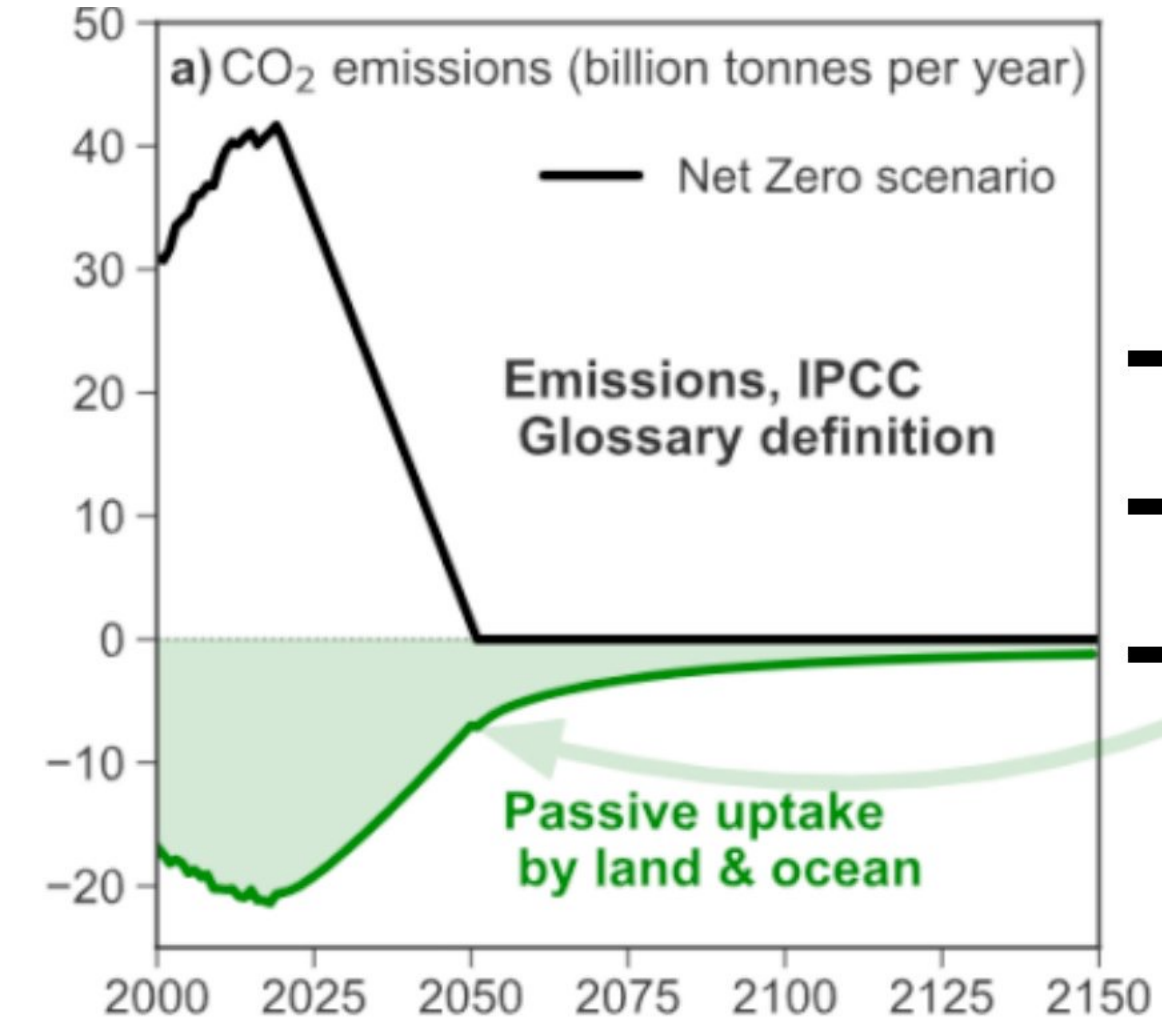
Não resolve em nada o problema da acidificação dos oceanos

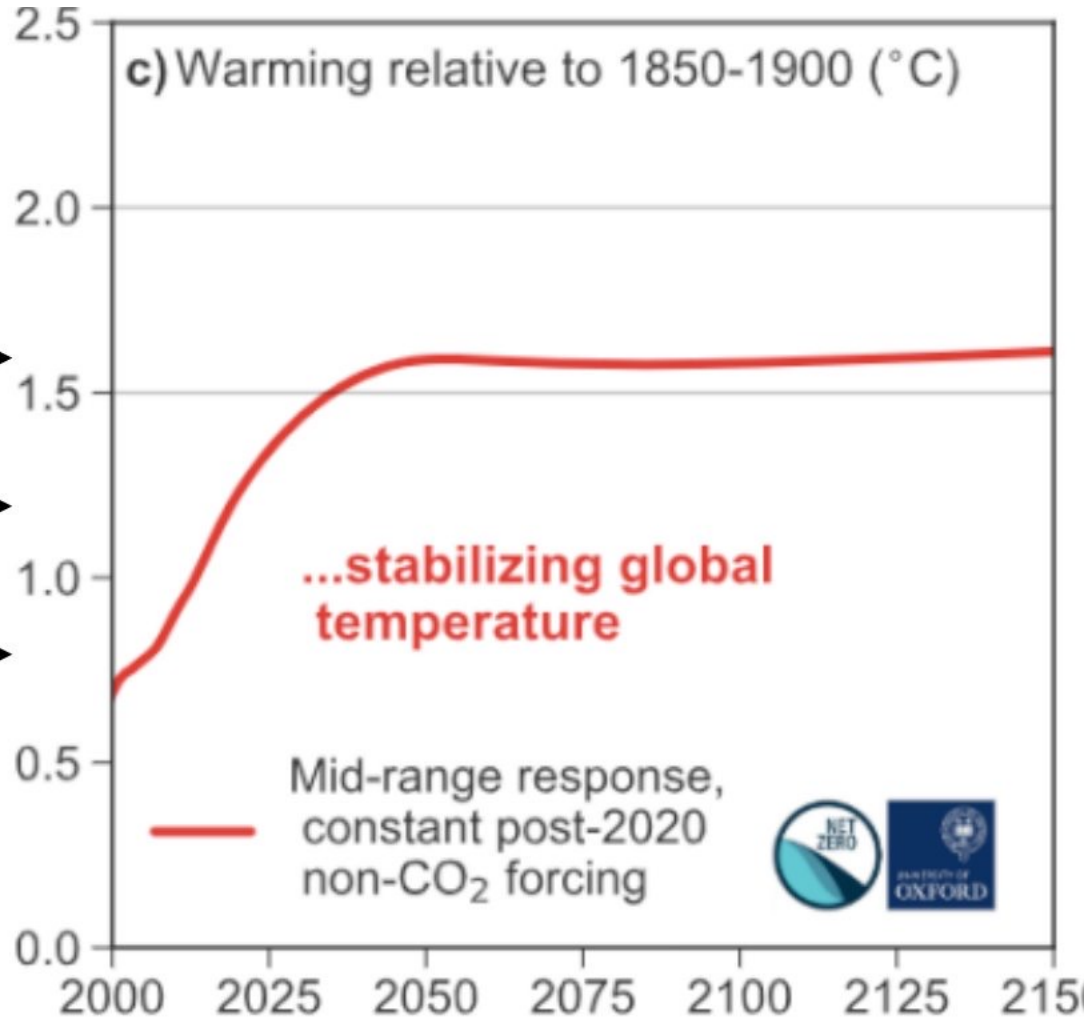
Pesadelo de governança global

Pode ter outras consequências climáticas imprevistas (p. ex. chuvas)

NENHUMA DELAS FOI COMPROVADA NA ESCALA NECESSÁRIA PARA ENFRENTAR A MUDANÇA CLIMÁTICA (AINDA).

A única coisa que sabemos que funciona é deixar no subsolo





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

Relembre a sessão. Quais são as três coisas que você mais quer lembrar? Reserve 60 segundos

MAIS EMISSÕES = MAIS AQUECIMENTO

só para quando as emissões param

Evitar o pior exigirá TANTO
adaptação quanto mitigação

Qualquer decisão de política precisará considerar muitas incertezas sobre a resposta do sistema climático, os cobenefícios e os trade-offs

As propostas de geoengenharia são, no máximo, paliativos e nunca foram comprovadas em grande escala

OBRIGADO