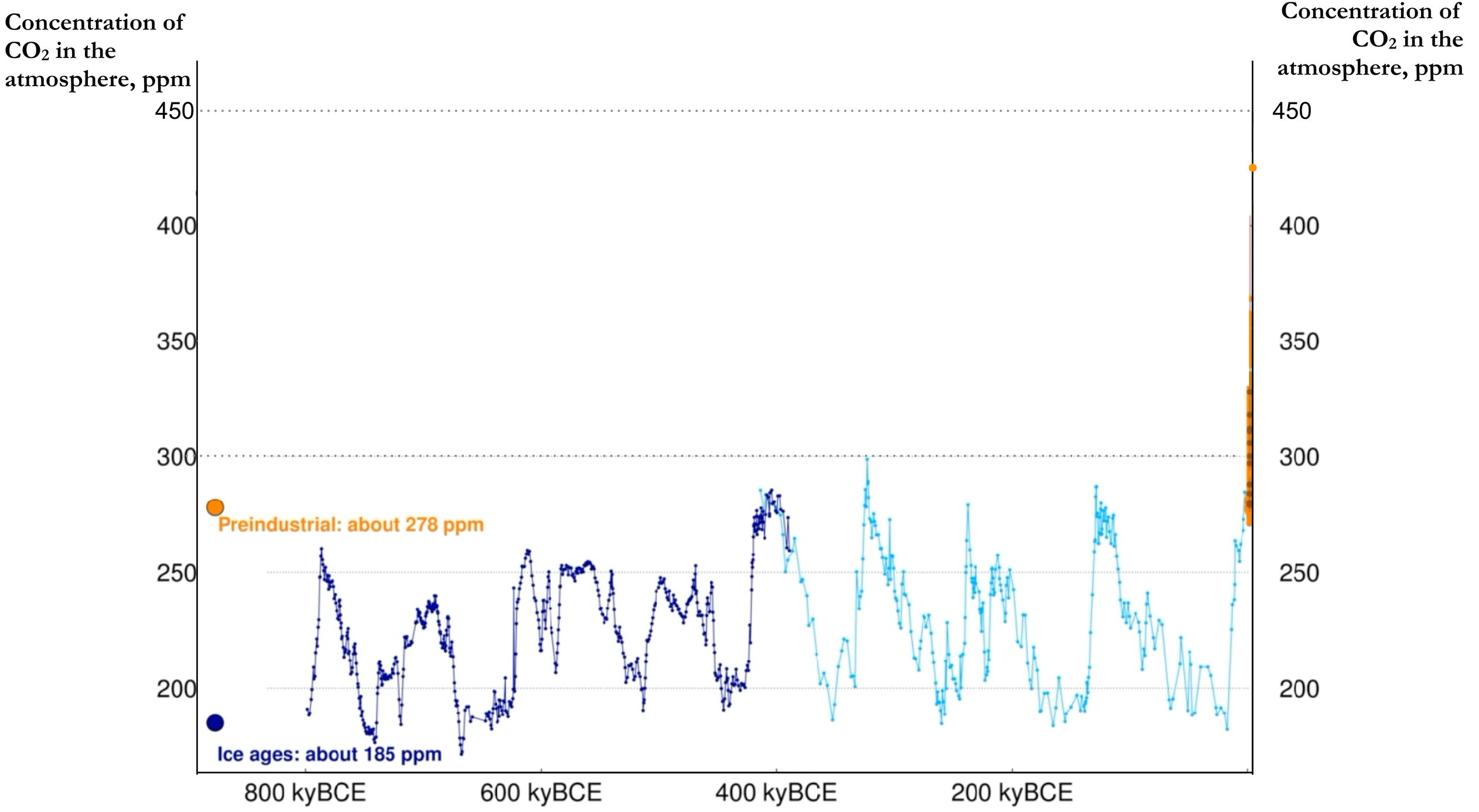
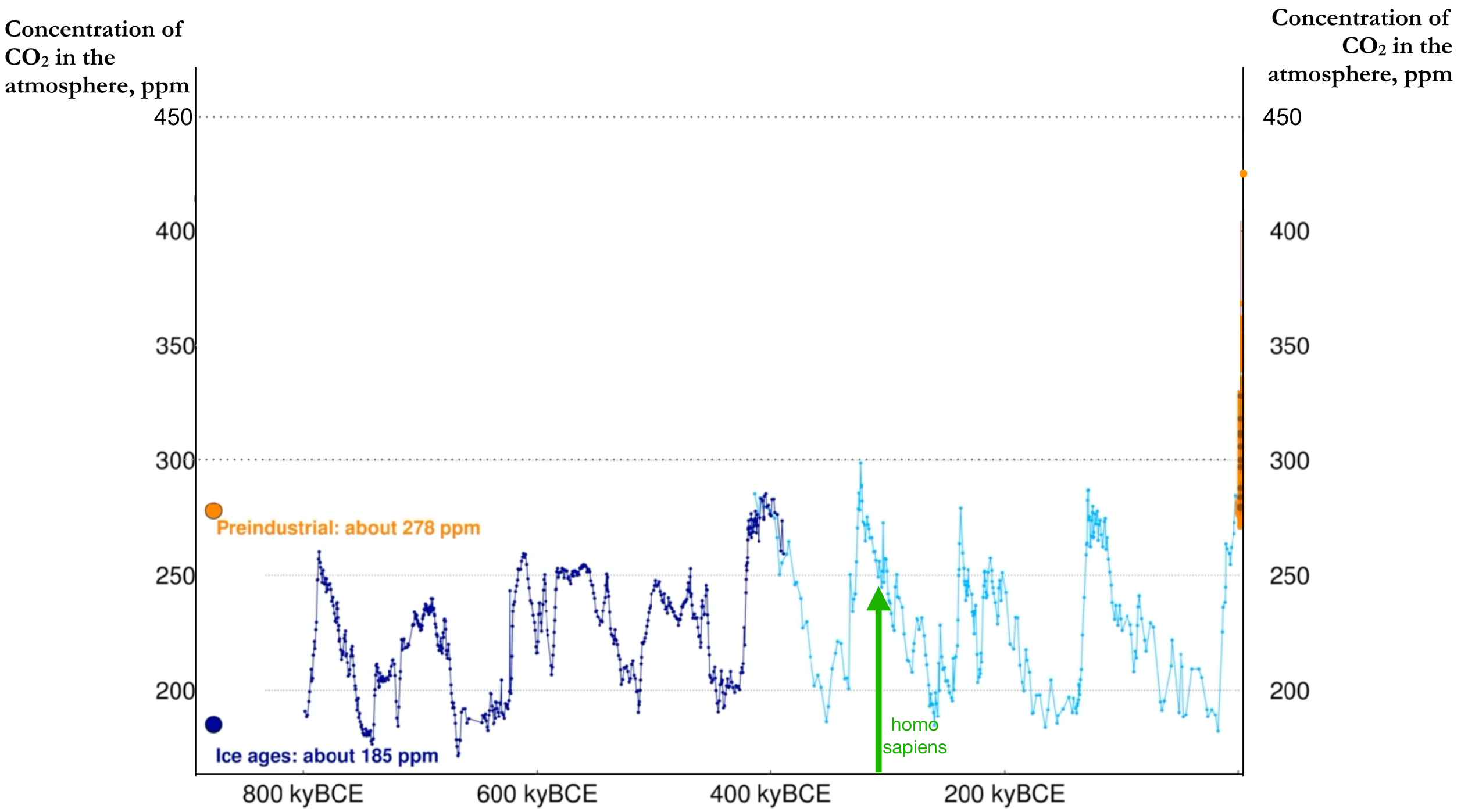
Carbon is Changing Our Planet: Consequences and Actions

Jeff Reimer
UC Berkeley & FPCB



http://www.esrl.noaa.gov/gmd/ccgg/trends/history.html



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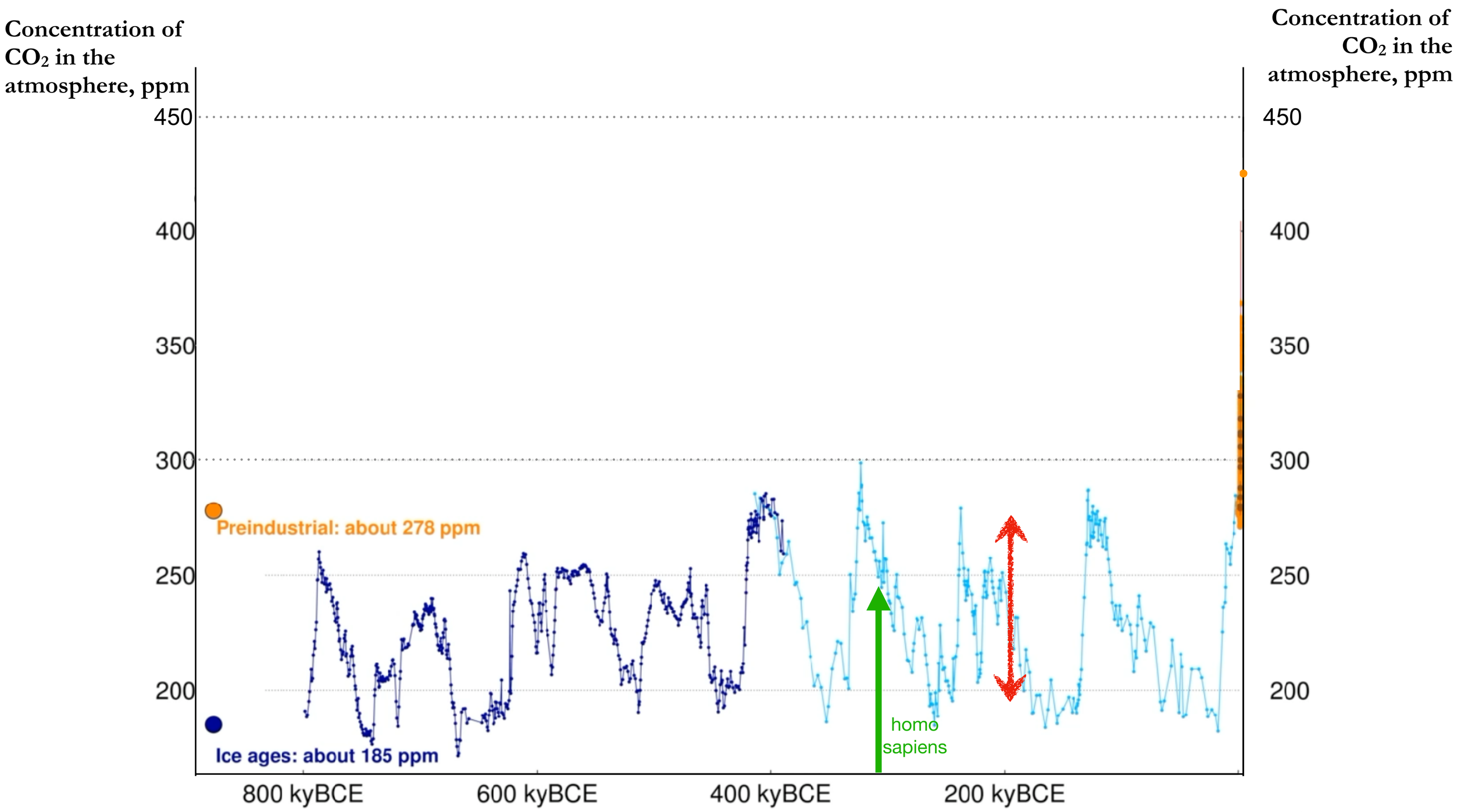

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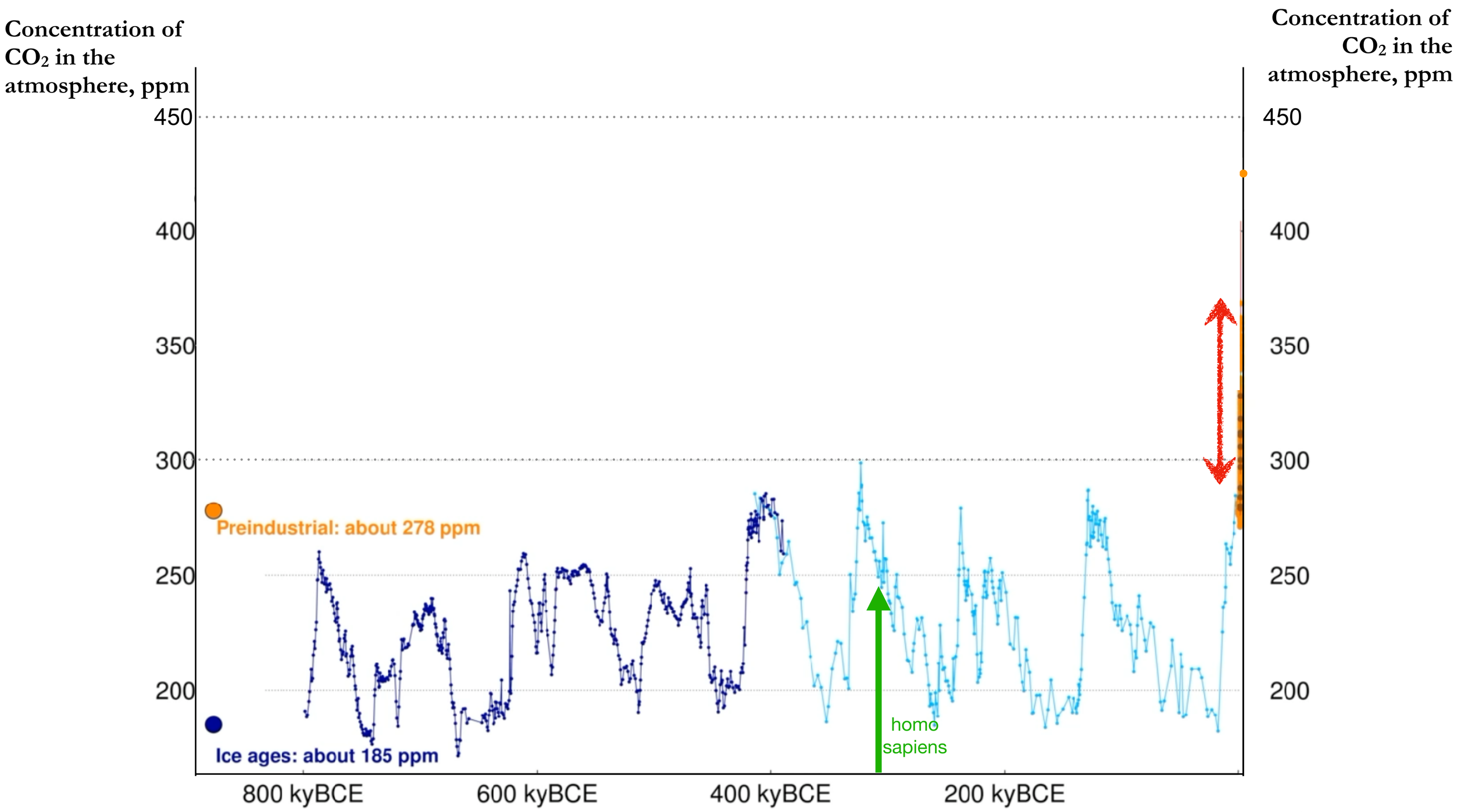

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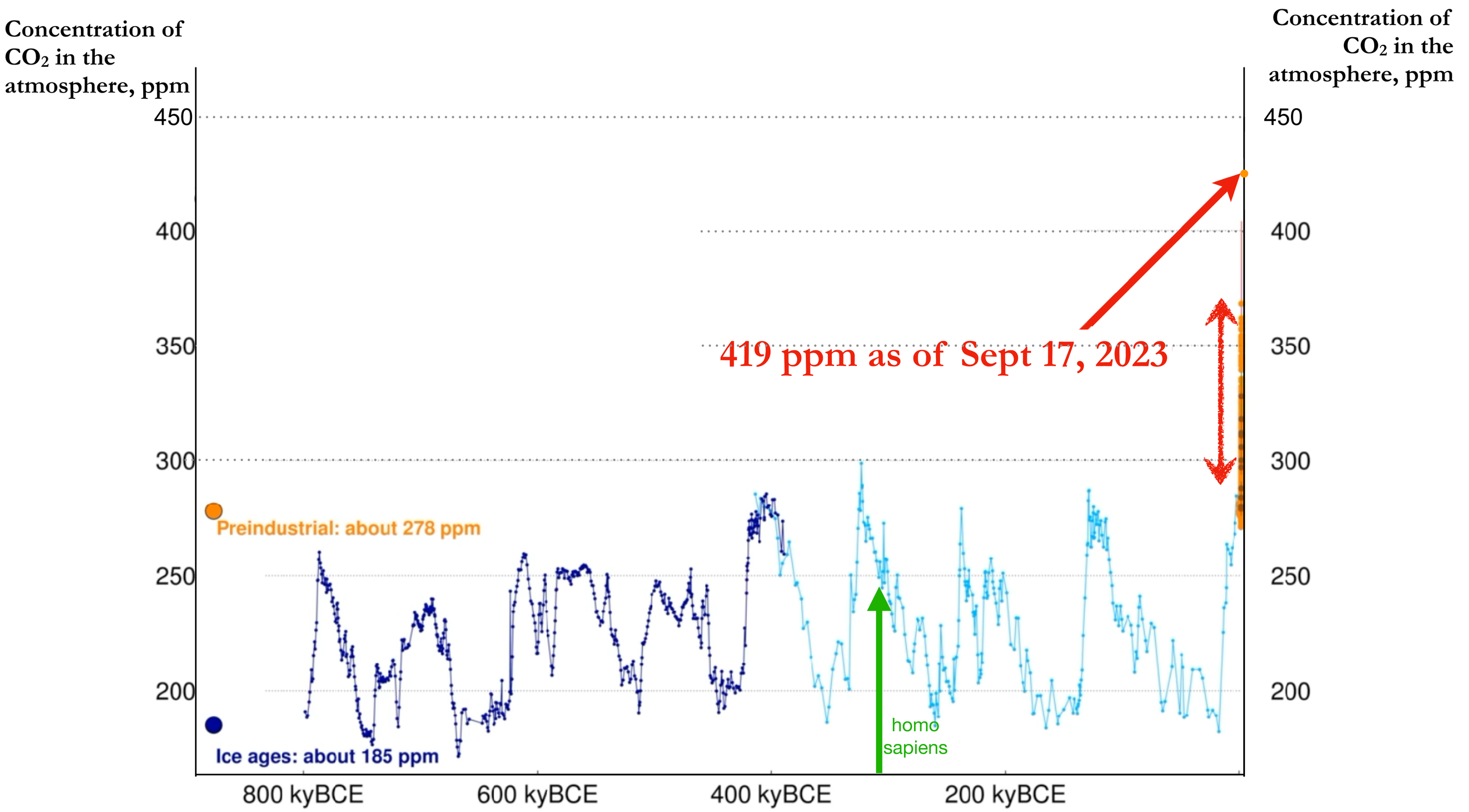

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1400 million tons
of CO_2 emitted worldwide
from coal plants in 2017*

*USEIA

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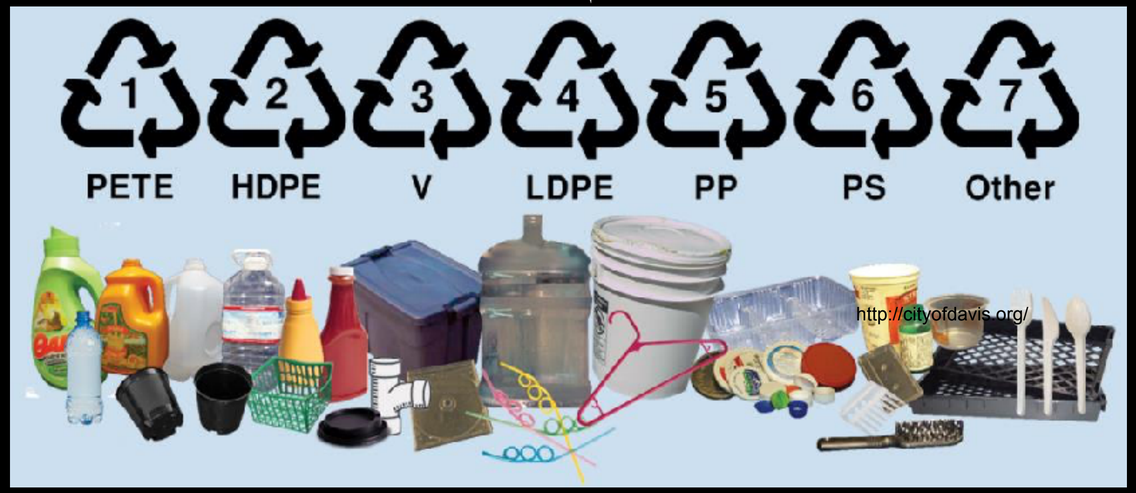
worldwide plastics
production in 2017:
344 million tons*

*Association of Plastics Manufacturers




https://www.worldometers.info/
https://blog.ricksteves.com/blog/palio-crowds/


Weight of 8.10 billion people:
5.11 x 10^11 kilograms,
0.51 gigatons
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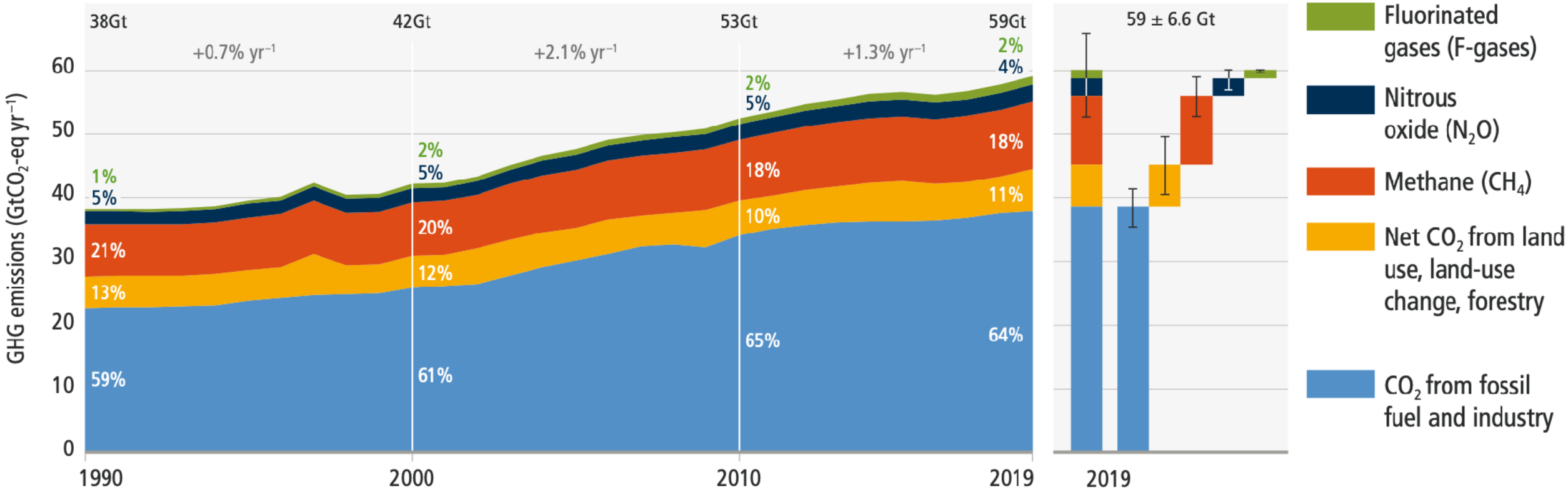
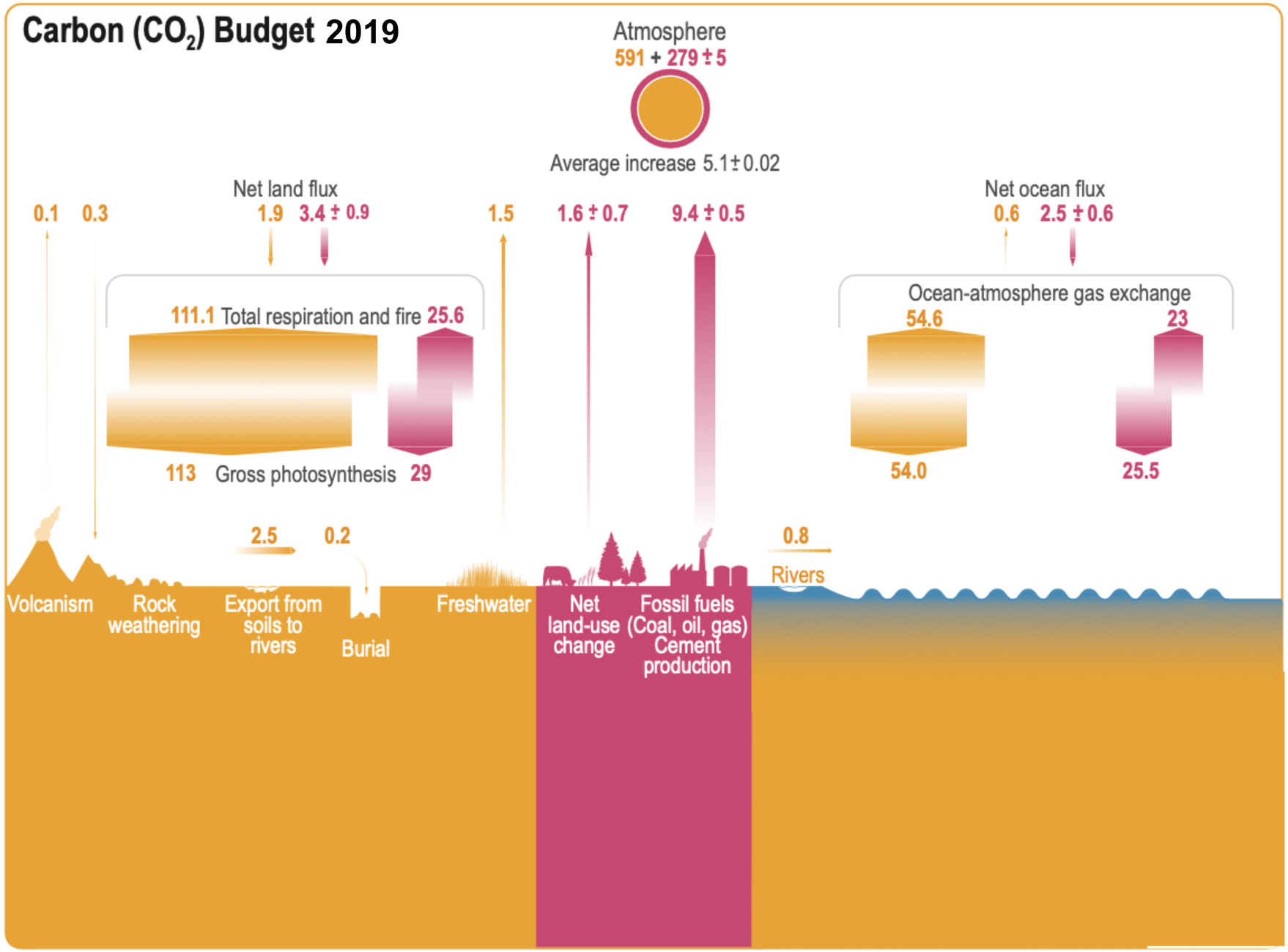
In 2021 humans emitted
36.4 gigatons of carbon
https://www.statista.com/statistics/276629/global-co2-emissions/
https://blog.ricksteves.com/blog/palio-crowds/

What is the source of all these recent CO_2 emissions?



Unless noted otherwise, all figures in this talk are adapted from IPCC_AR6_FullReport_2022

Where does all that CO_2 go?



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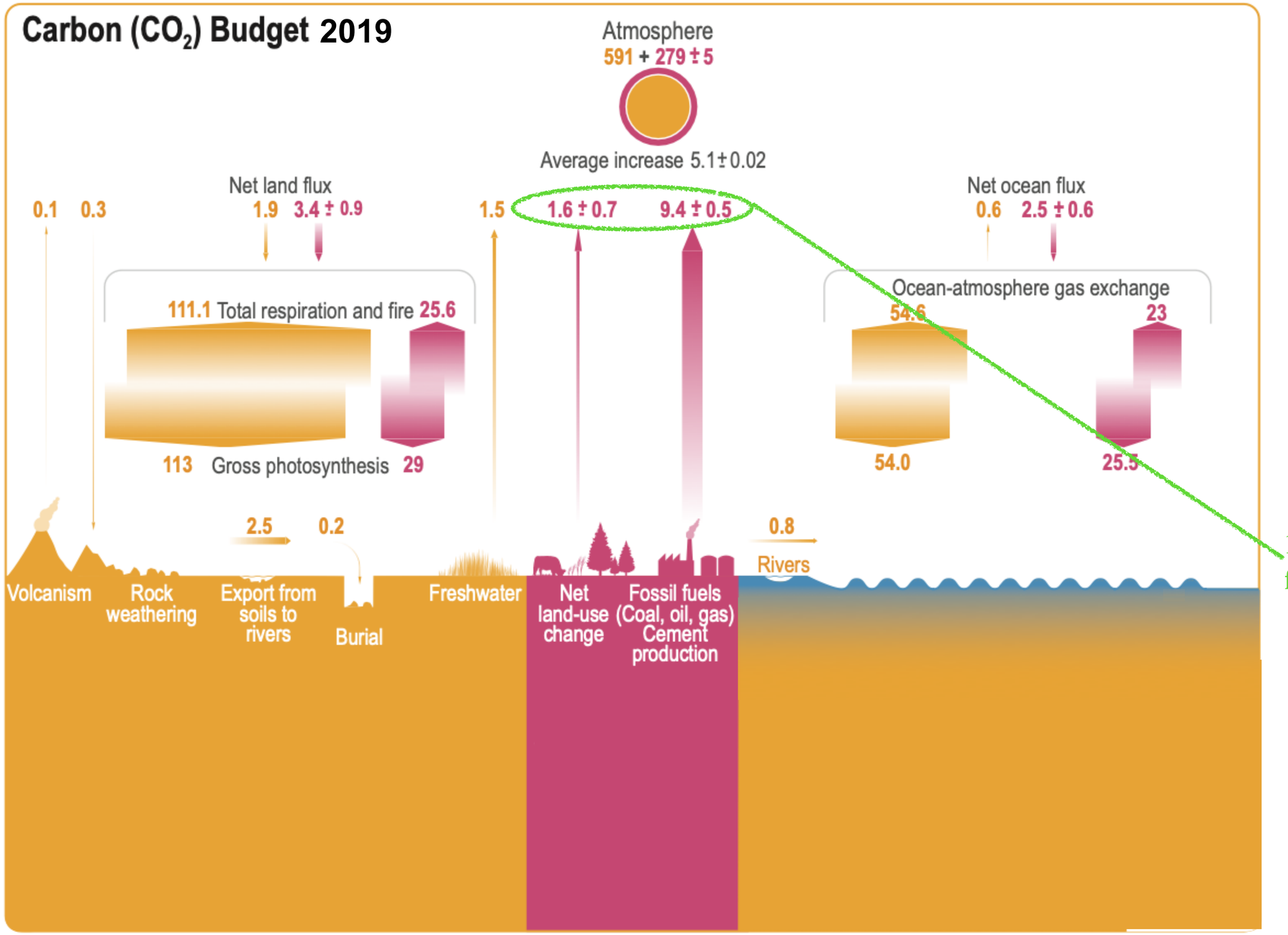

10.9 ± 0.9 GT yr^{-1} were emitted from human activities

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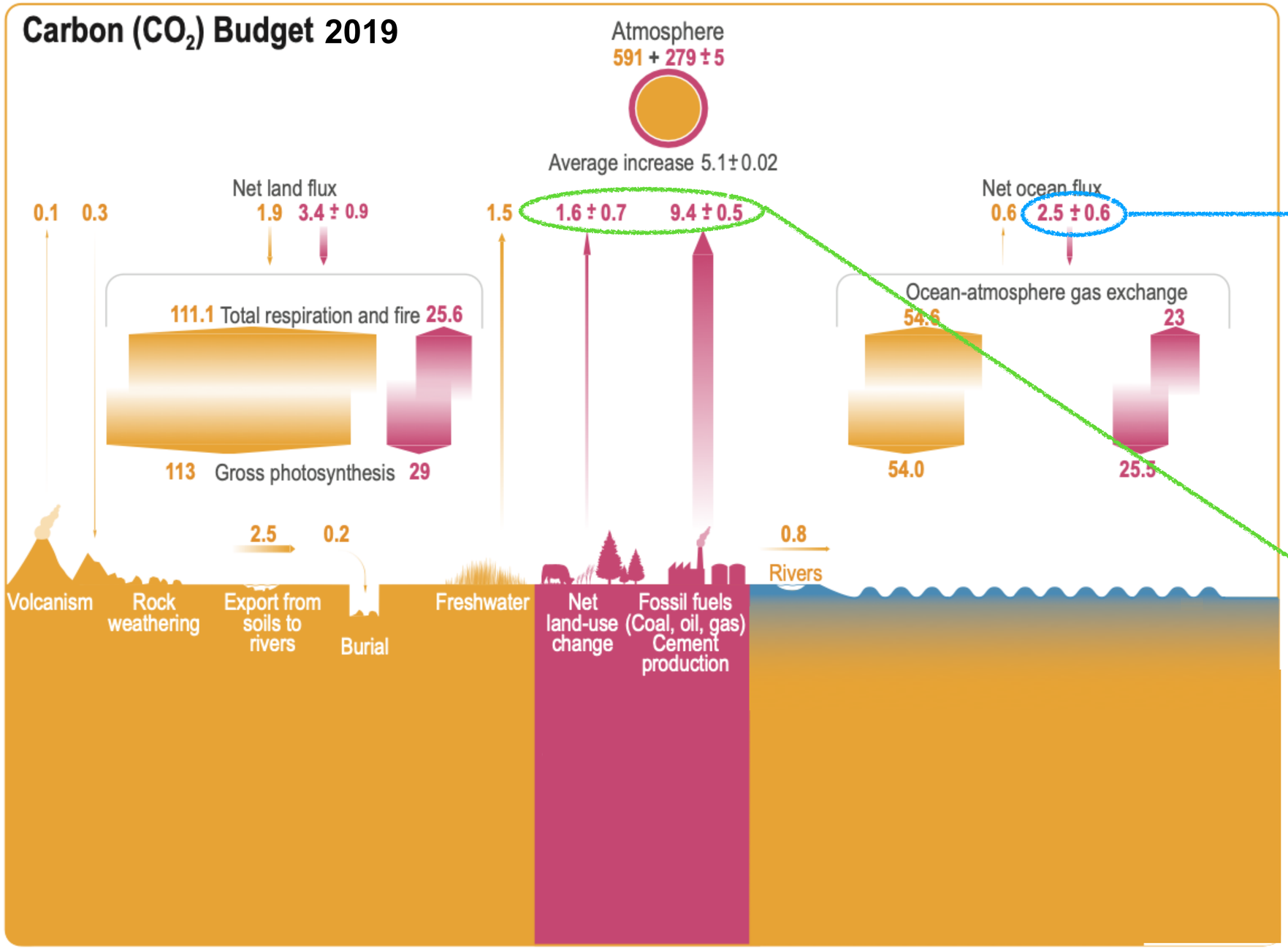

23% taken up by oceans

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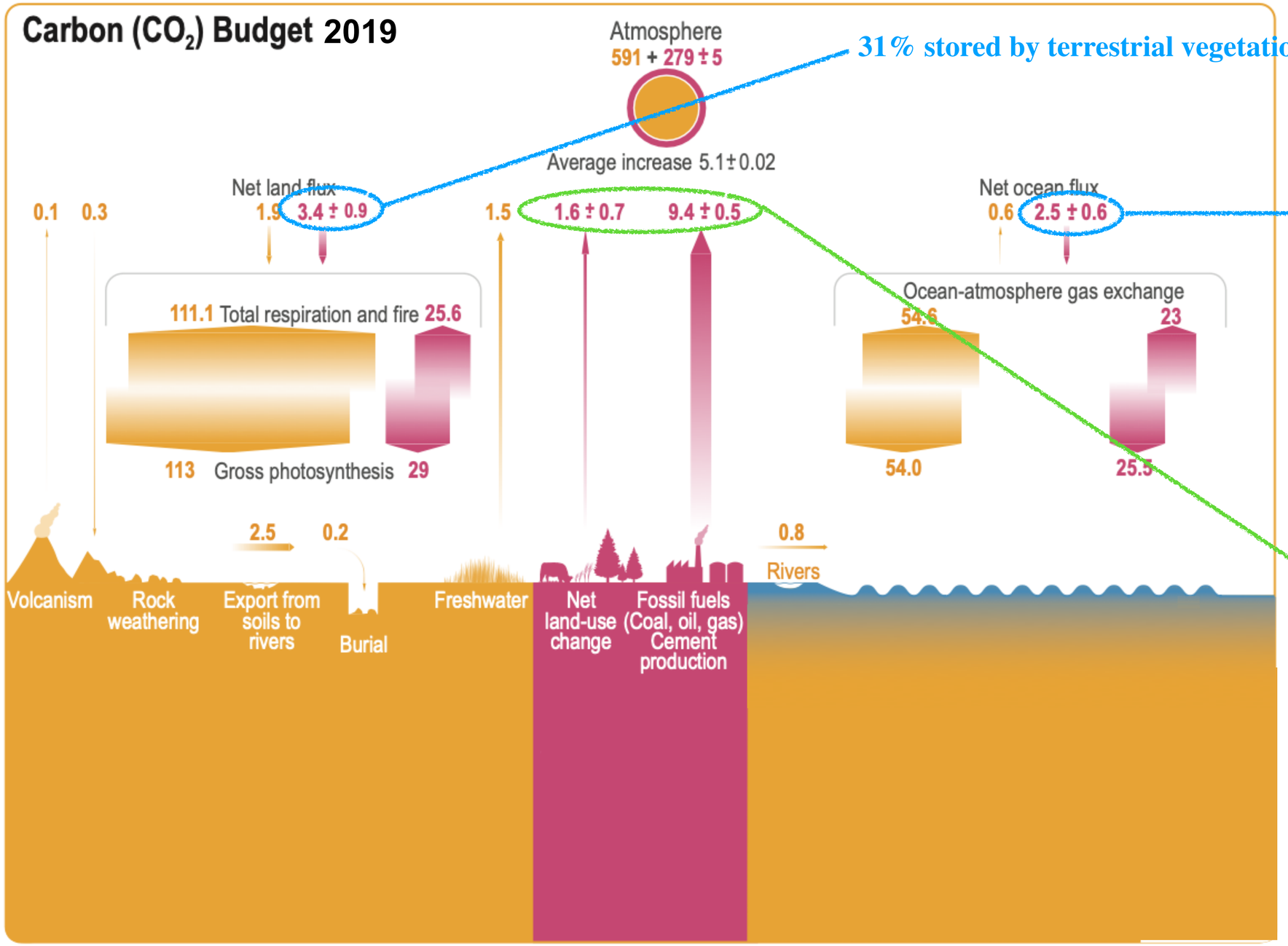

31% stored by terrestrial vegetation

23% taken up by oceans

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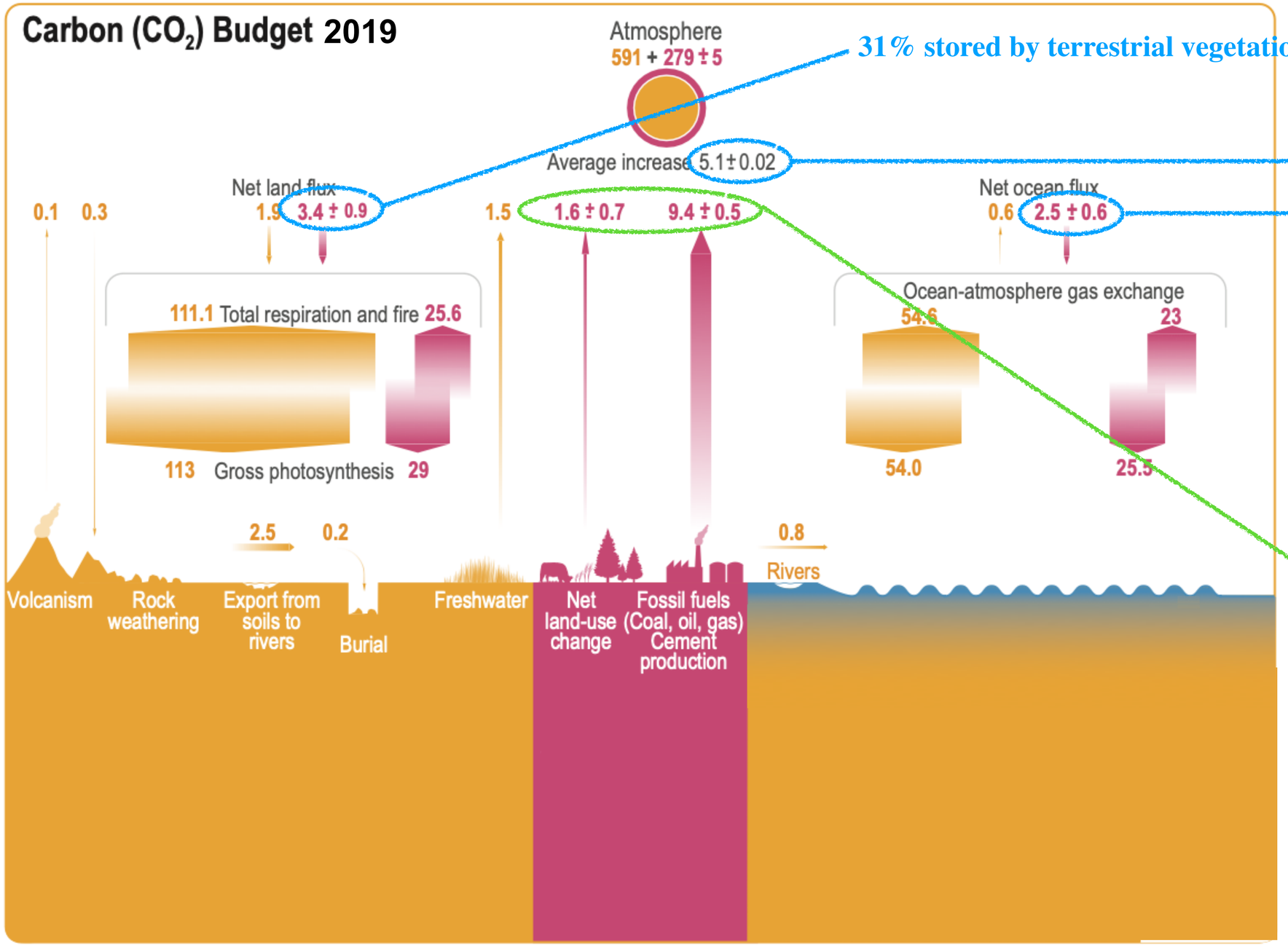
Where does all that CO_2 go?



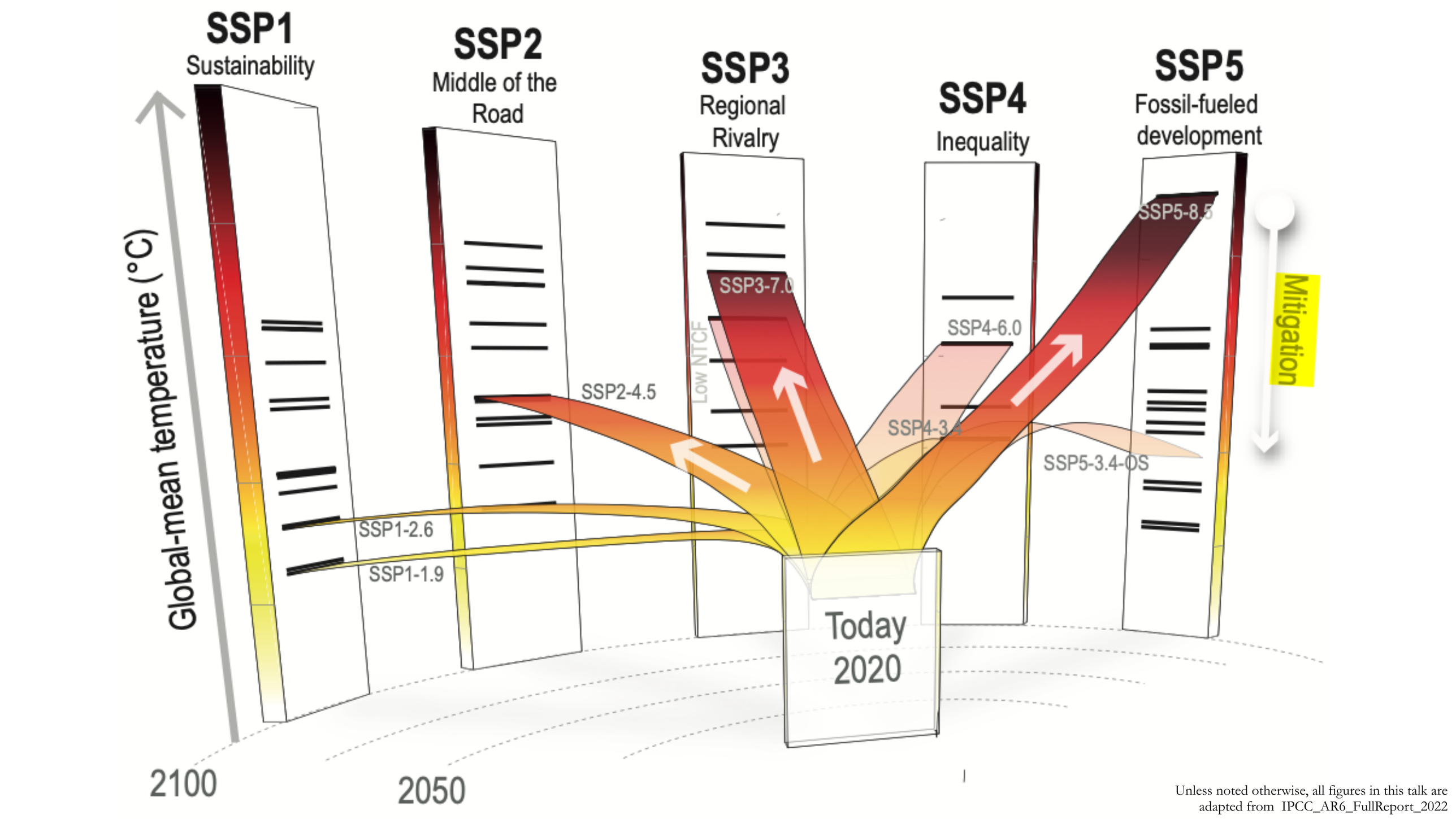
31% stored by terrestrial vegetation

46% accumulated in the atmosphere

23% taken up by oceans

10.9 ± 0.9 GT yr^{-1} were emitted from human activities

CO_2 in the future:
our choices



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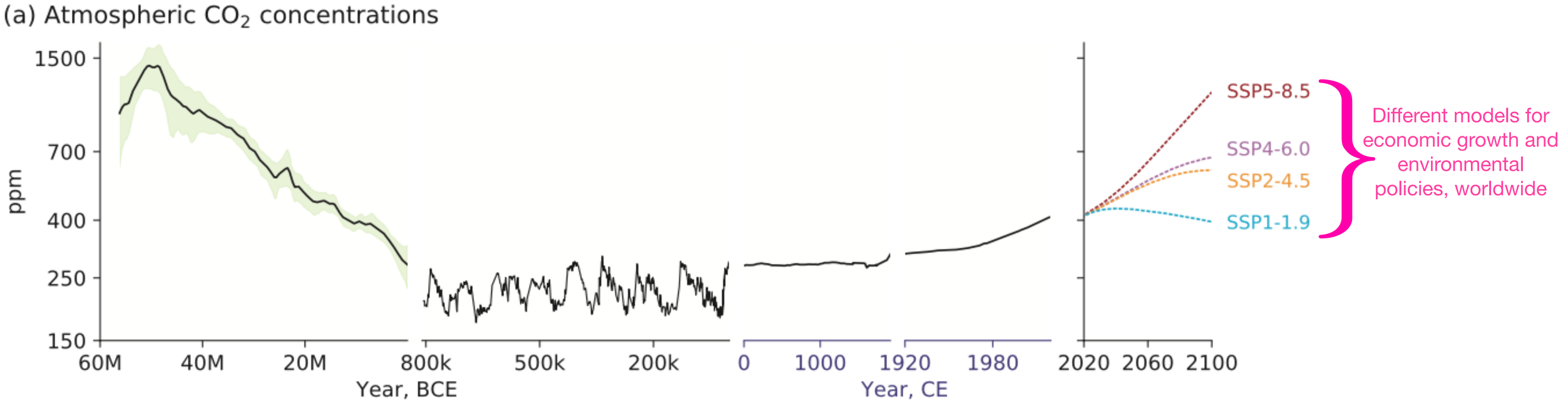
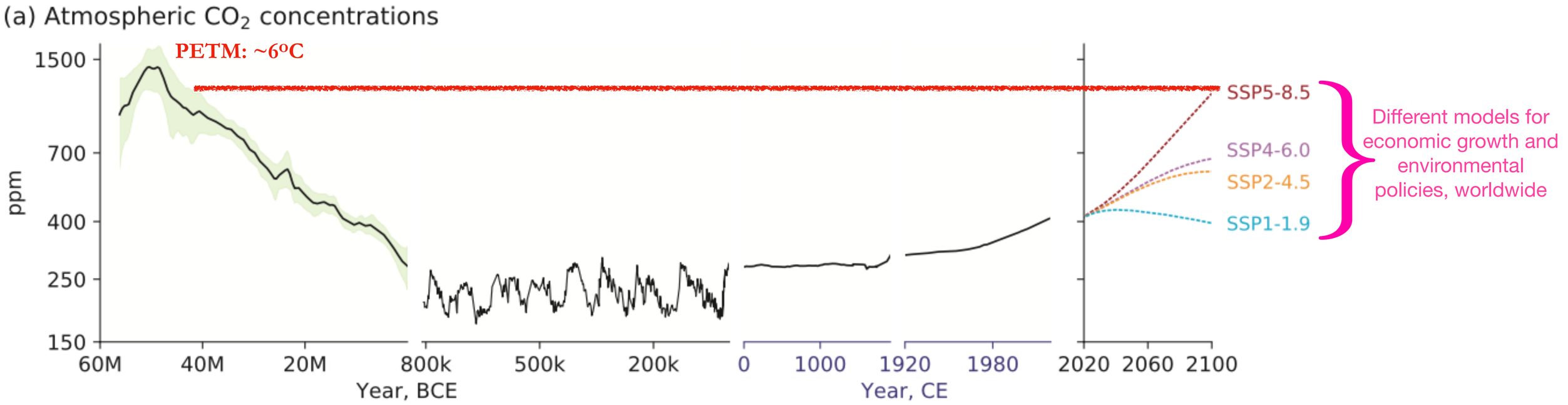

(a) Atmospheric CO_2 concentrations
1500
700
400
250
150
ppm
60M
40M
20M
800k
500k
200k
0
1000
1920
1980
2020
2060
2100
Year, BCE
Year, CE
SSP5-8.5
SSP4-6.0
SSP2-4.5
SSP1-1.9
Different models for economic growth and environmental policies, worldwide


(a) Atmospheric CO_2 concentrations
PETM: ~6ºC
1500
700
400
250
150
ppm
60M
40M
20M
800k
500k
200k
0
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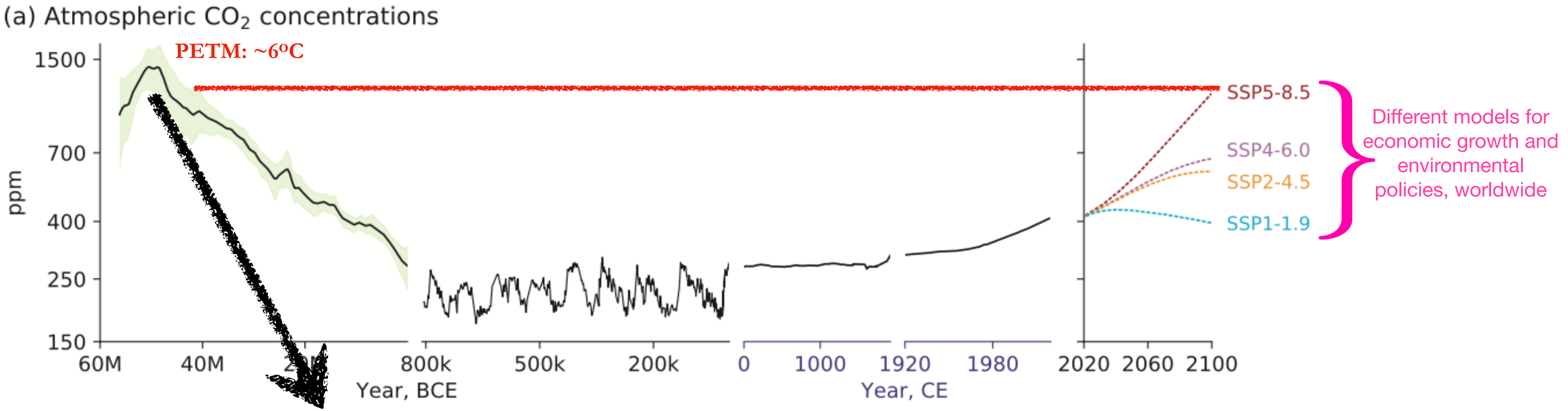
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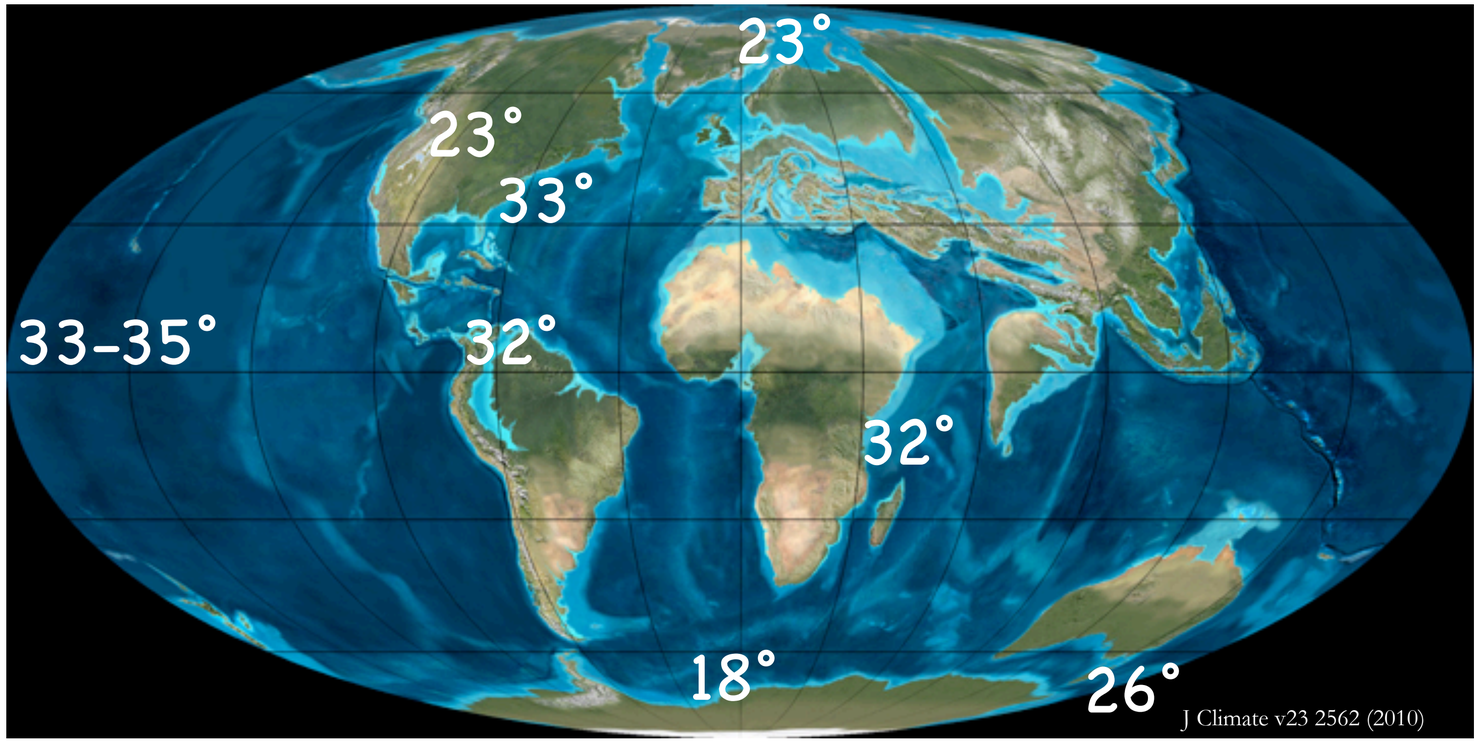
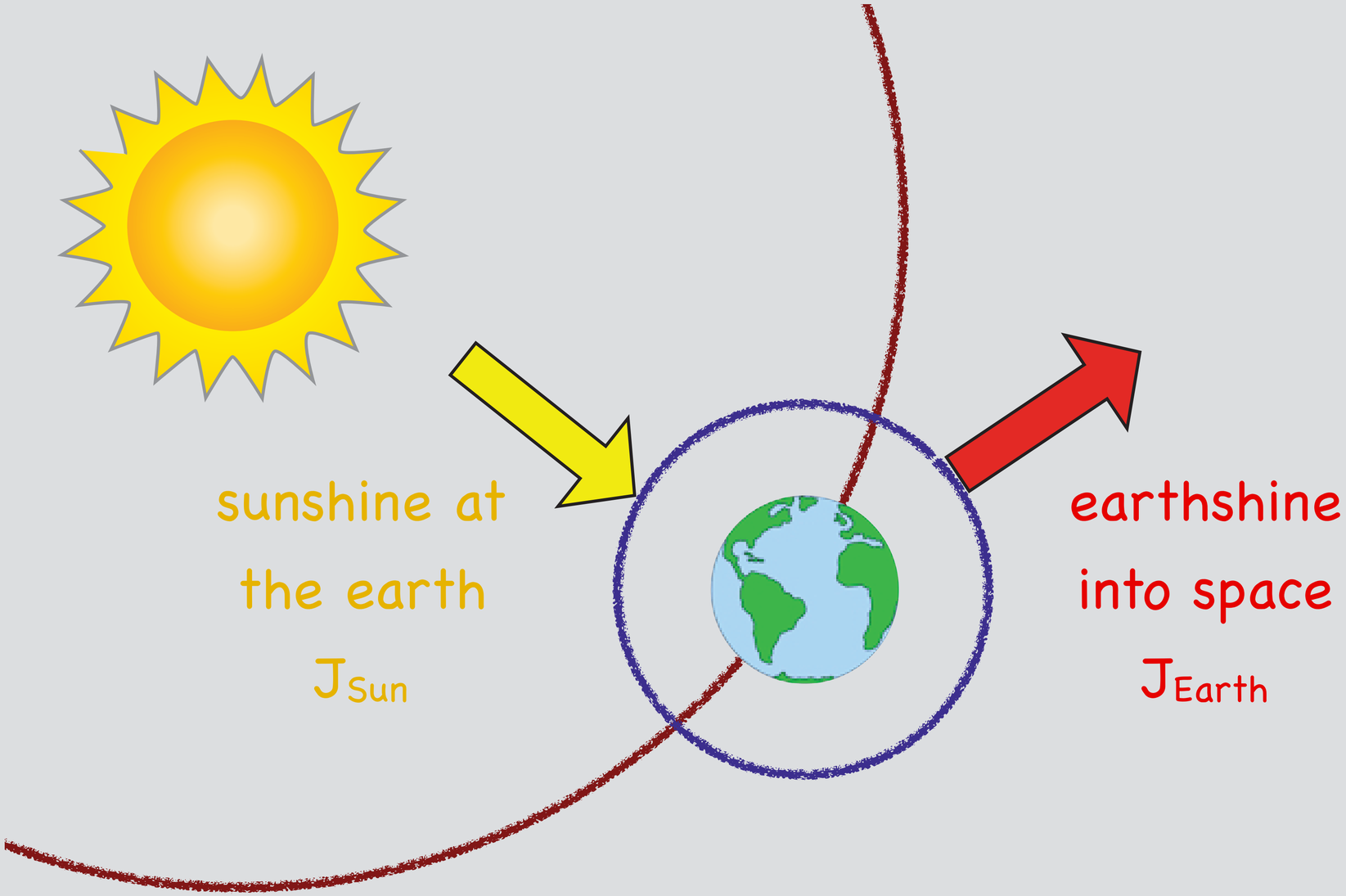

23°
23°
33°
33–35°
32°
32°
18°
26°
J Climate v23 2562 (2010)

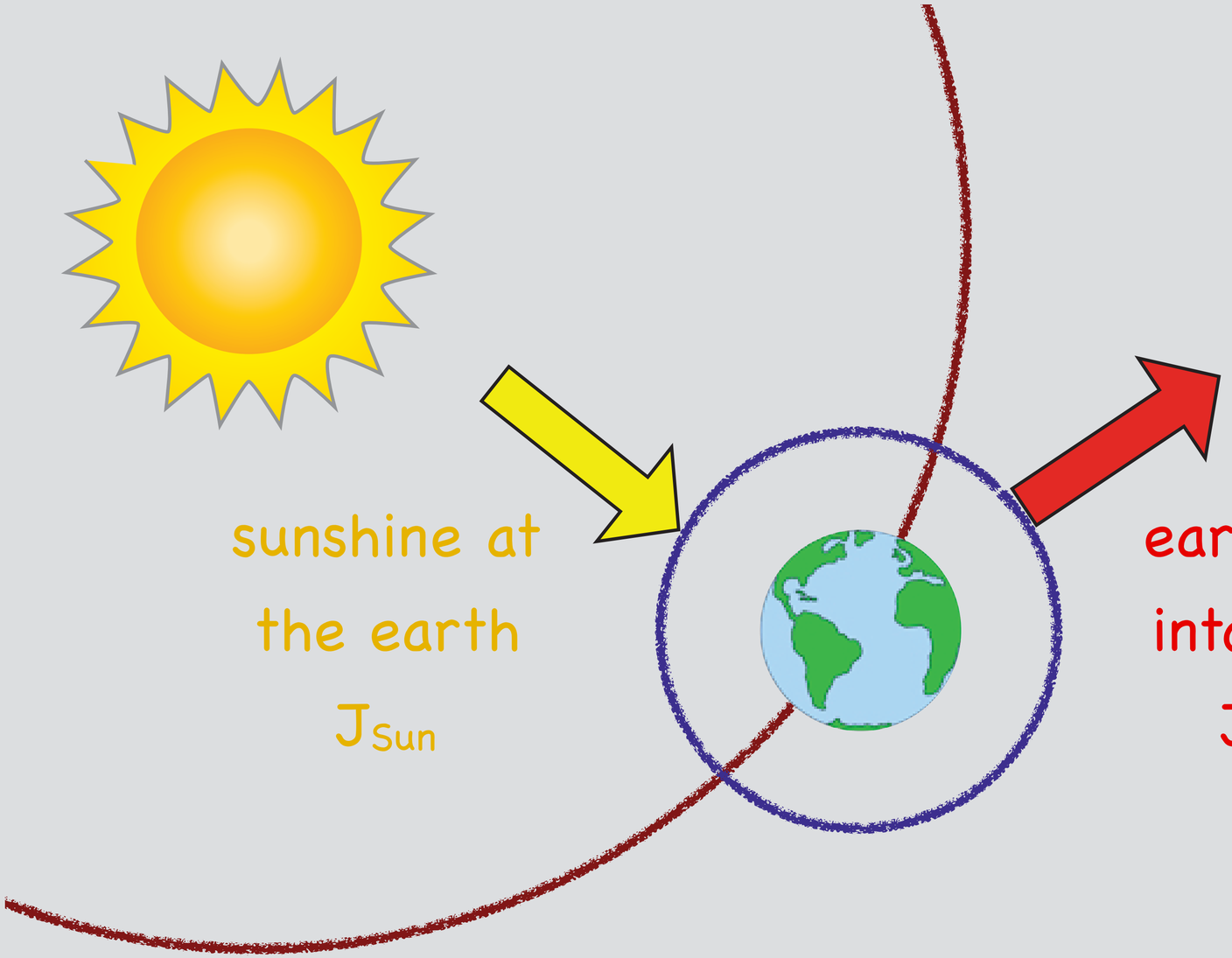
Radiative forcing

Radiative forcing



Carbon Capture and Sequestration (JAR with Berend Smit, Curt Oldenburg, Ian Bourg), World Scientific Press, 2013.

Radiative forcing



sunshine at the earth

J_{Sun}

earthshine into space

J_{Earth}

$$\mathrm{J}[=]\frac{energy}{area-time} \quad \mathrm{e.g.,}\frac{joules}{m^2-sec}=\frac{watts}{m^2}$$

$$=\sigma \mathrm{T}^4$$

"black body radiation"

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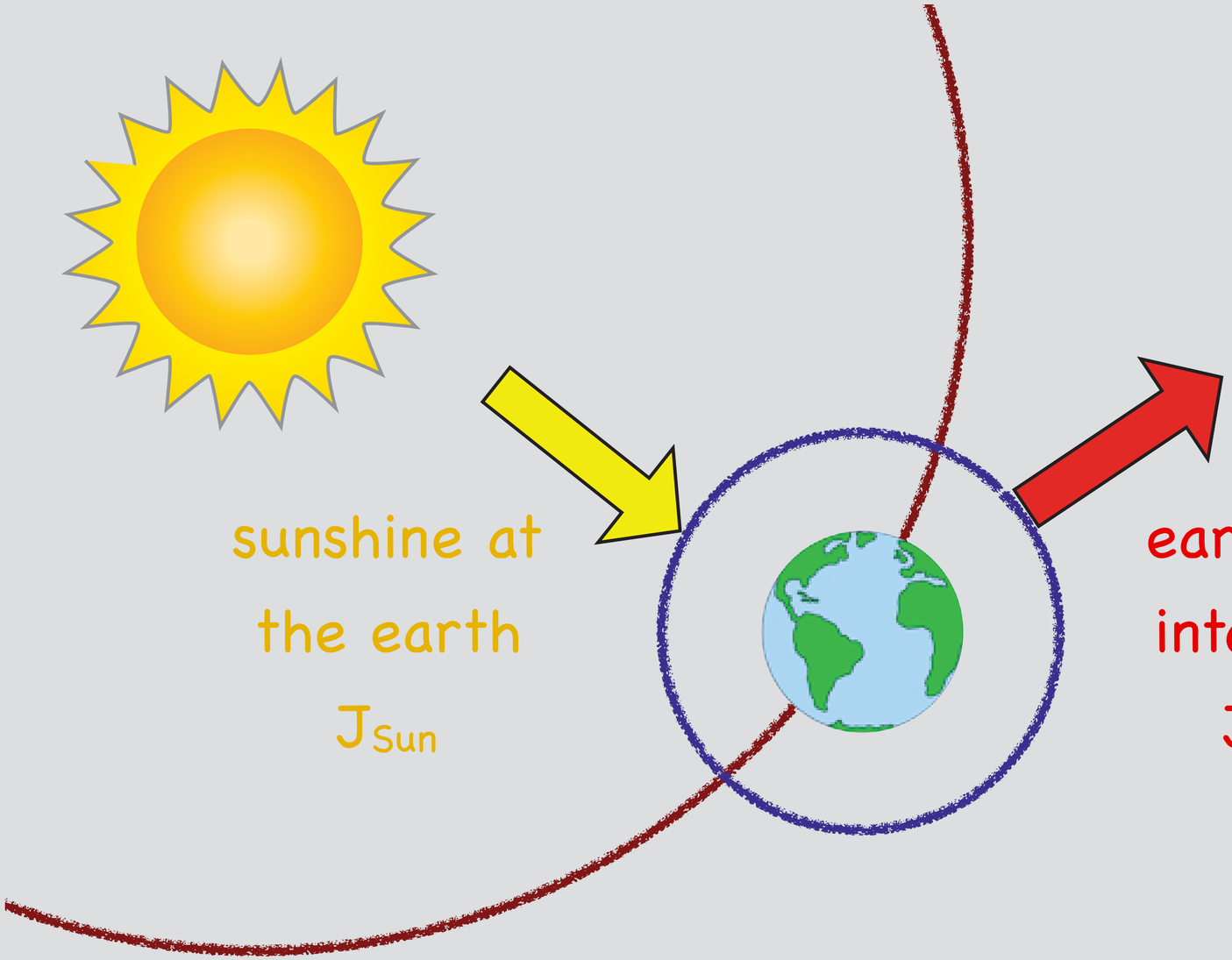
Radiative forcing



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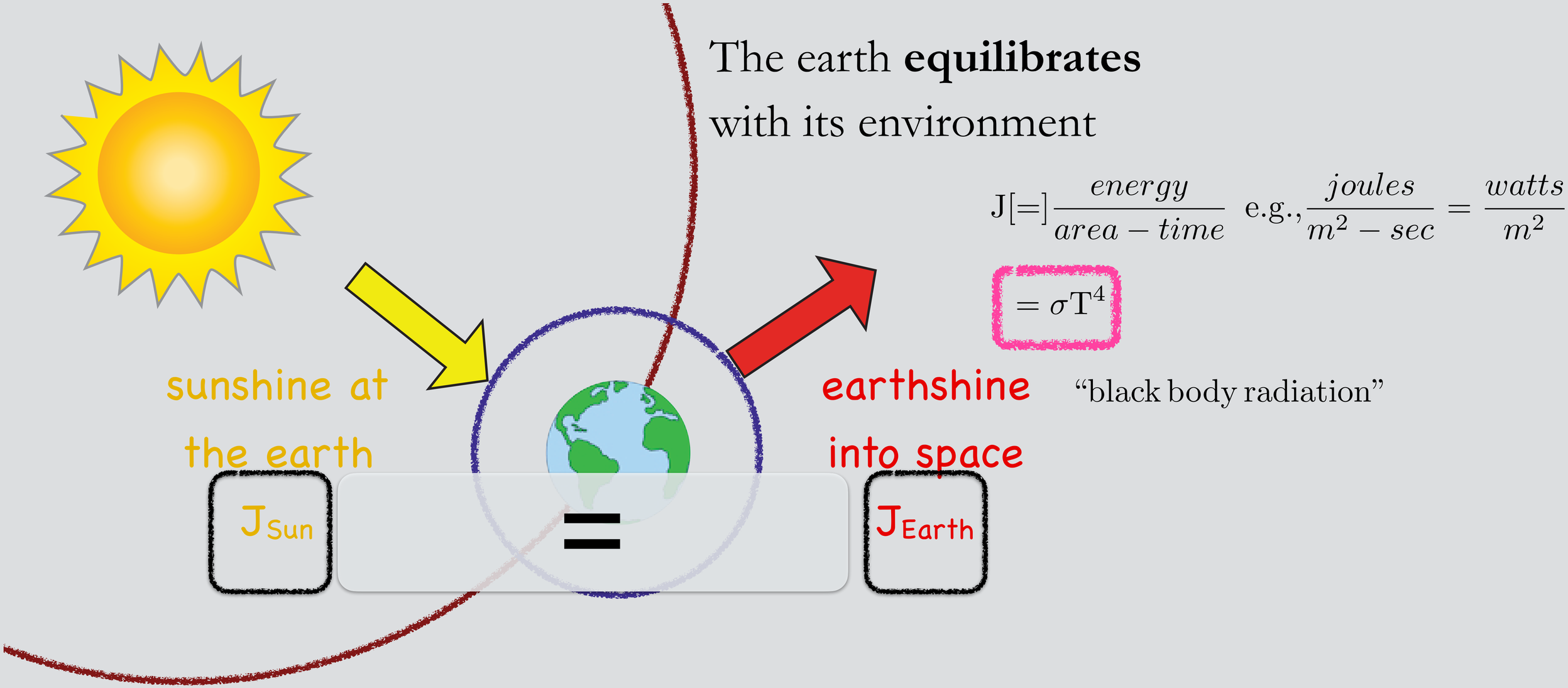

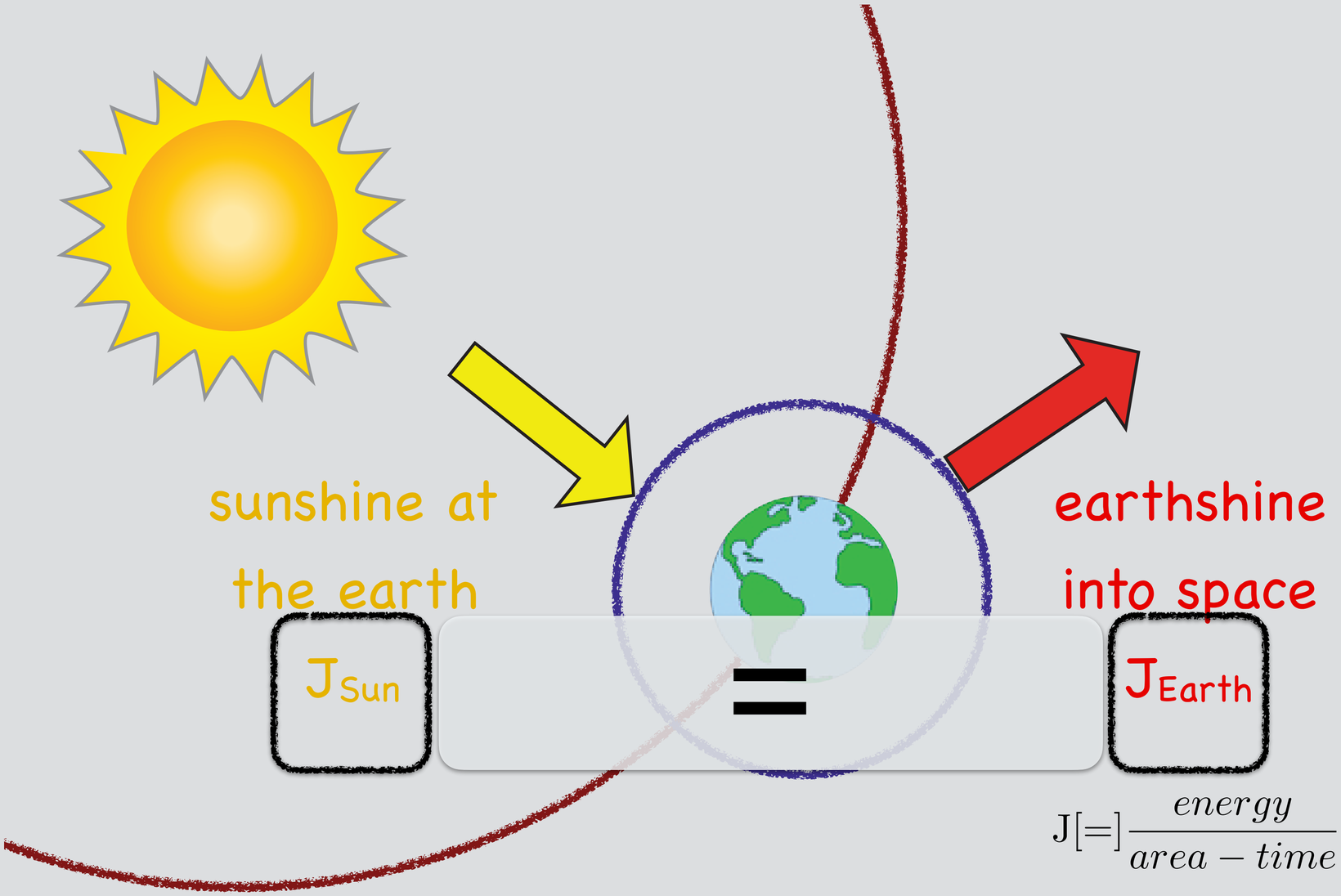

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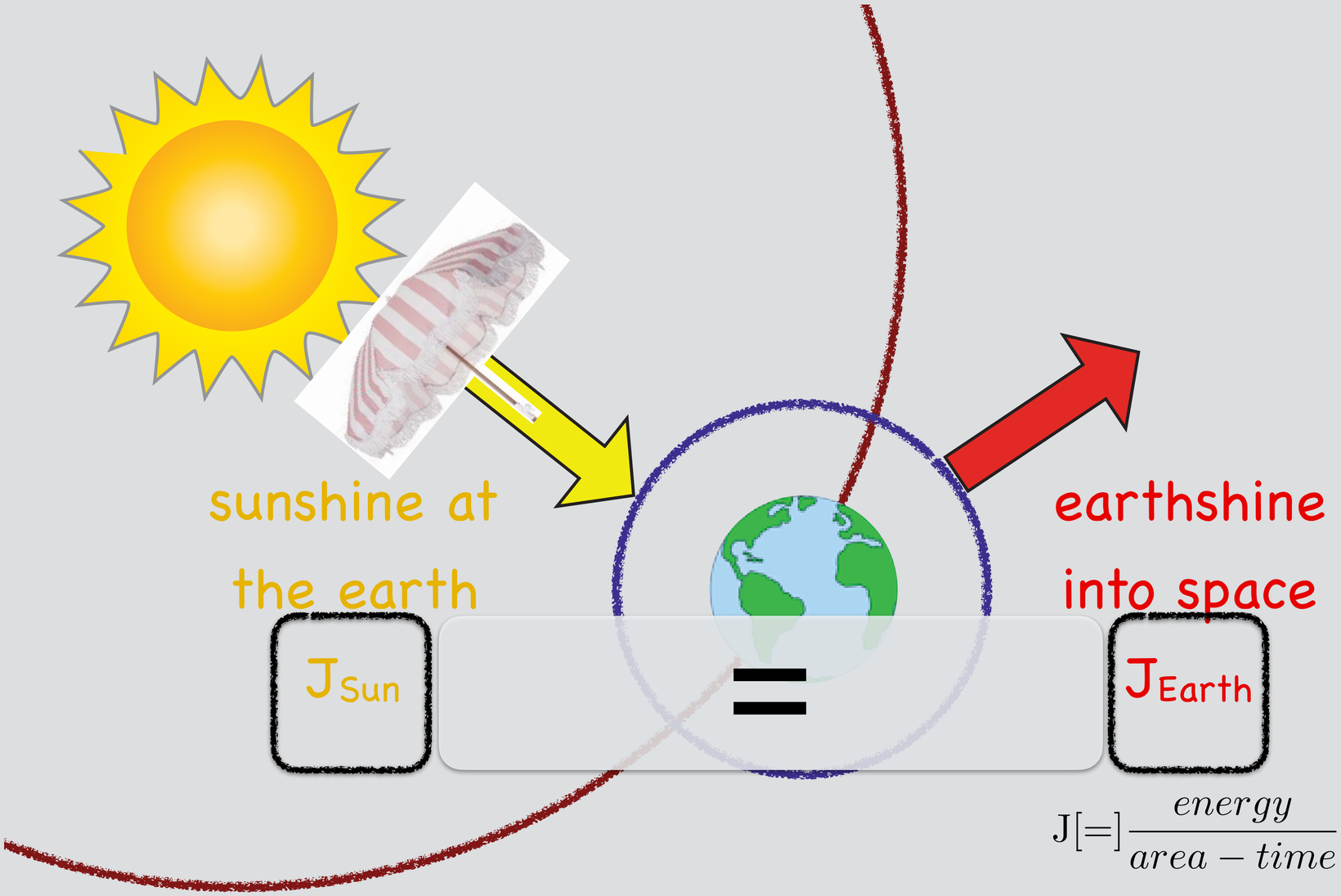

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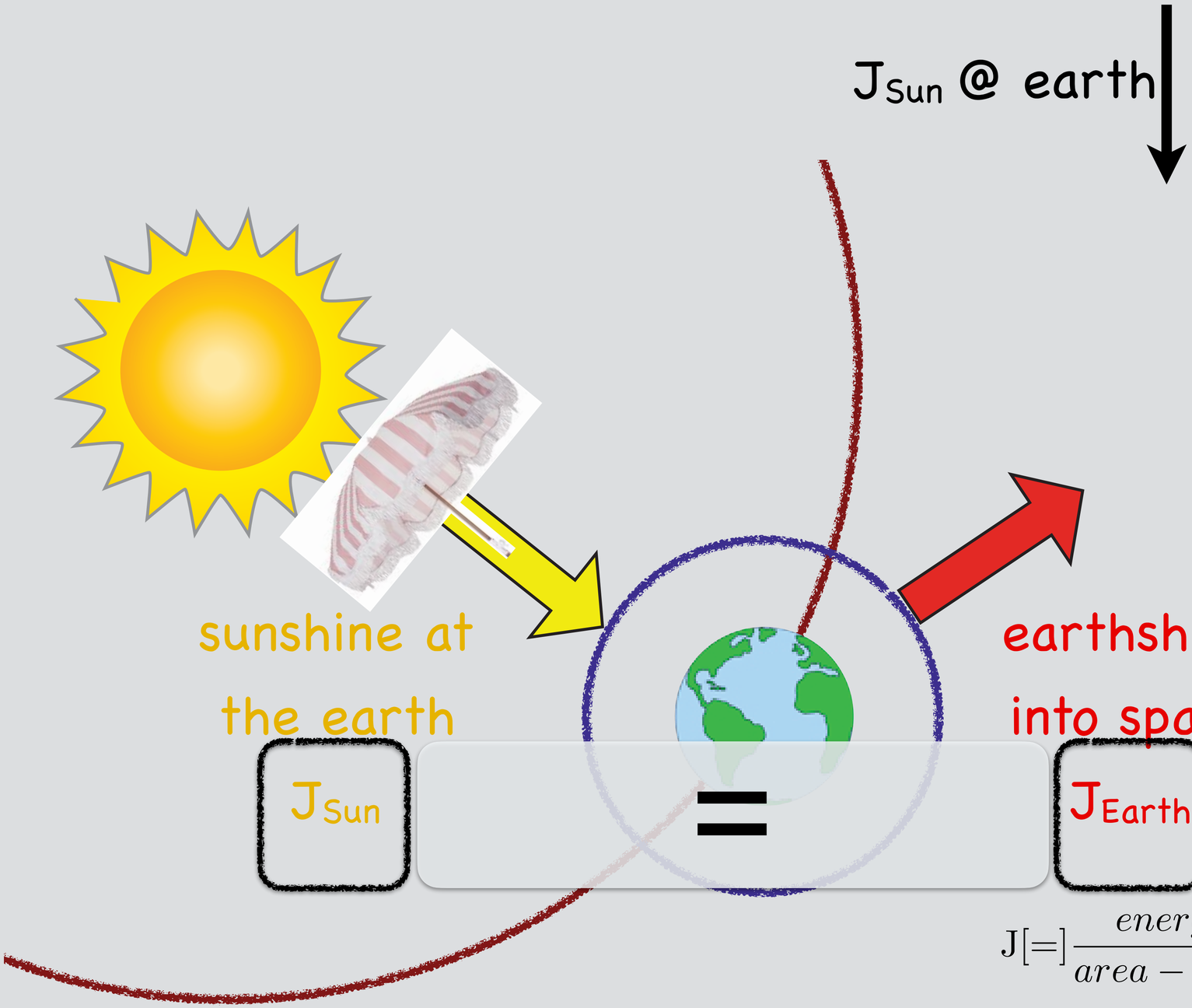

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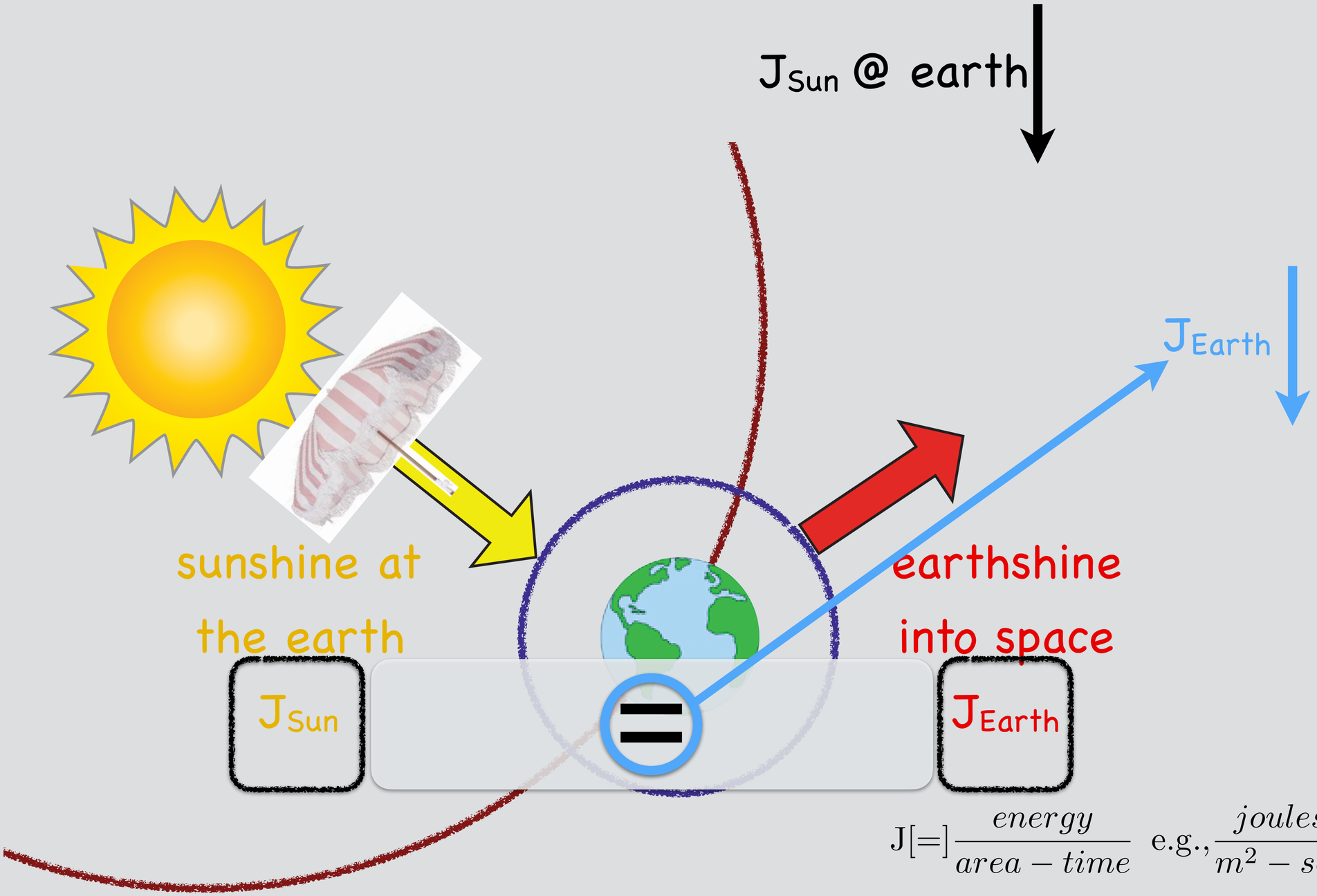

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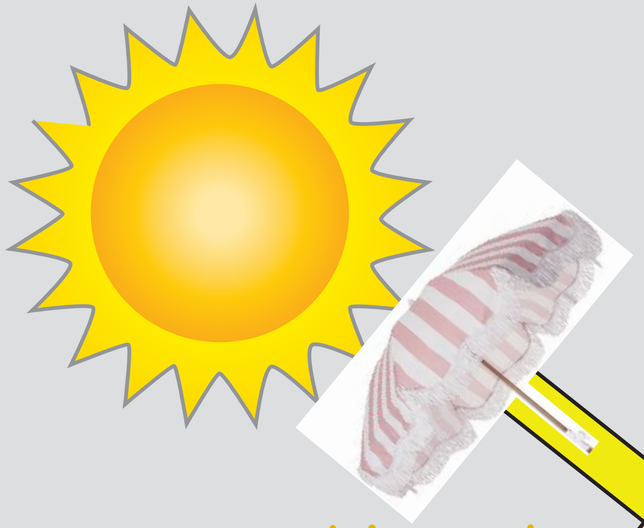
J_{Sun} @ earth



sunshine at the earth

earthshine into space

J_{Earth}

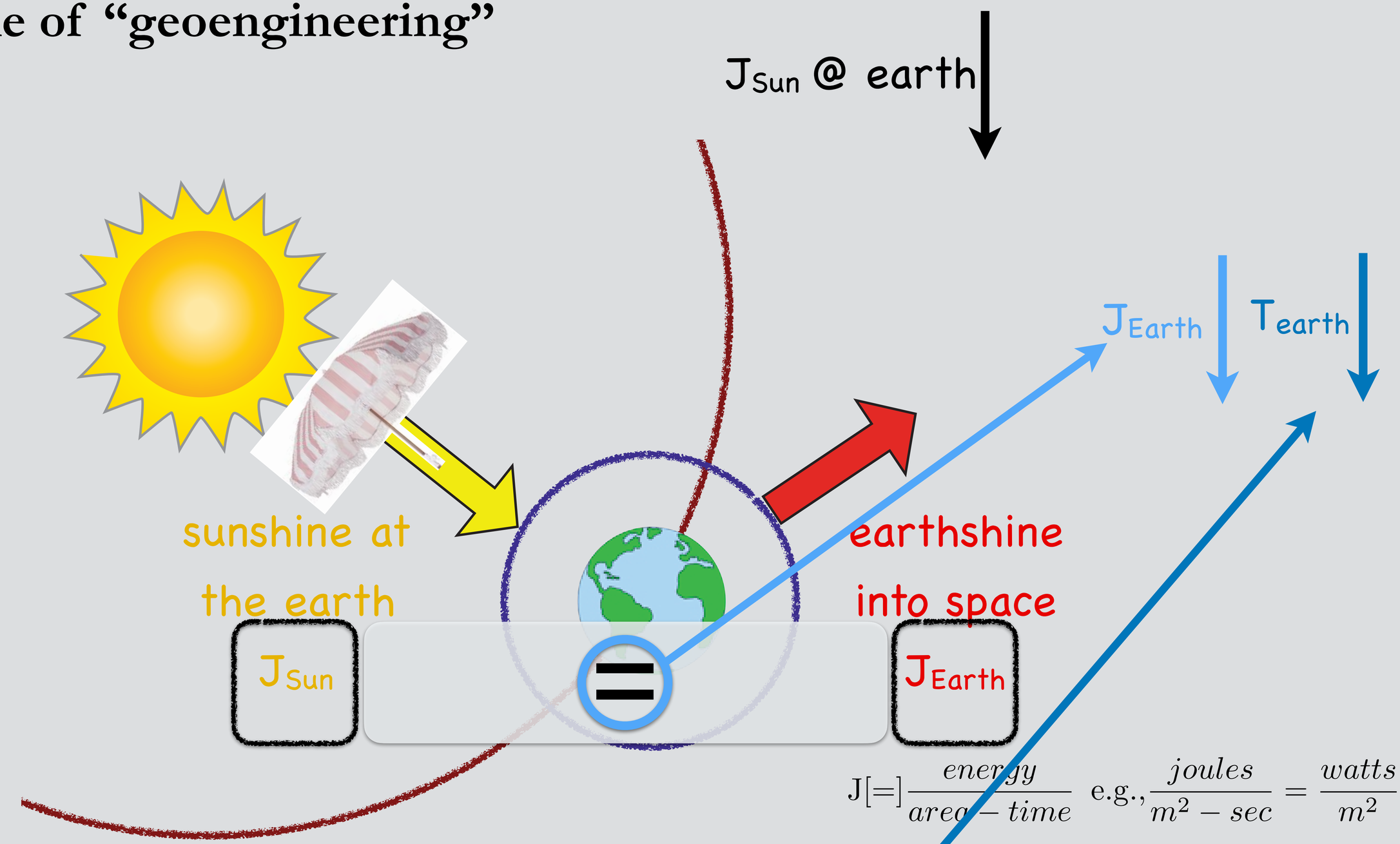
T_{earth}

J_{Sun} = J_{Earth}

$$J[=]\frac{energy}{area-time} \quad \text{e.g.,} \frac{joules}{m^2-sec} = \frac{watts}{m^2}$$

$$= \sigma T^4$$

an example of "geoengineering"



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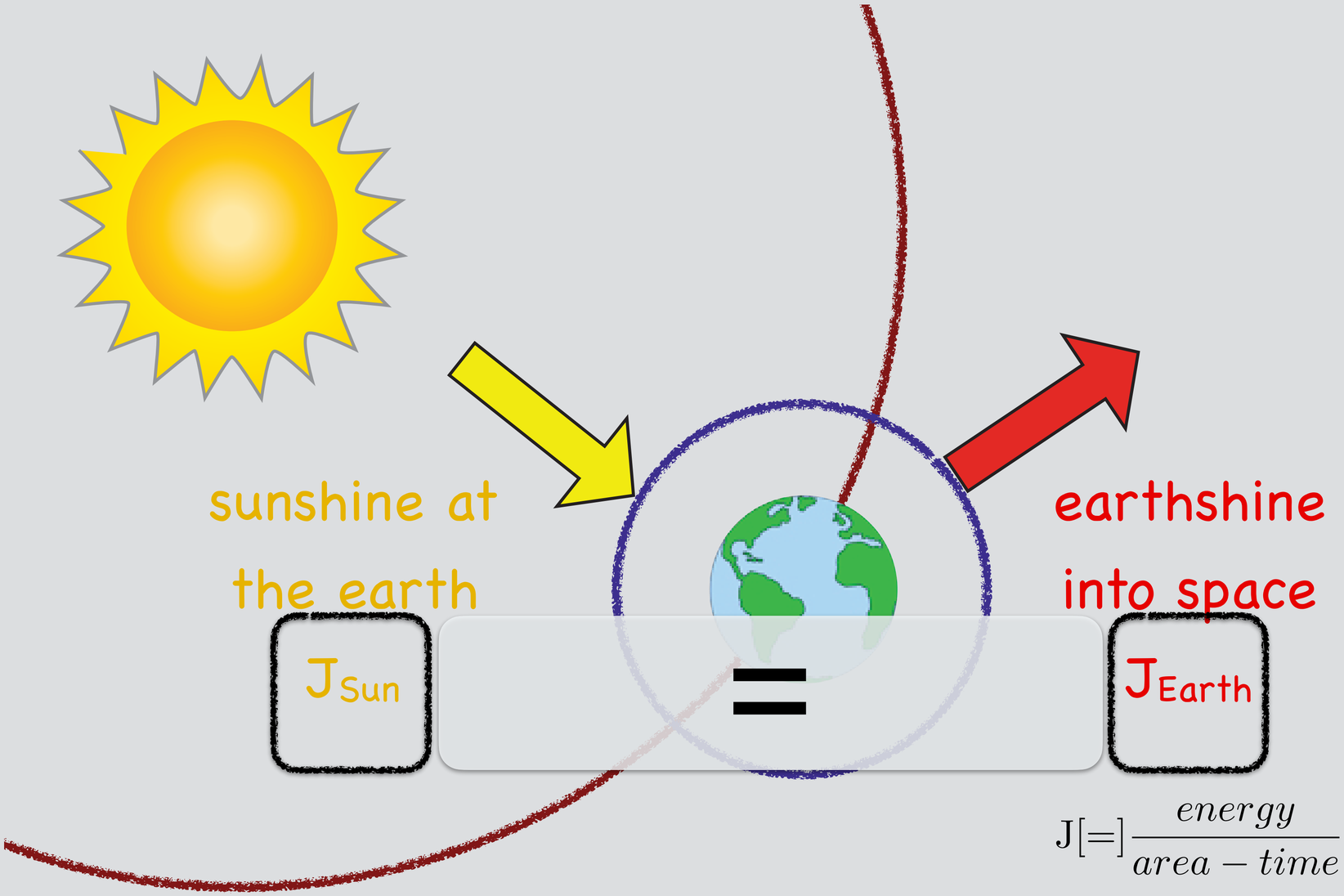

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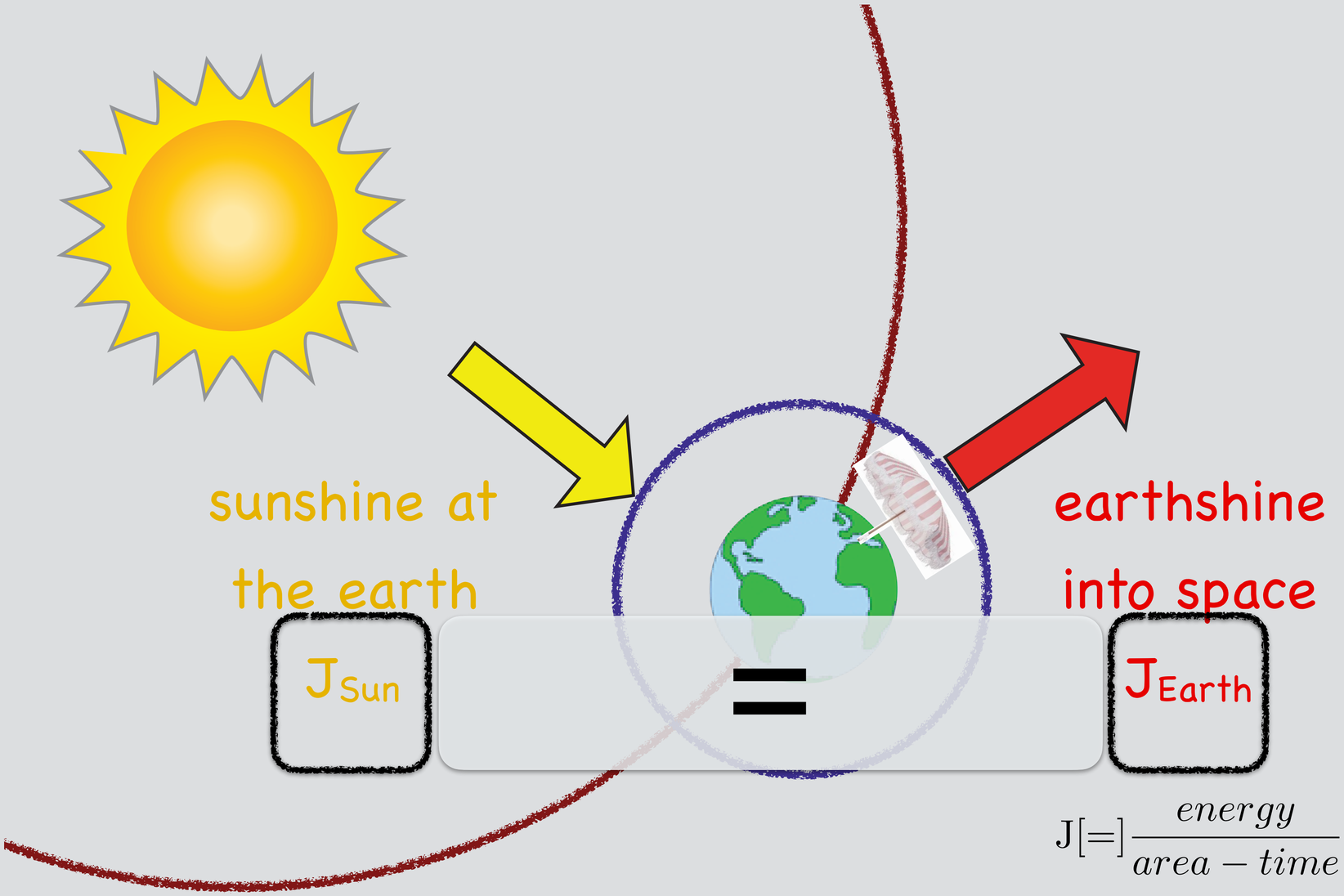

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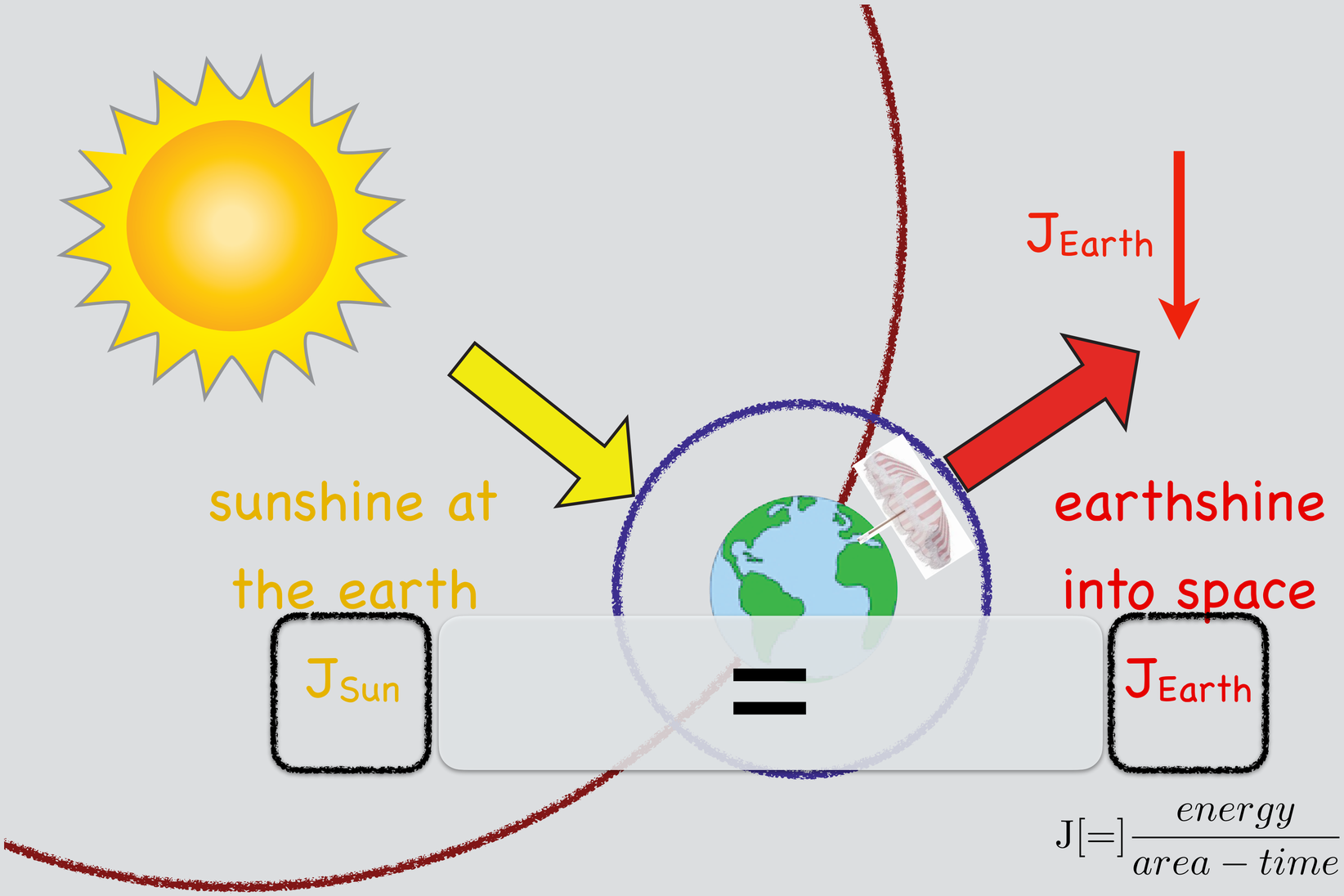

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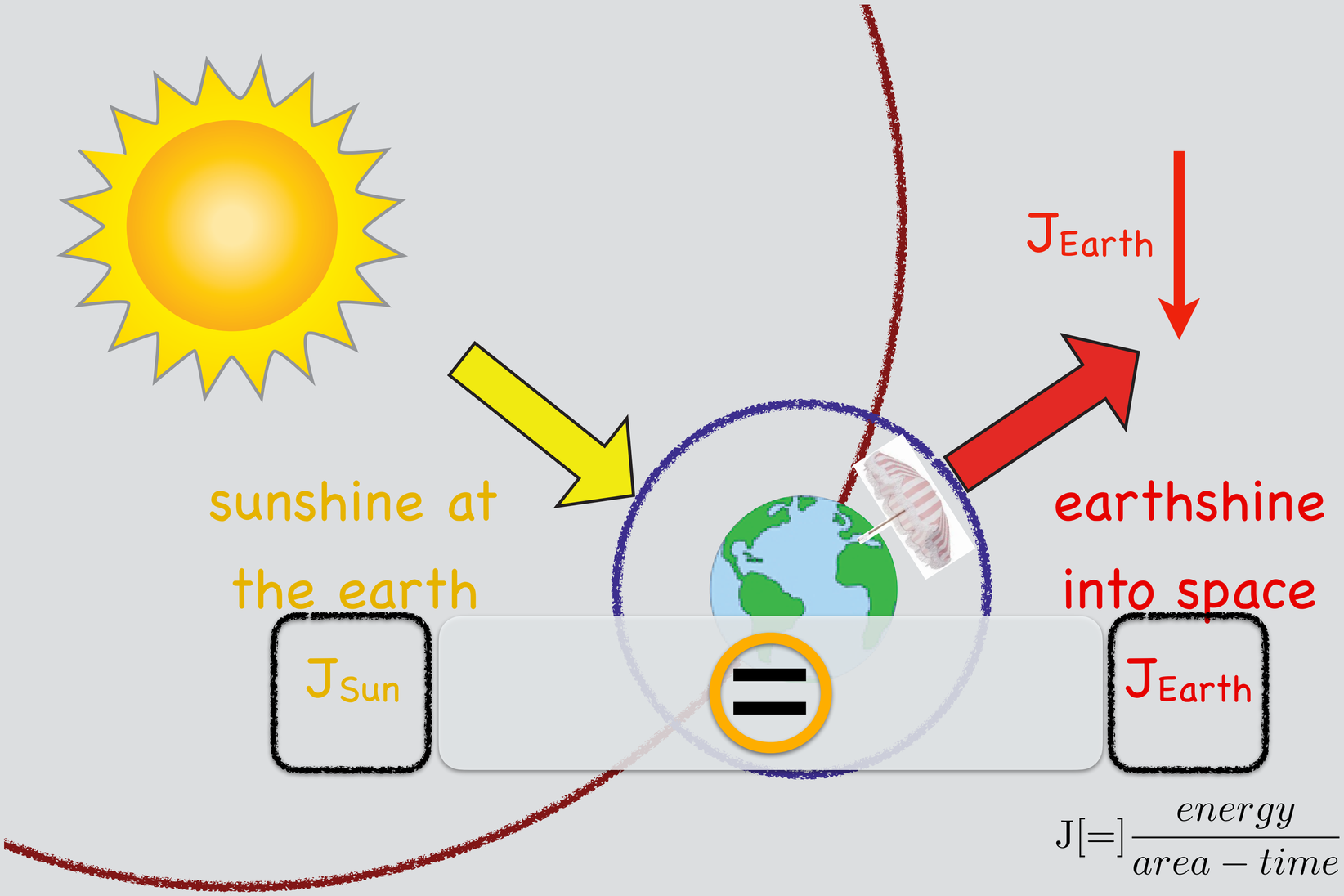

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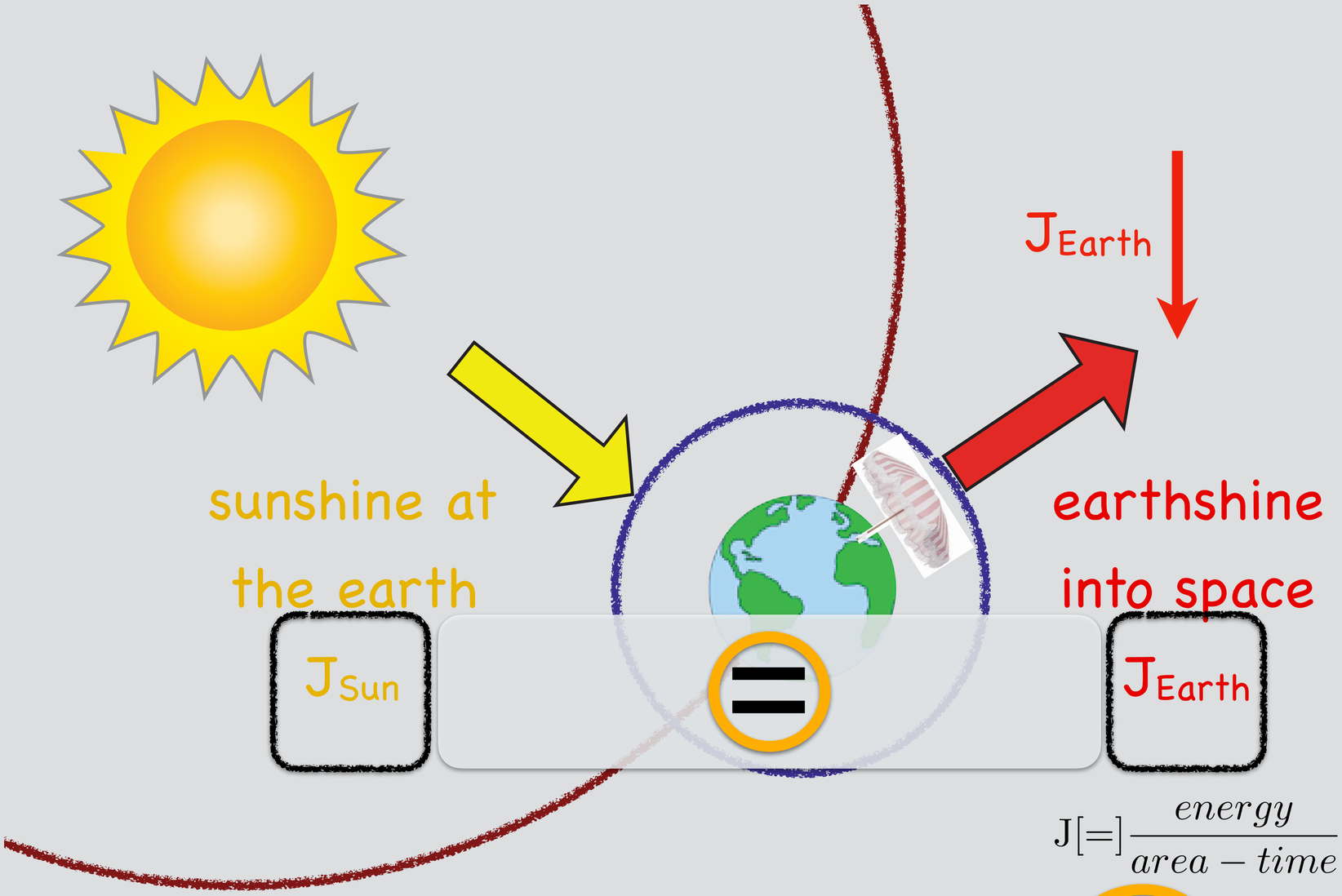

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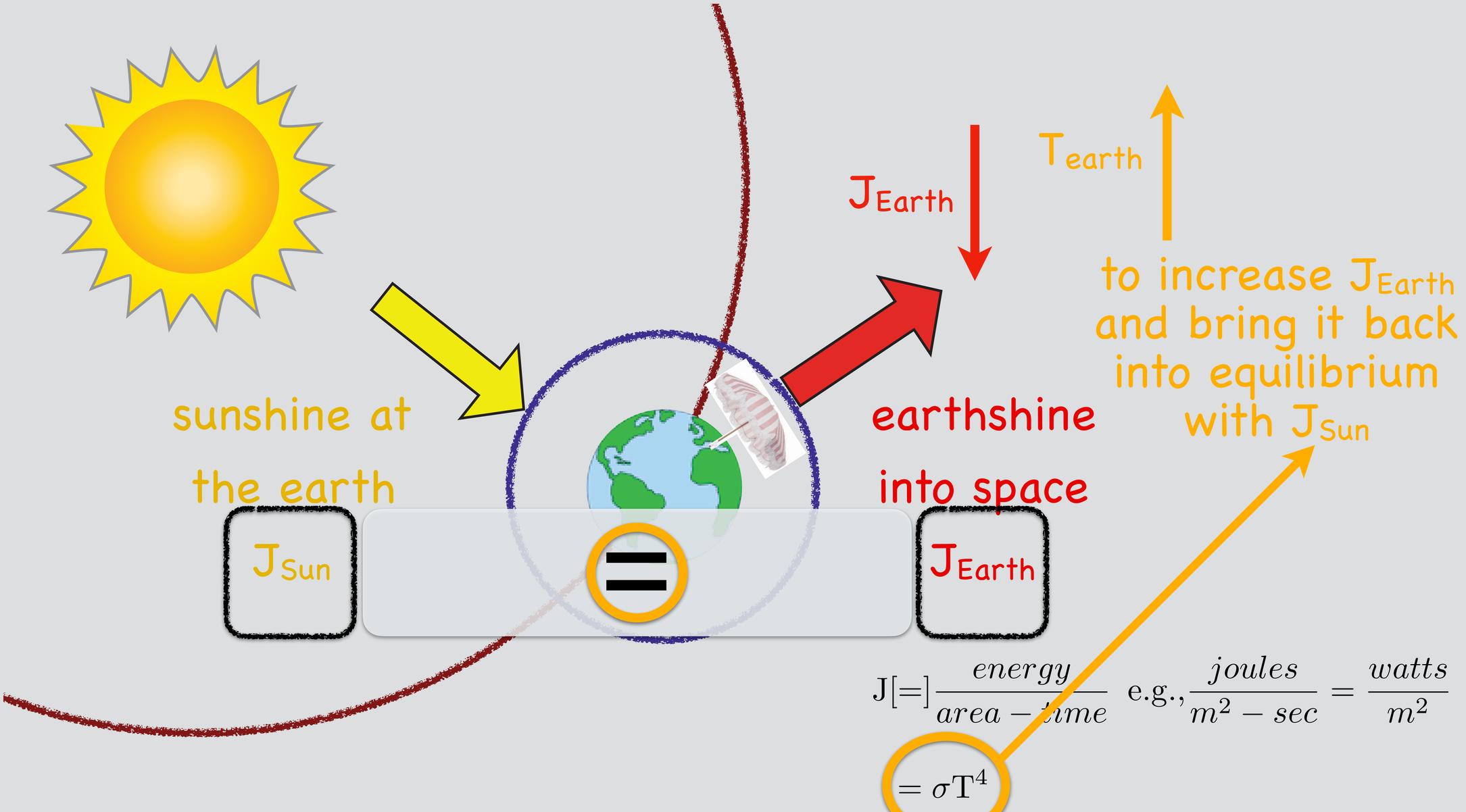
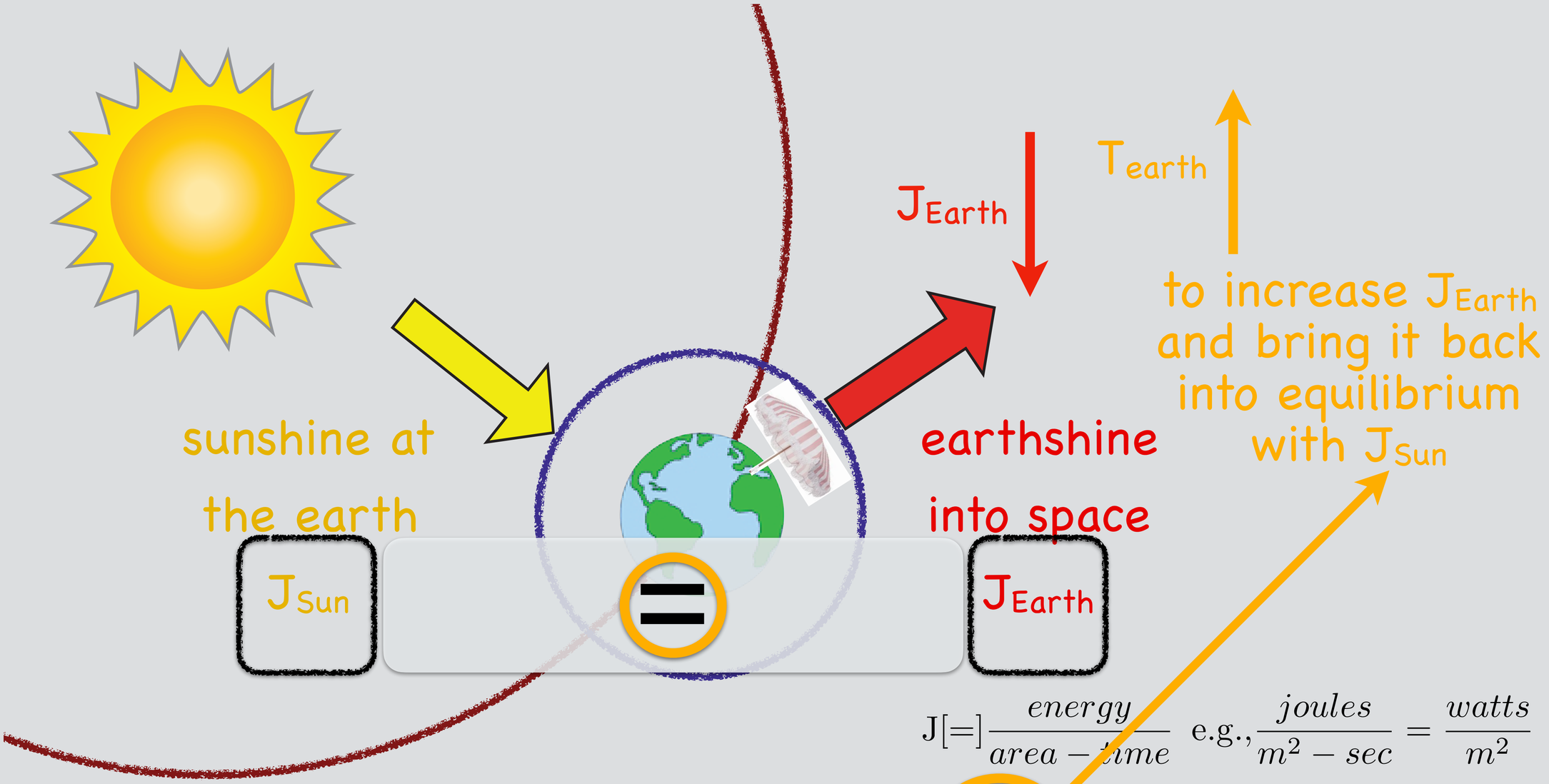

J_{Earth}
T_{earth}
to increase J_{Earth} and bring it back into equilibrium with J_{Sun}
sunshine at the earth
earthshine into space
J_{Sun}
=
J_{Earth}
$J[=]\frac{energy}{area - time}$ e.g., $\frac{joules}{m^2 - sec} = \frac{watts}{m^2}$
$= \sigma T^4$

Umbrella@earth is an example of changes in "radiative forcing"



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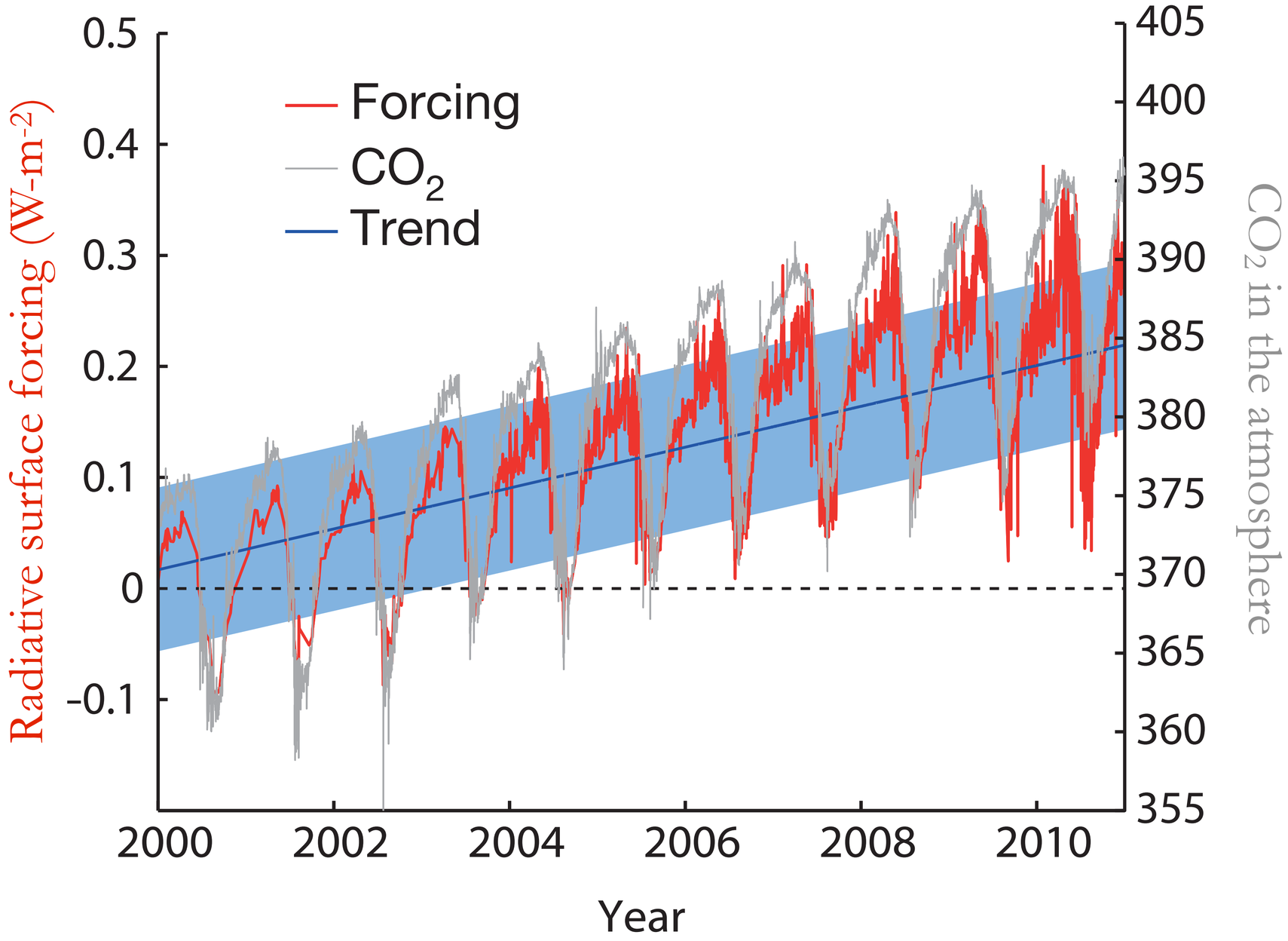
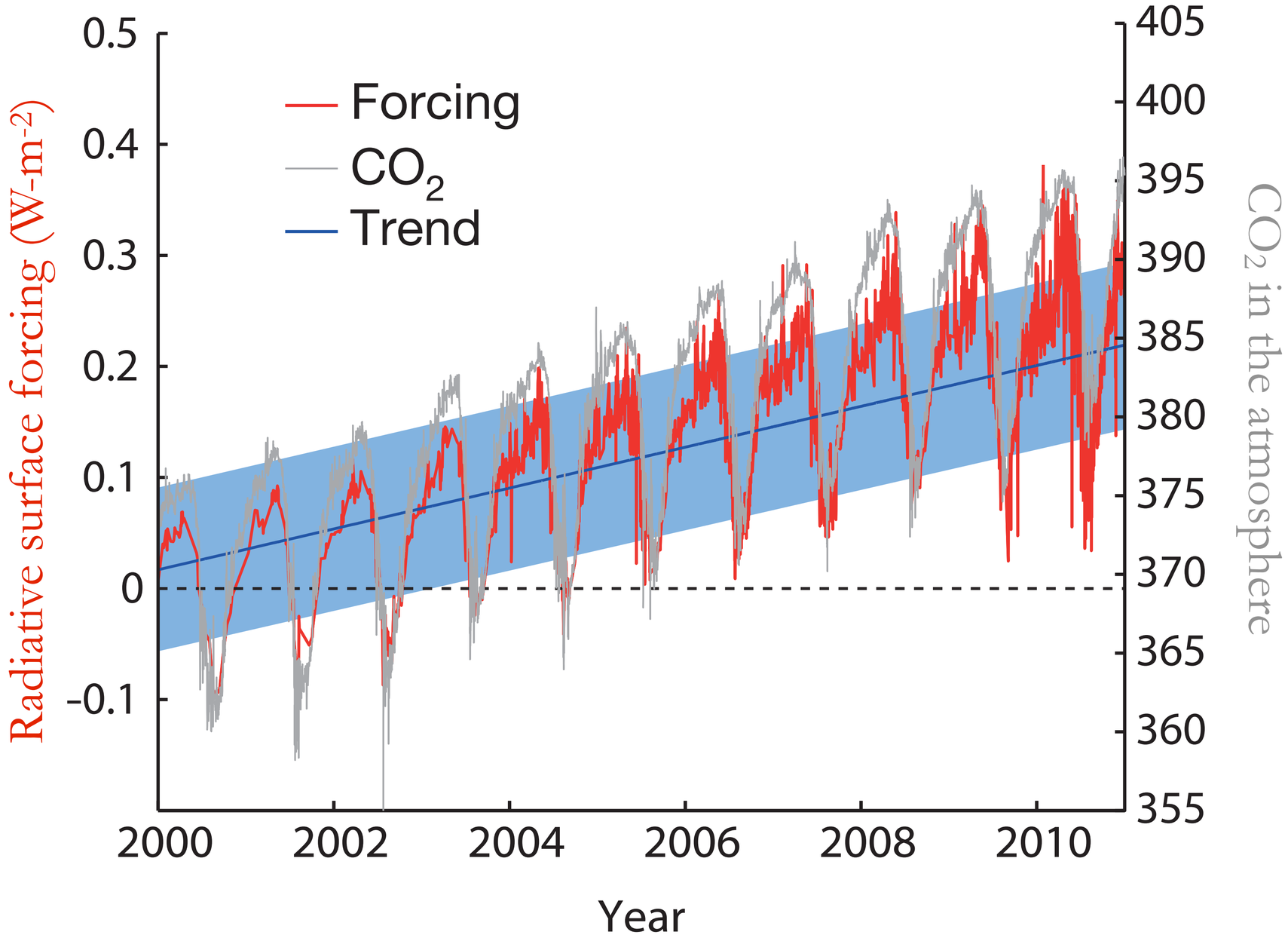


Feldman, D.R., Collins, W.D., Gero, P.J., Torn, M.S., Mlawer, E.J., and Shippert, T. R., Nature, 2015

radiative forcing from CO_2 has been measured



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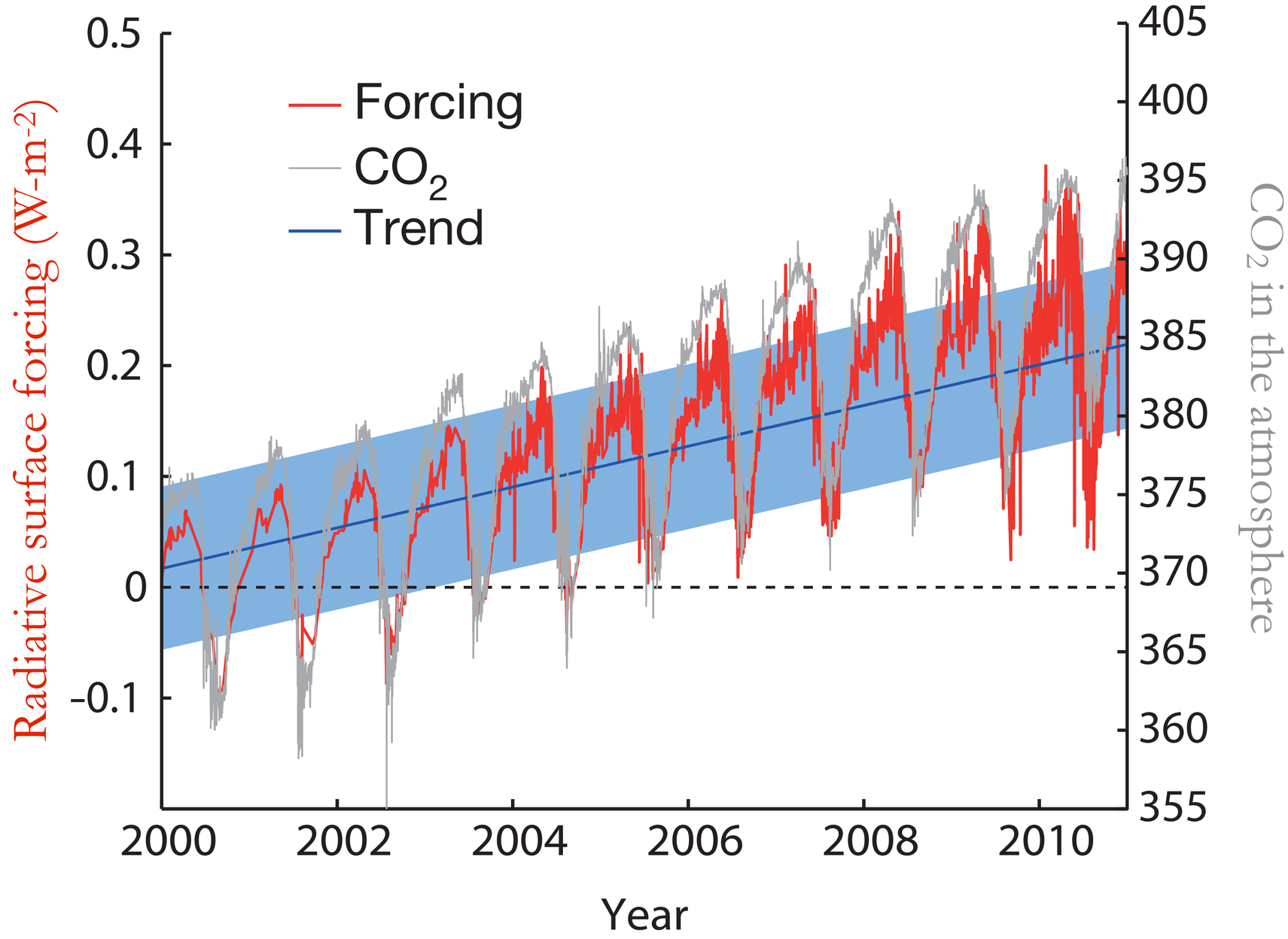

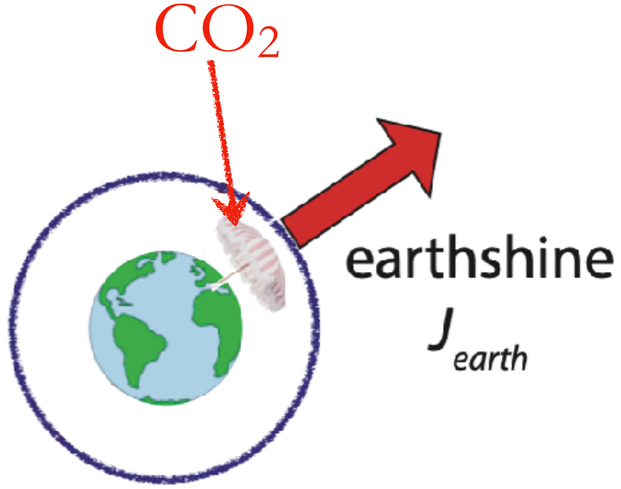

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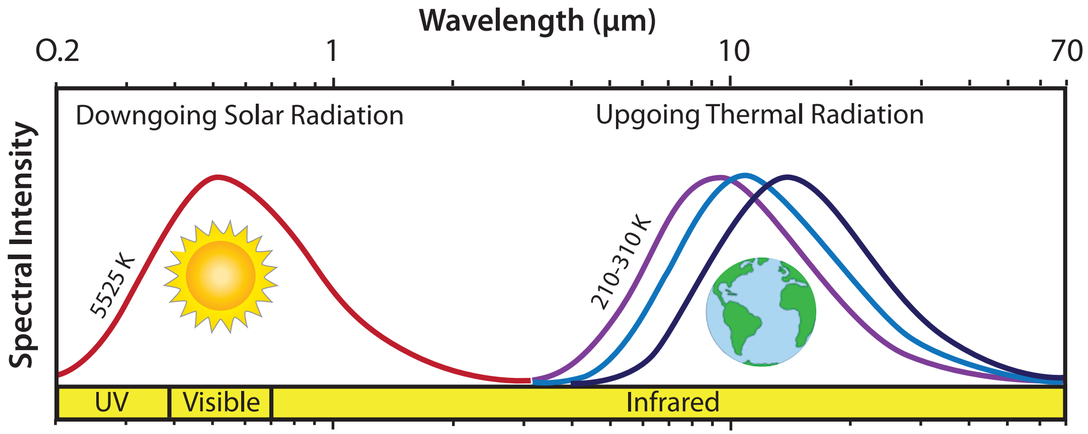
"black body radiation"

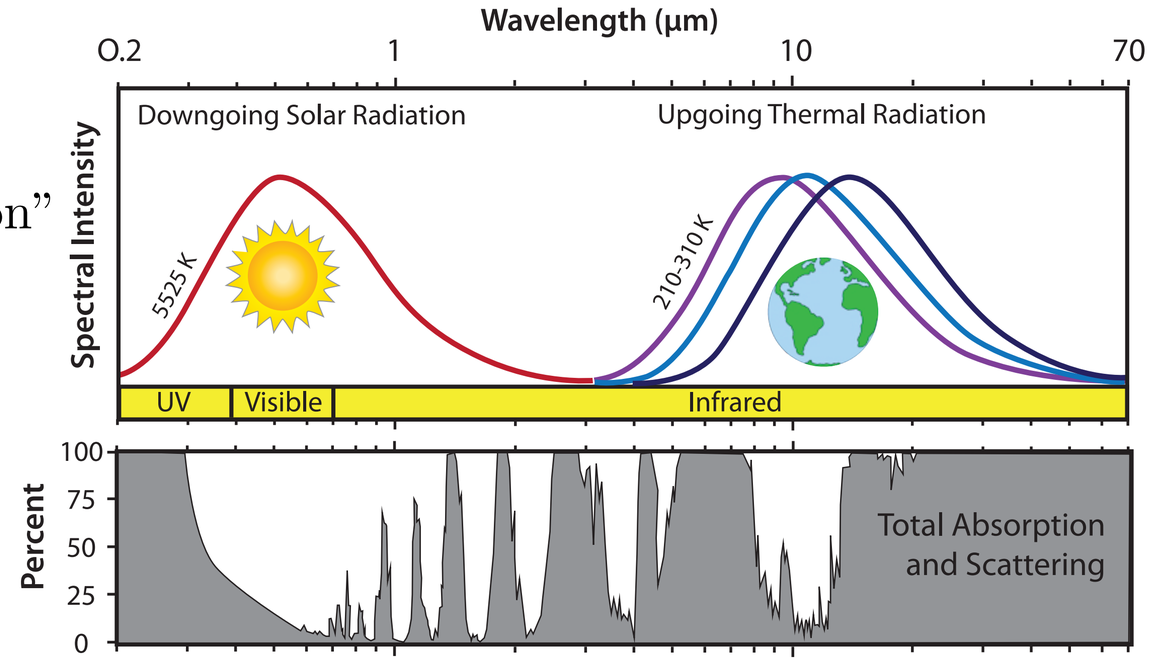
$$\sigma T^4$$



Carbon Capture and Sequestration (JAR with Berend Smit, Curt Oldenburg, Ian Bourg), World Scientific Press, 2013.

"black body radiation"

σT^4



The role of our atmosphere:
absorb incoming sunshine…
and
absorb outgoing earthshine

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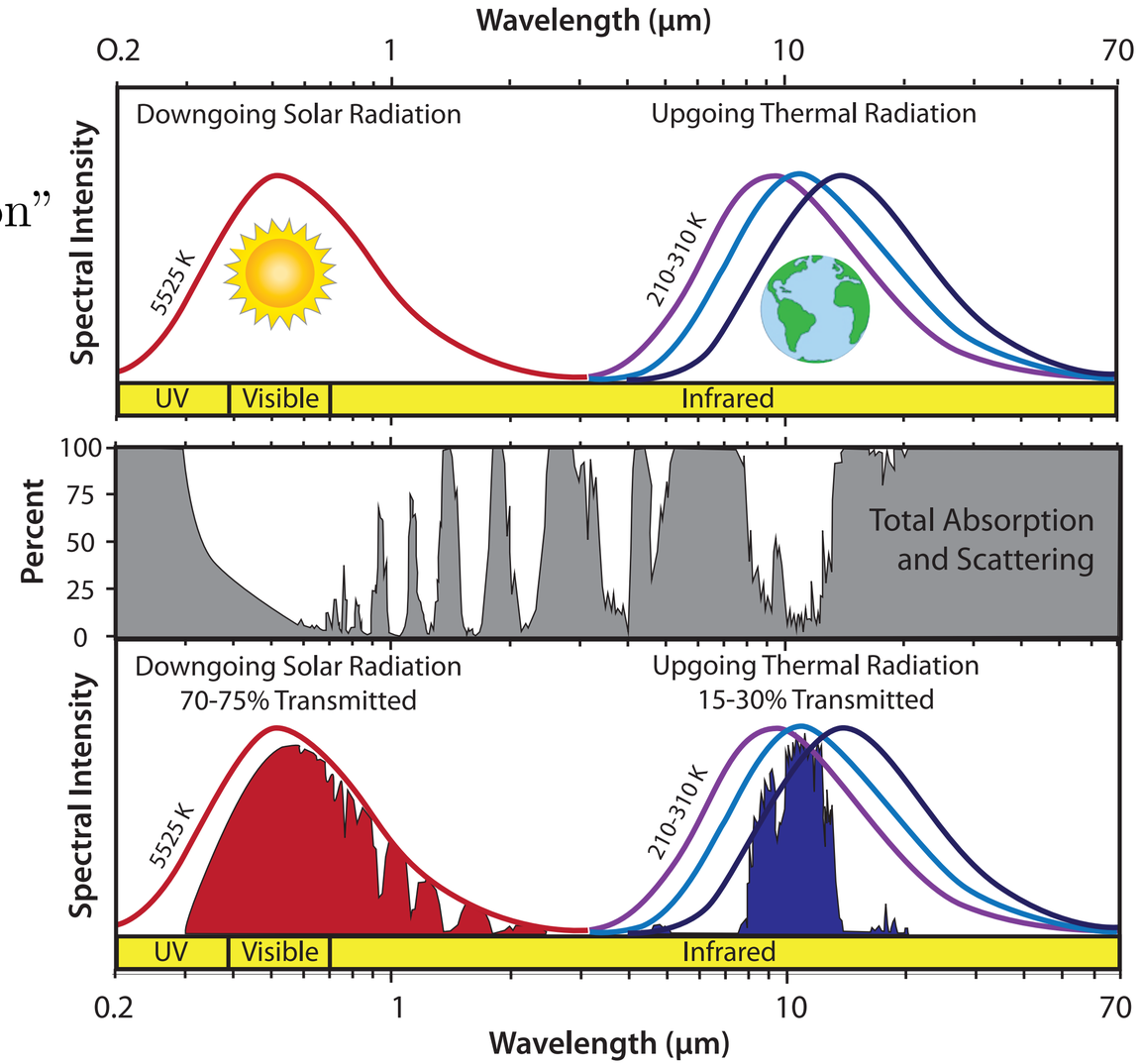

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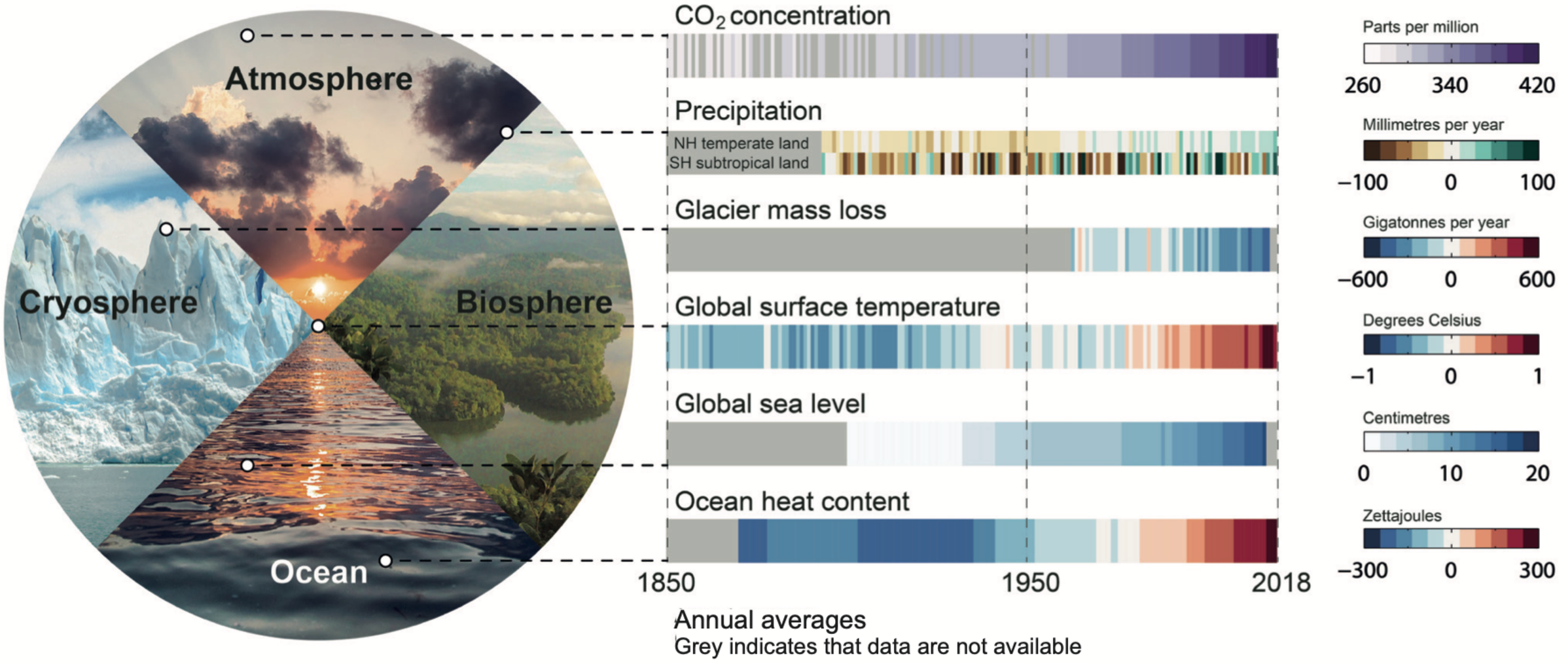
Consequences


Atmosphere
Cryosphere
Biosphere
Ocean
CO_2 concentration
Parts per million
260
340
420
Precipitation
NH temperate land
SH subtropical land
Millimetres per year
−100
0
100
Glacier mass loss
Gigatonnes per year
−600
0
600
Global surface temperature
Degrees Celsius
−1
0
1
Global sea level
Centimetres
0
10
20
Ocean heat content
Zettajoules
−300
0
300
1850
1950
2018
Annual averages
Grey indicates that data are not available

Global warming has increased global economic inequality

Noah S. Diffenbaugh[a,b,1] and Marshall Burke[a,c,d]

9808–9813 | PNAS | May 14, 2019 | vol. 116 | no. 20

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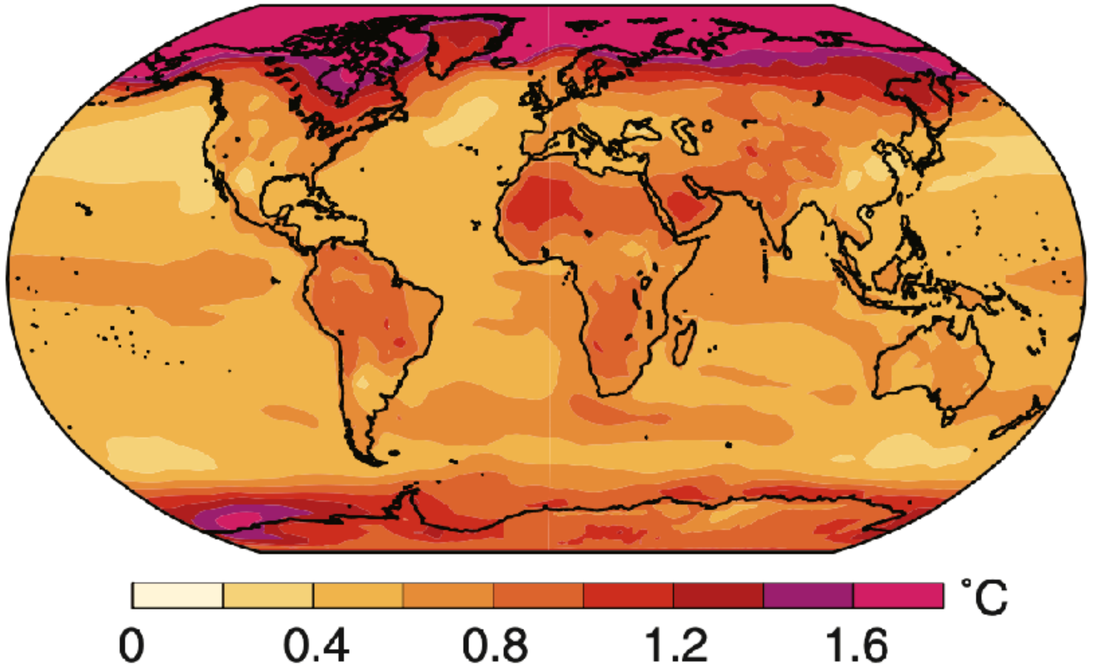
change in temperature from anthropogenic forcing



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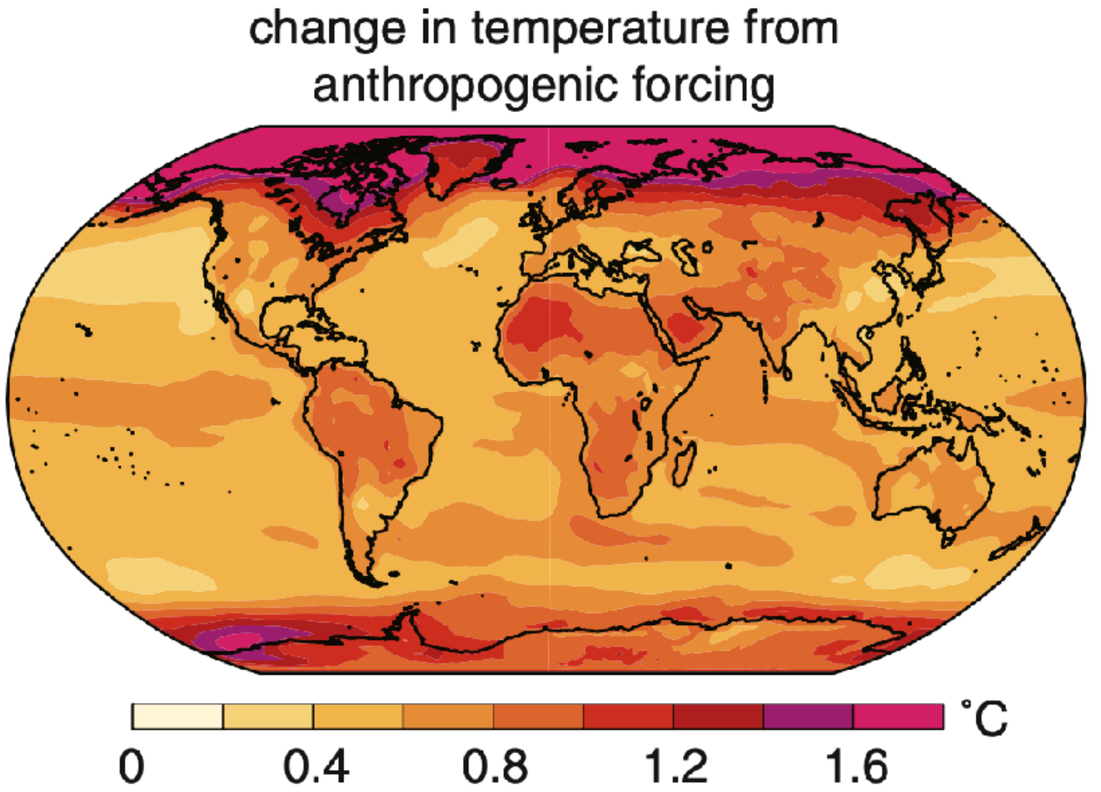

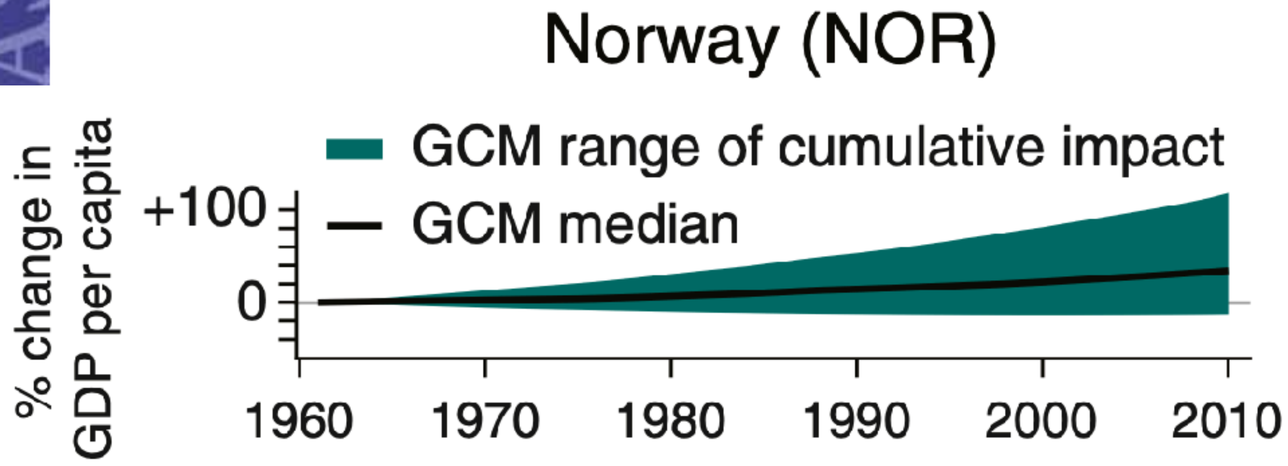

"Cool" countries benefit economically with warming

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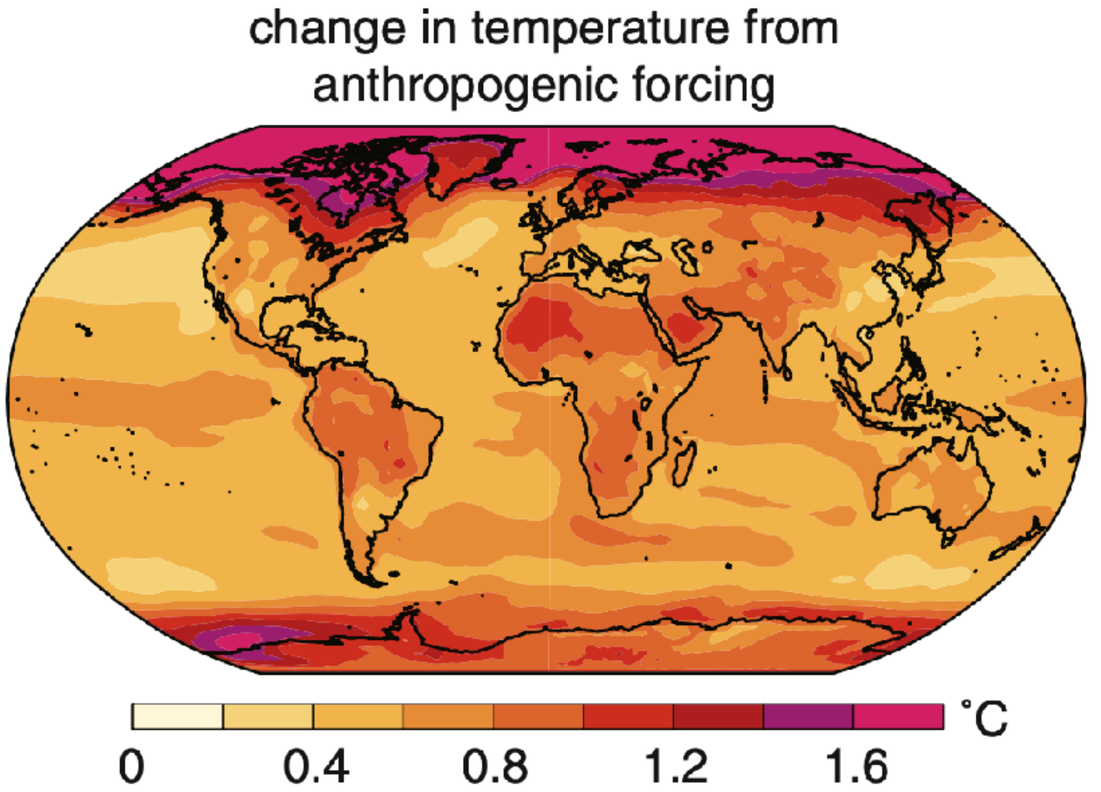

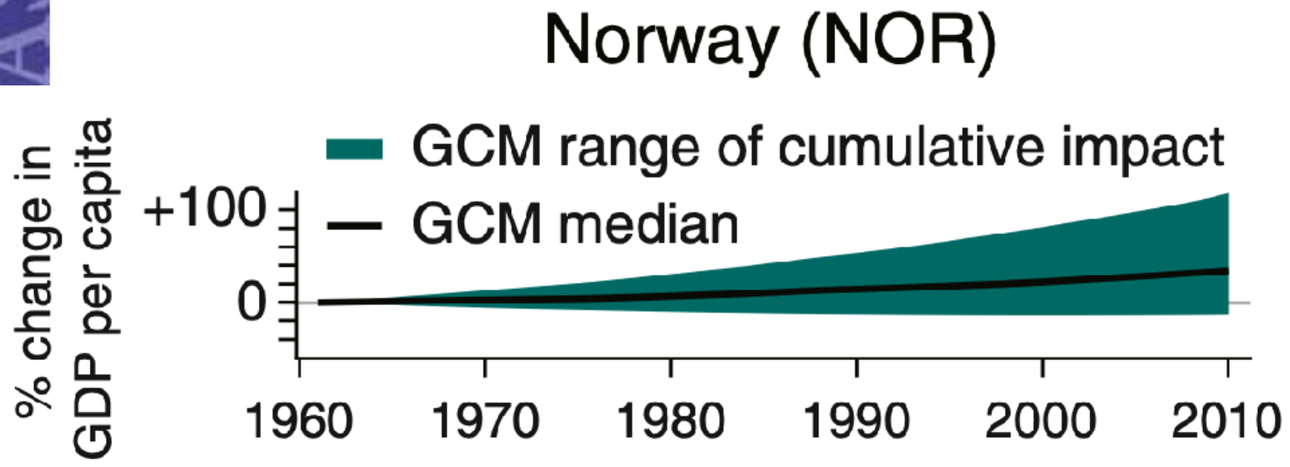

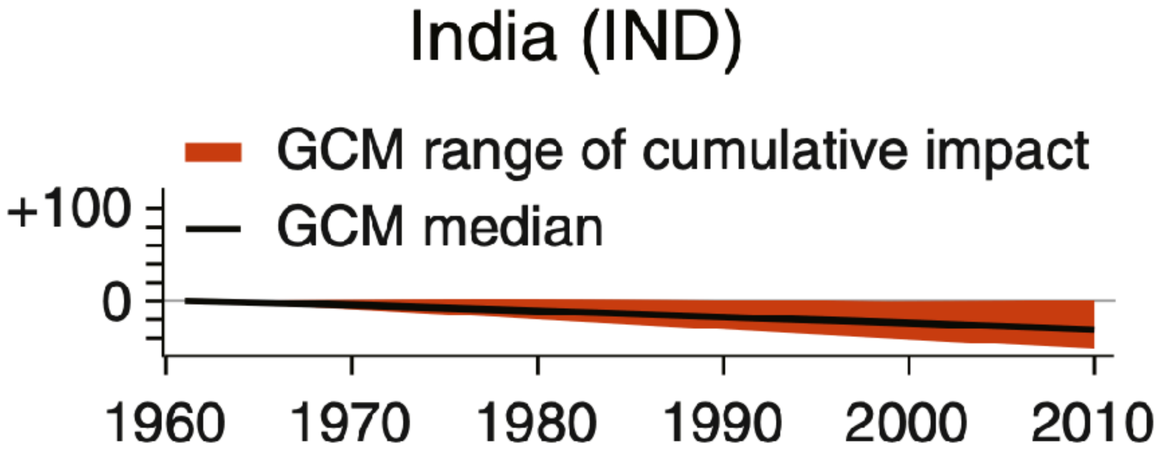

"Cool" countries benefit economically with warming

"Warm" countries experience cumulative losses with warming

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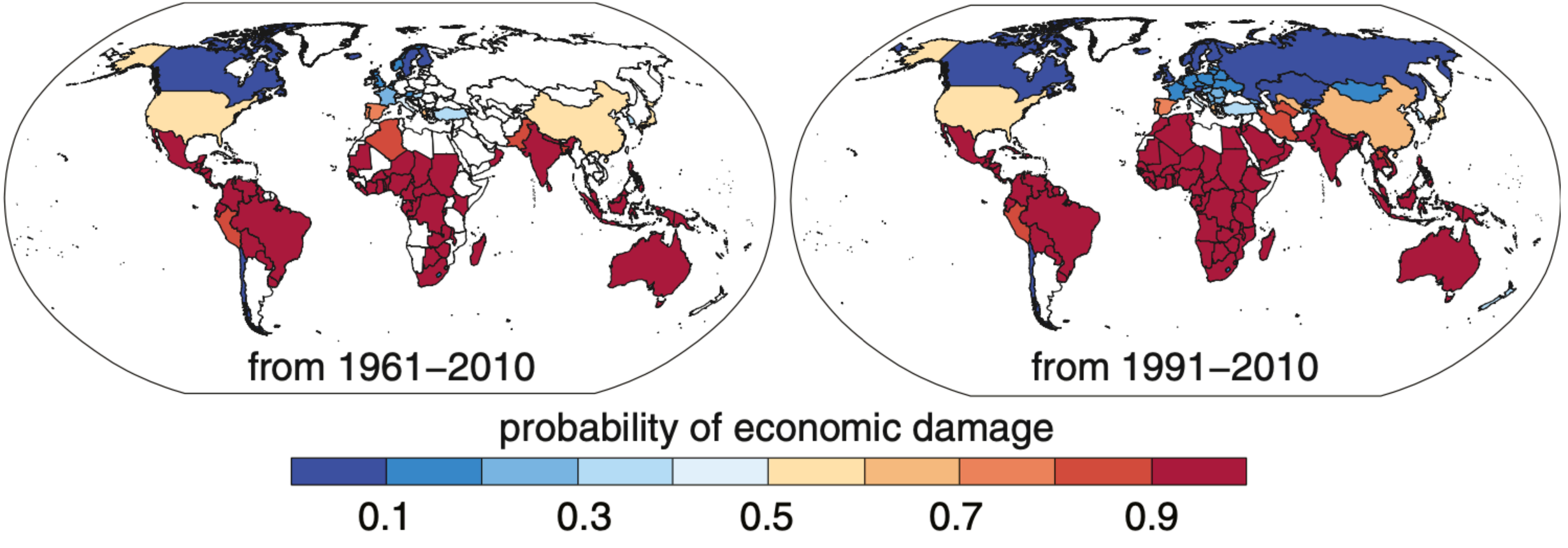

nature climate change

NATURE CLIMATE CHANGE | VOL 8 | AUGUST 2018 | 723–729 |

ARTICLES

https://doi.org/10.1038/s41558-018-0222-x

Higher temperatures increase suicide rates in the United States and Mexico USA, Chile, Canada

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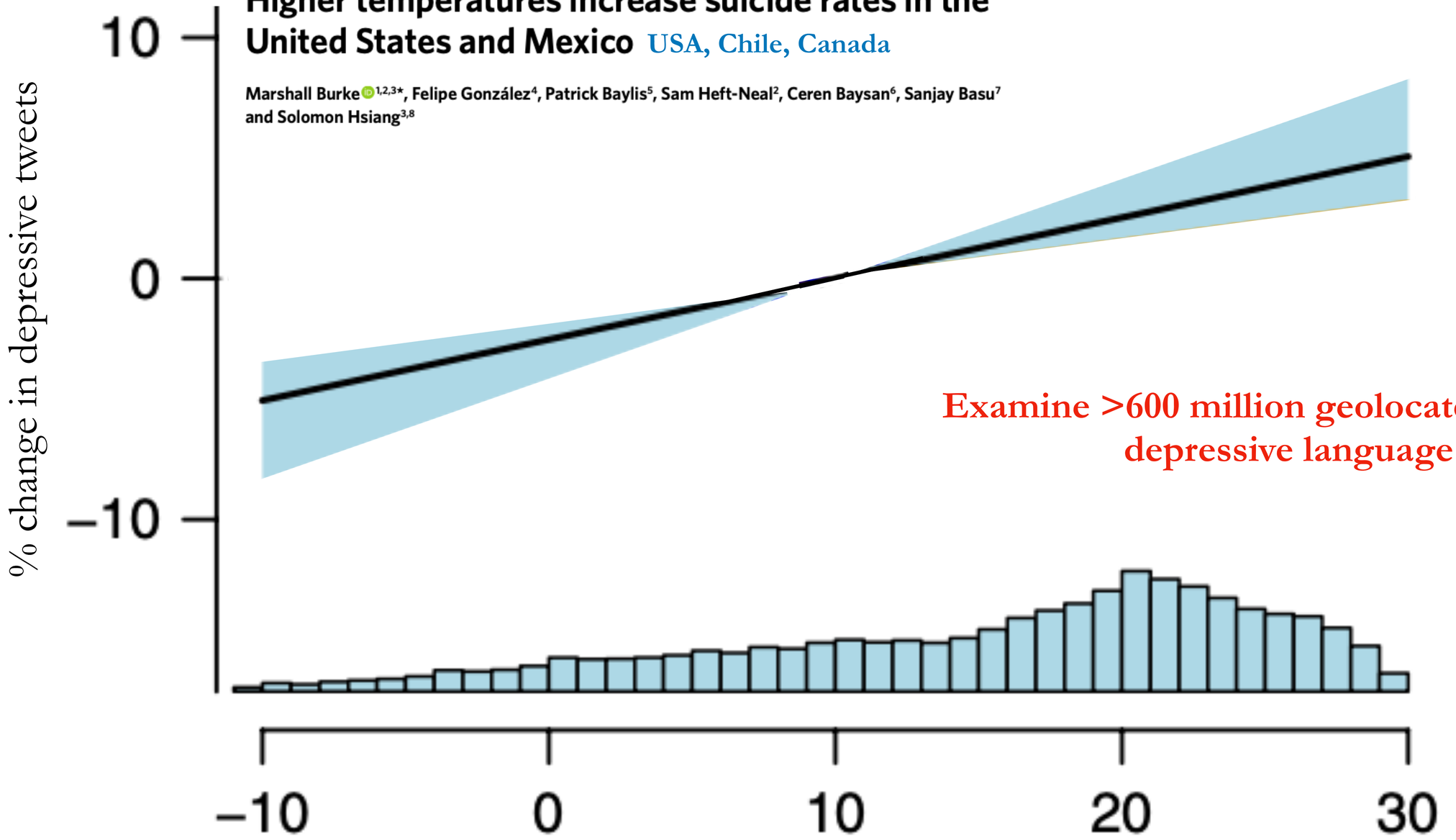

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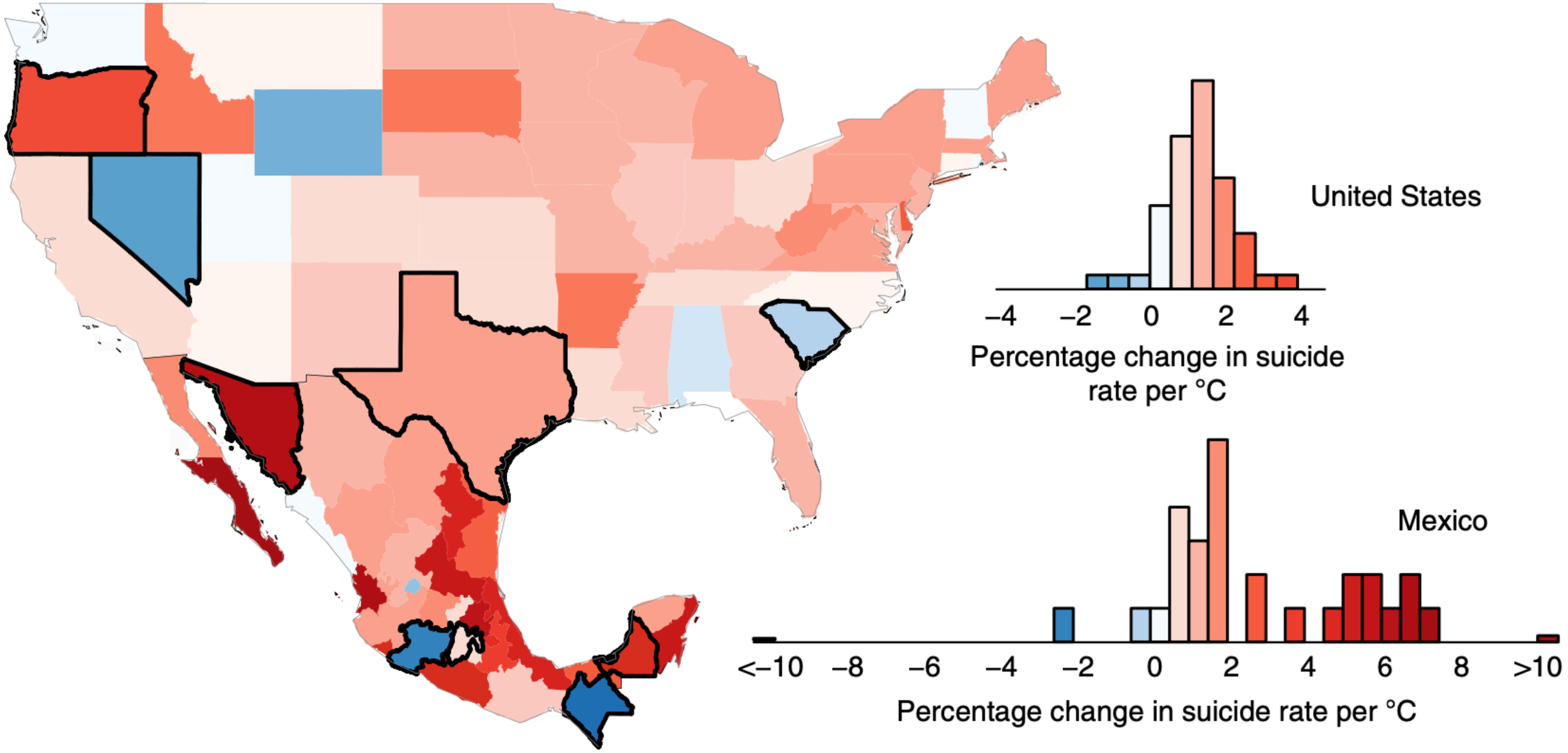
We are more likely to commit suicide when it is hot…



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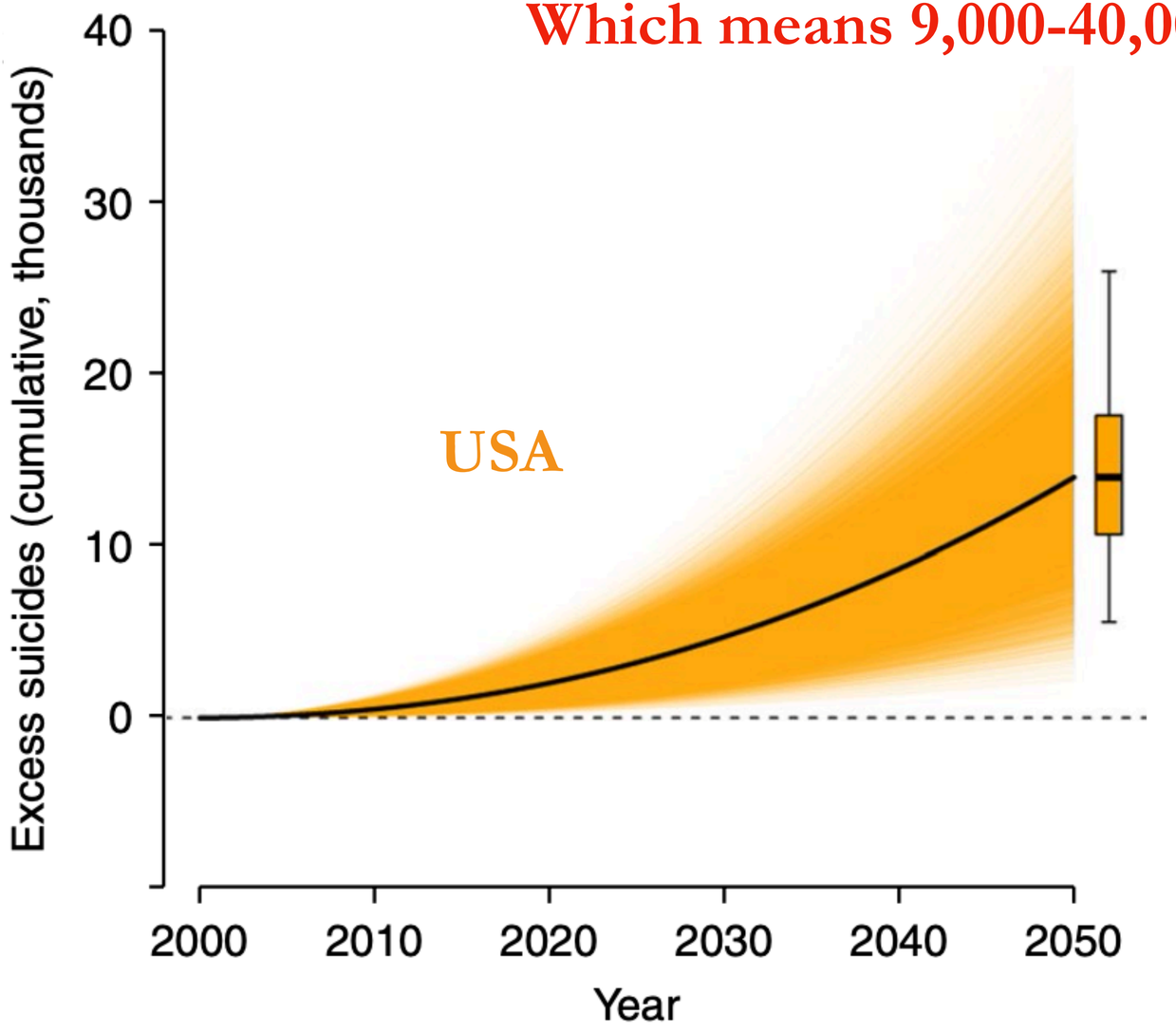
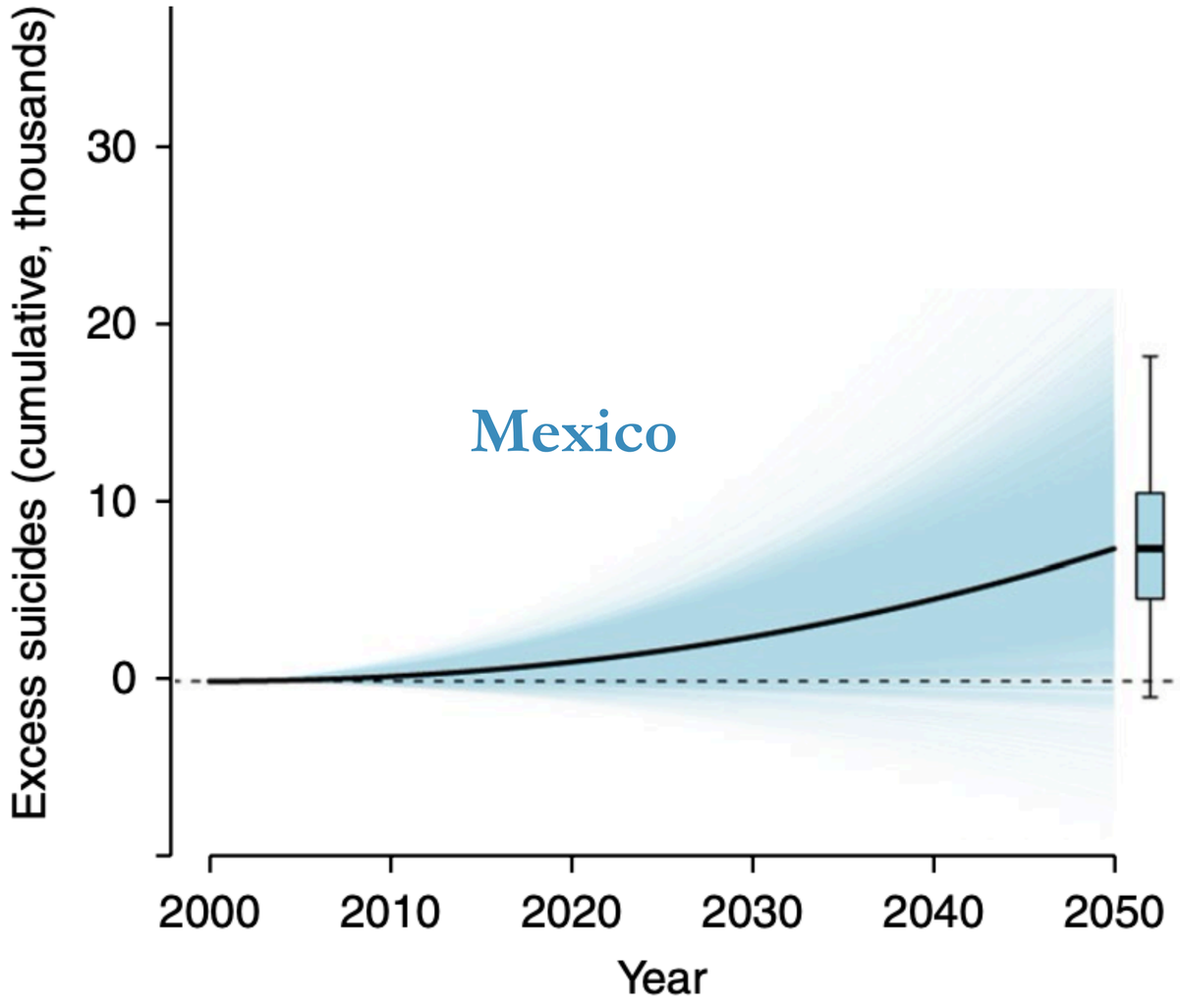
Higher temperatures increase suicide rates in the United States and Mexico

Which means 9,000-40,000 additional suicides





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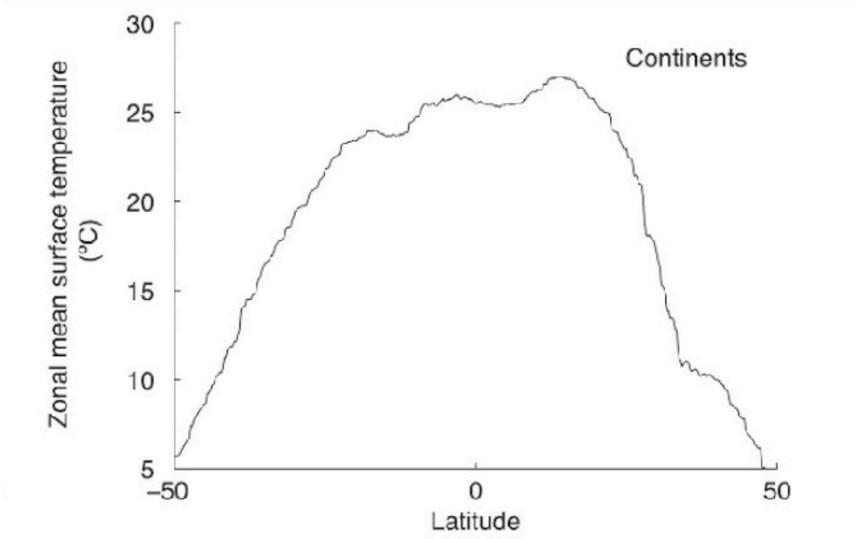

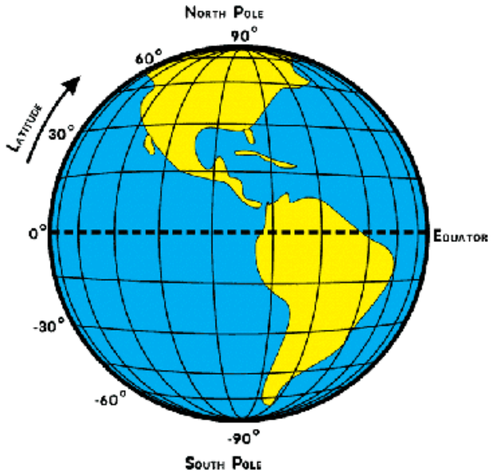

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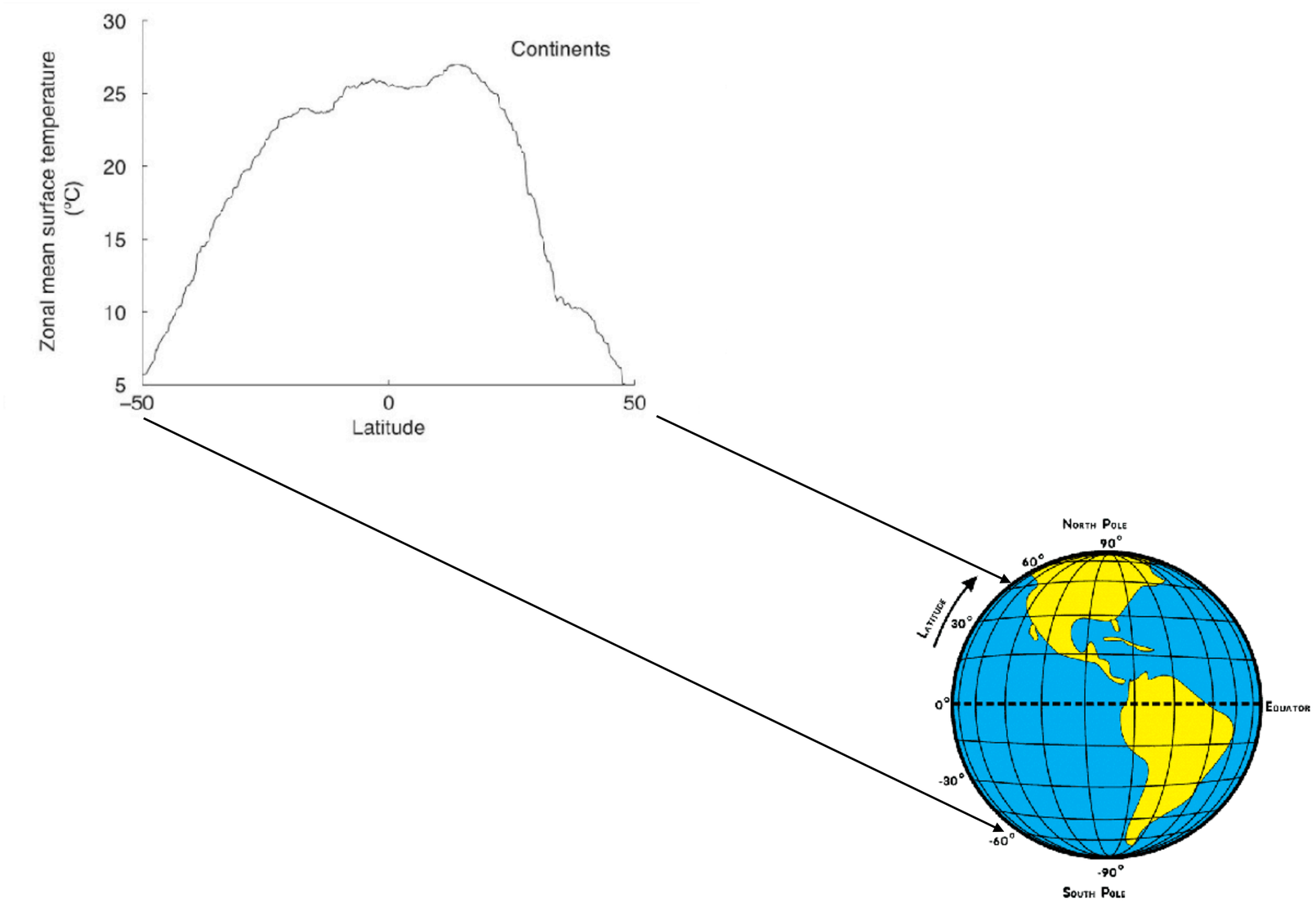

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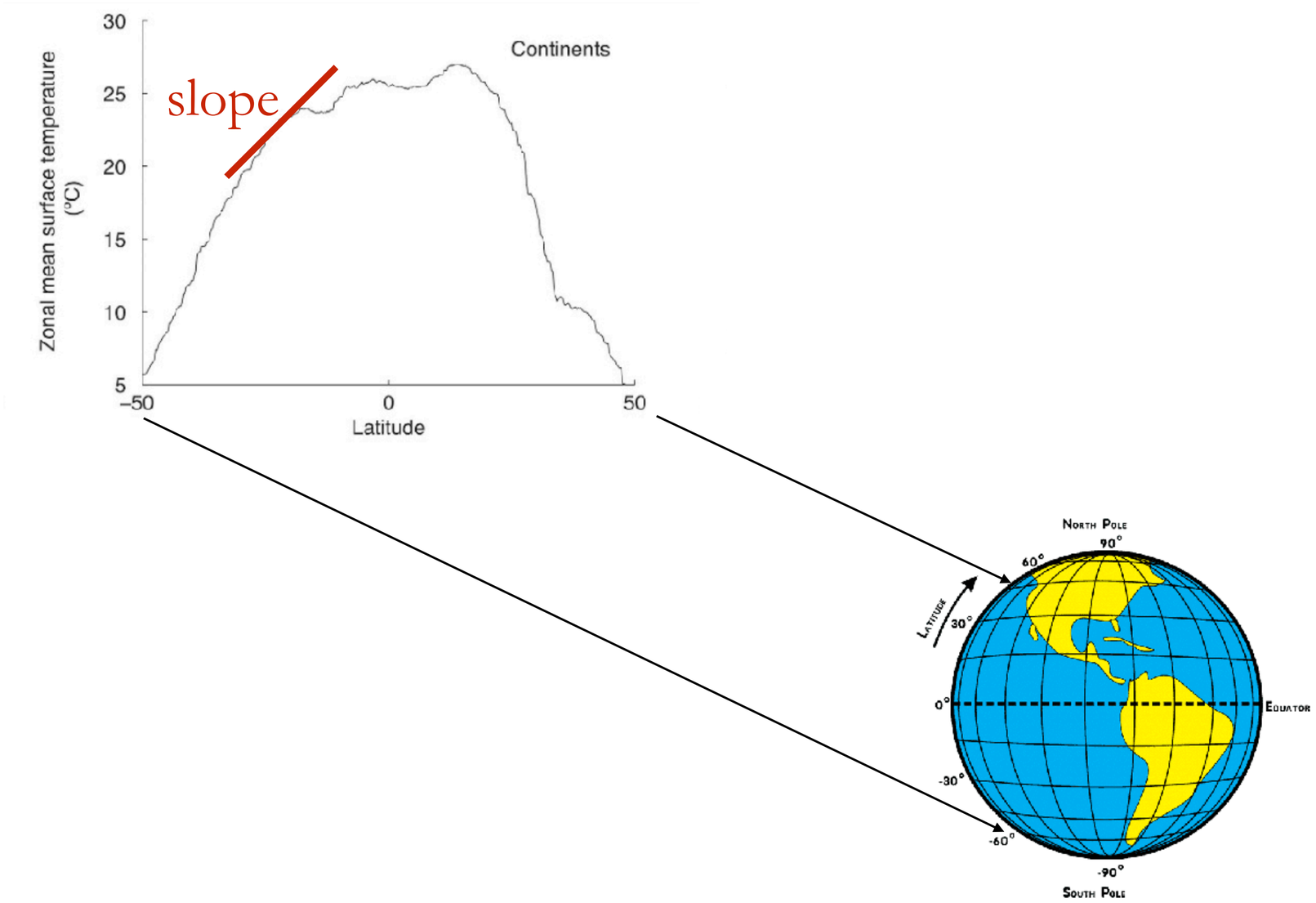

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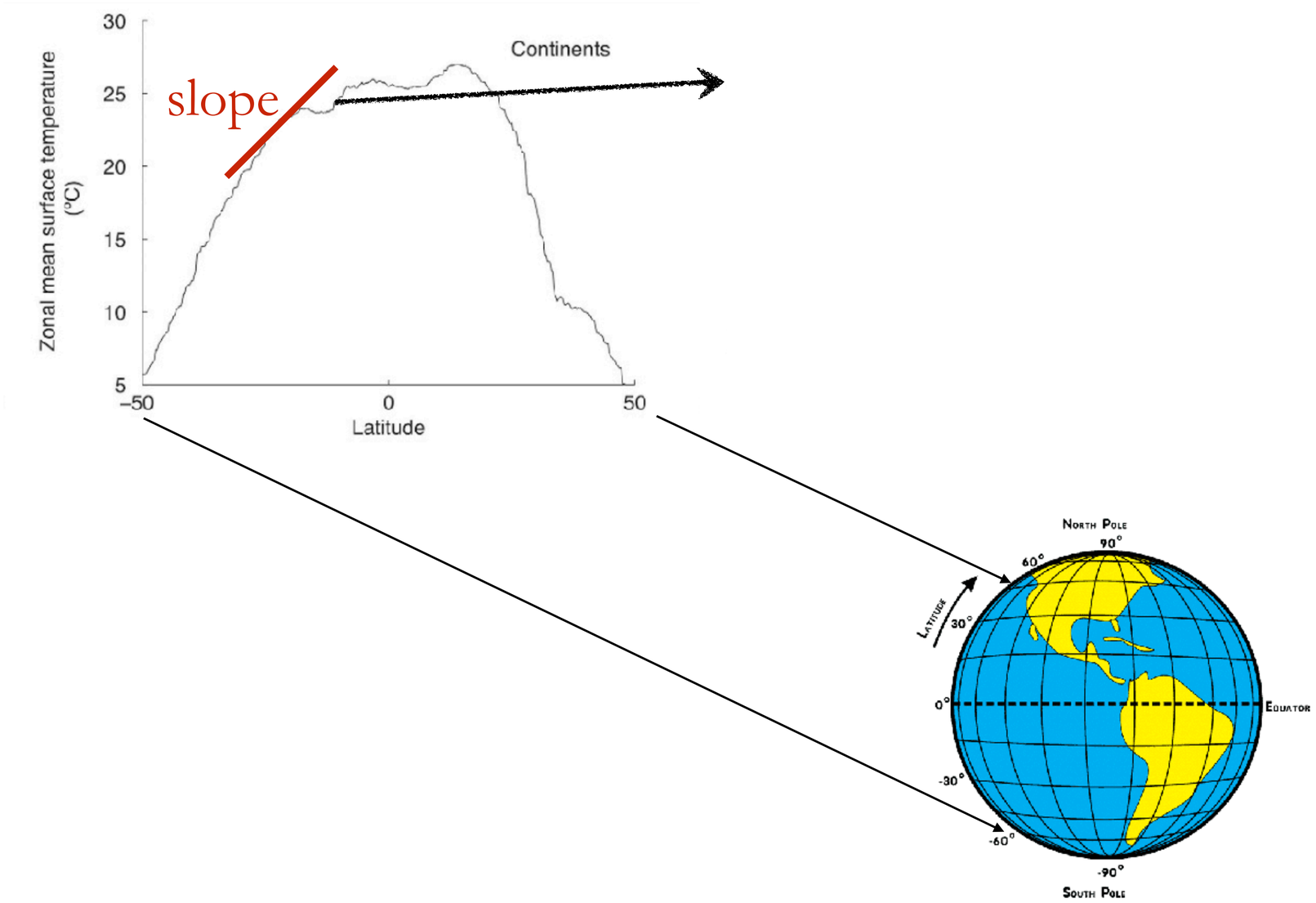

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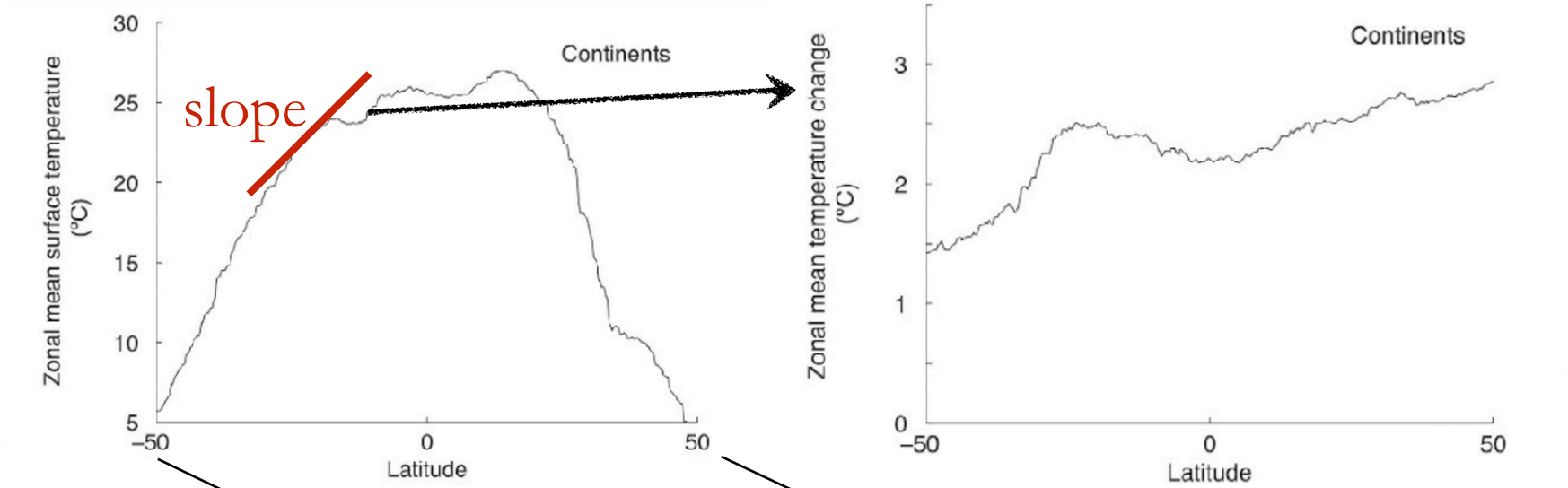

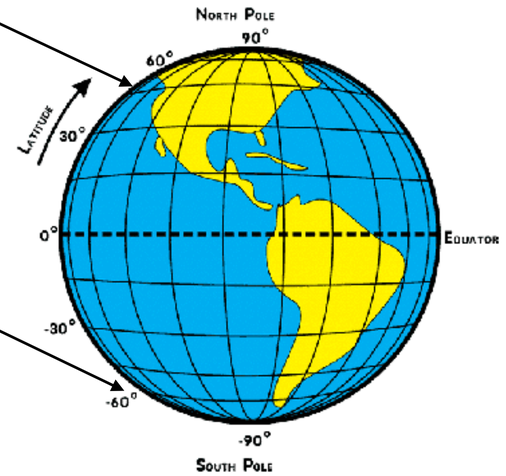

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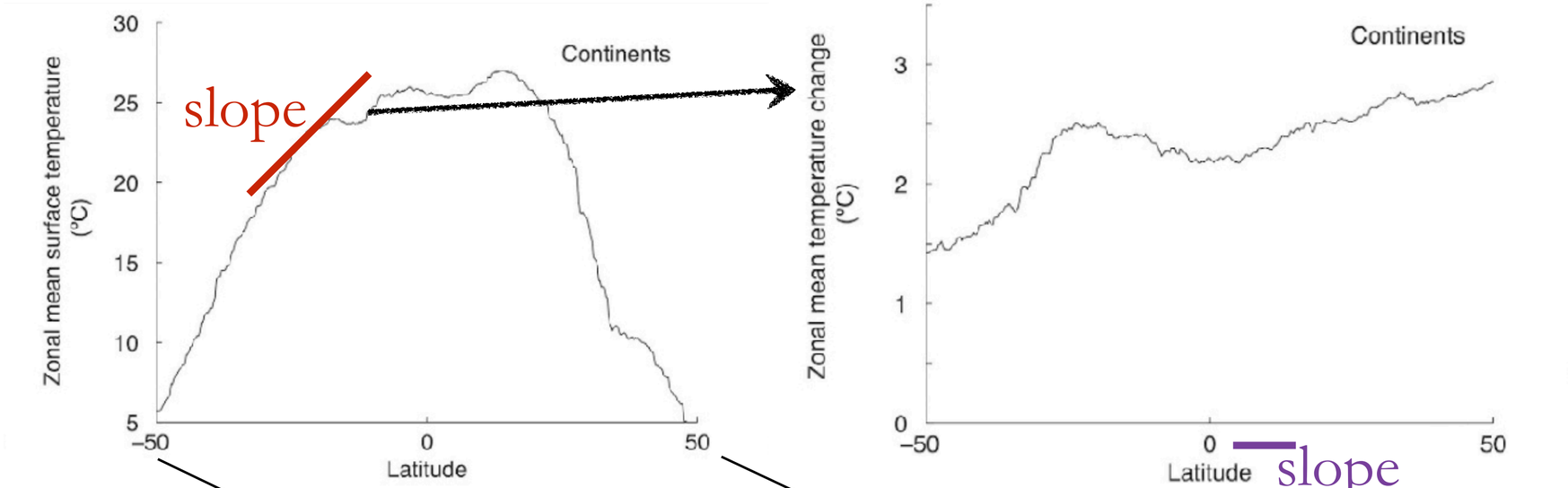

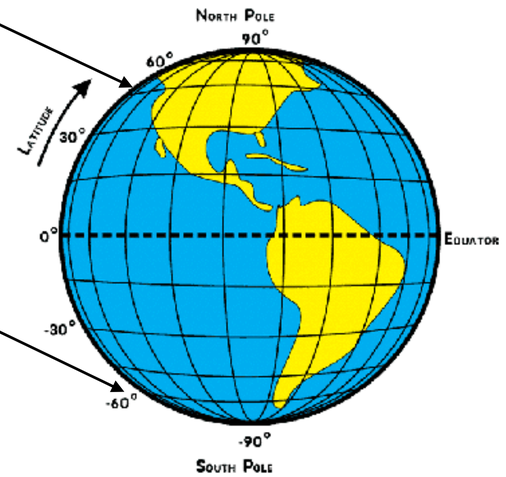

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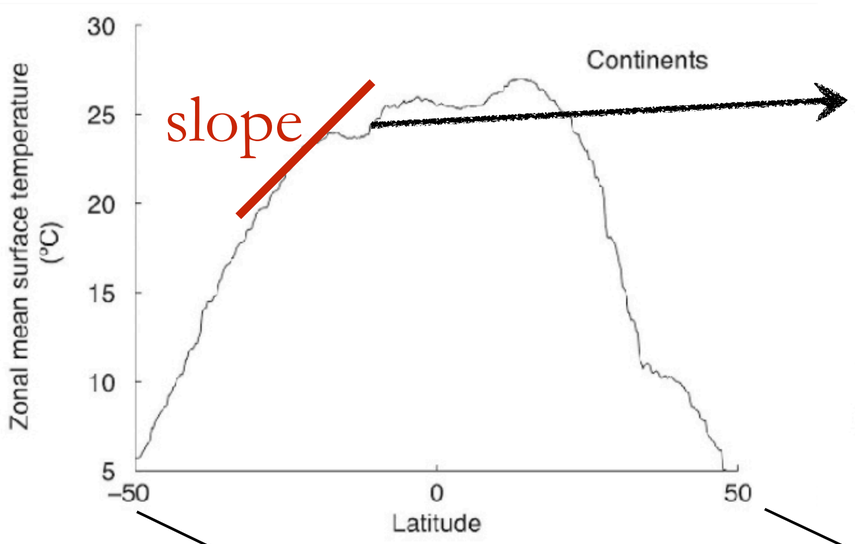

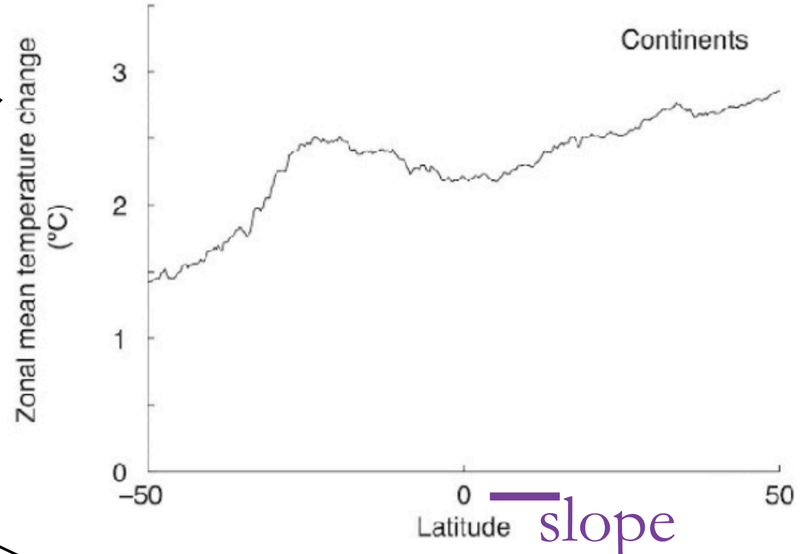

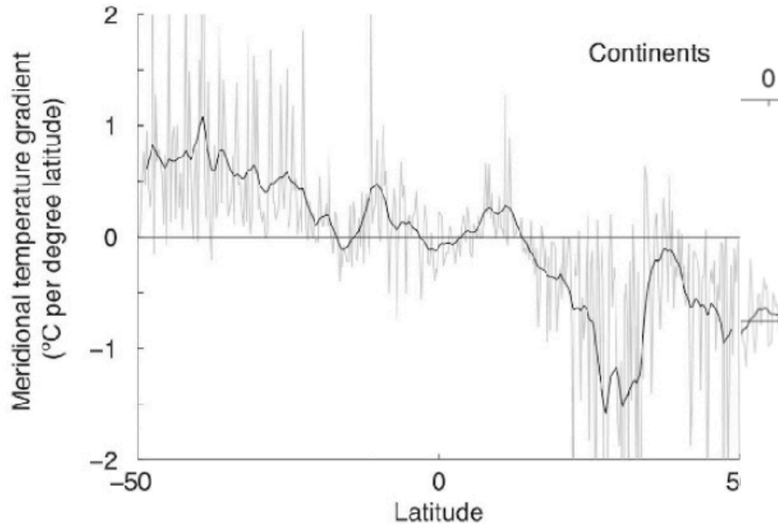

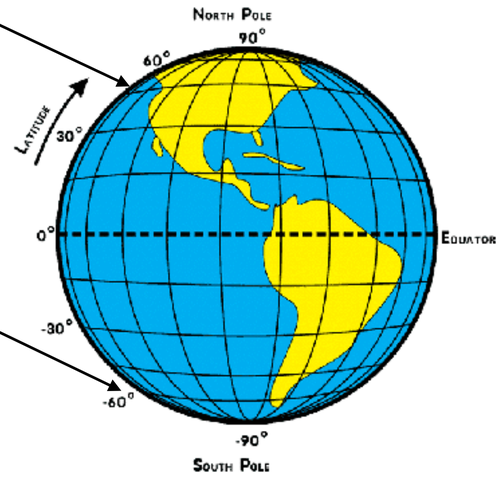

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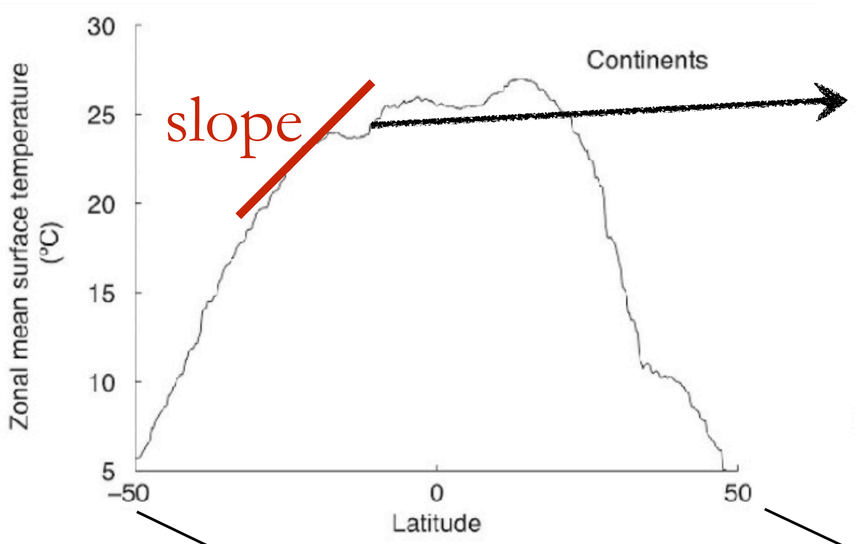

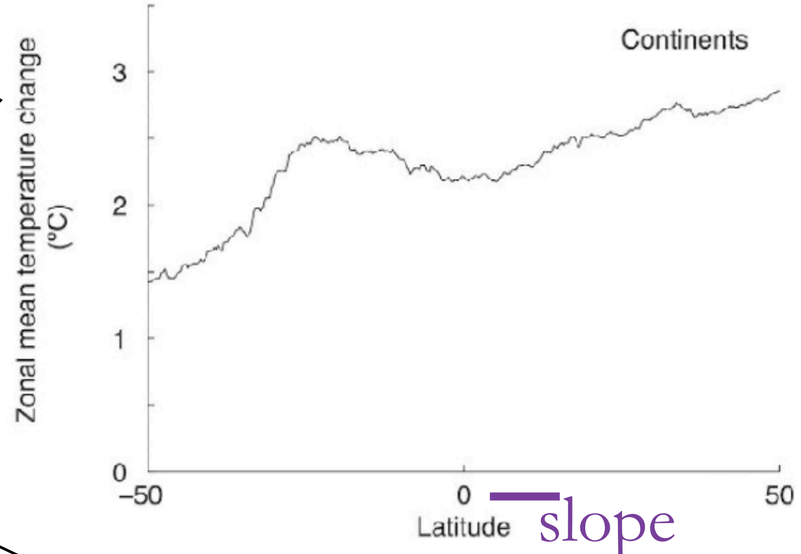

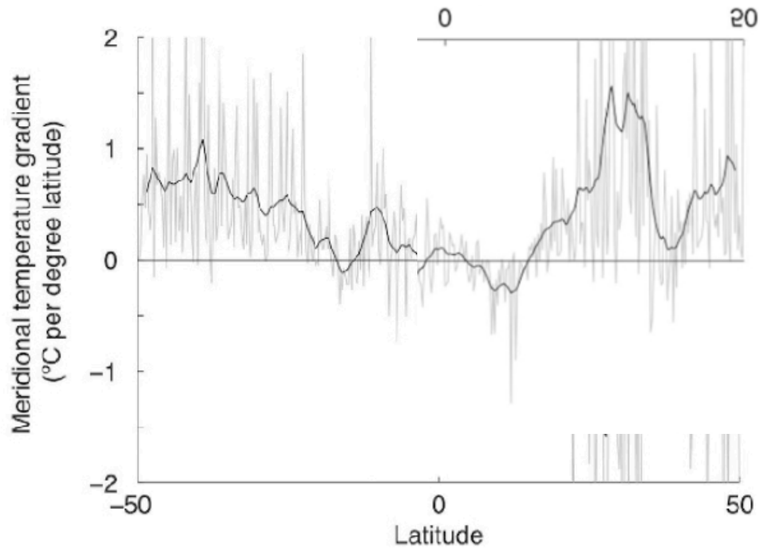

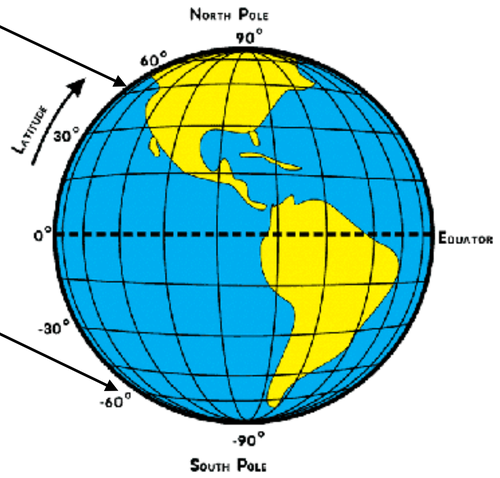

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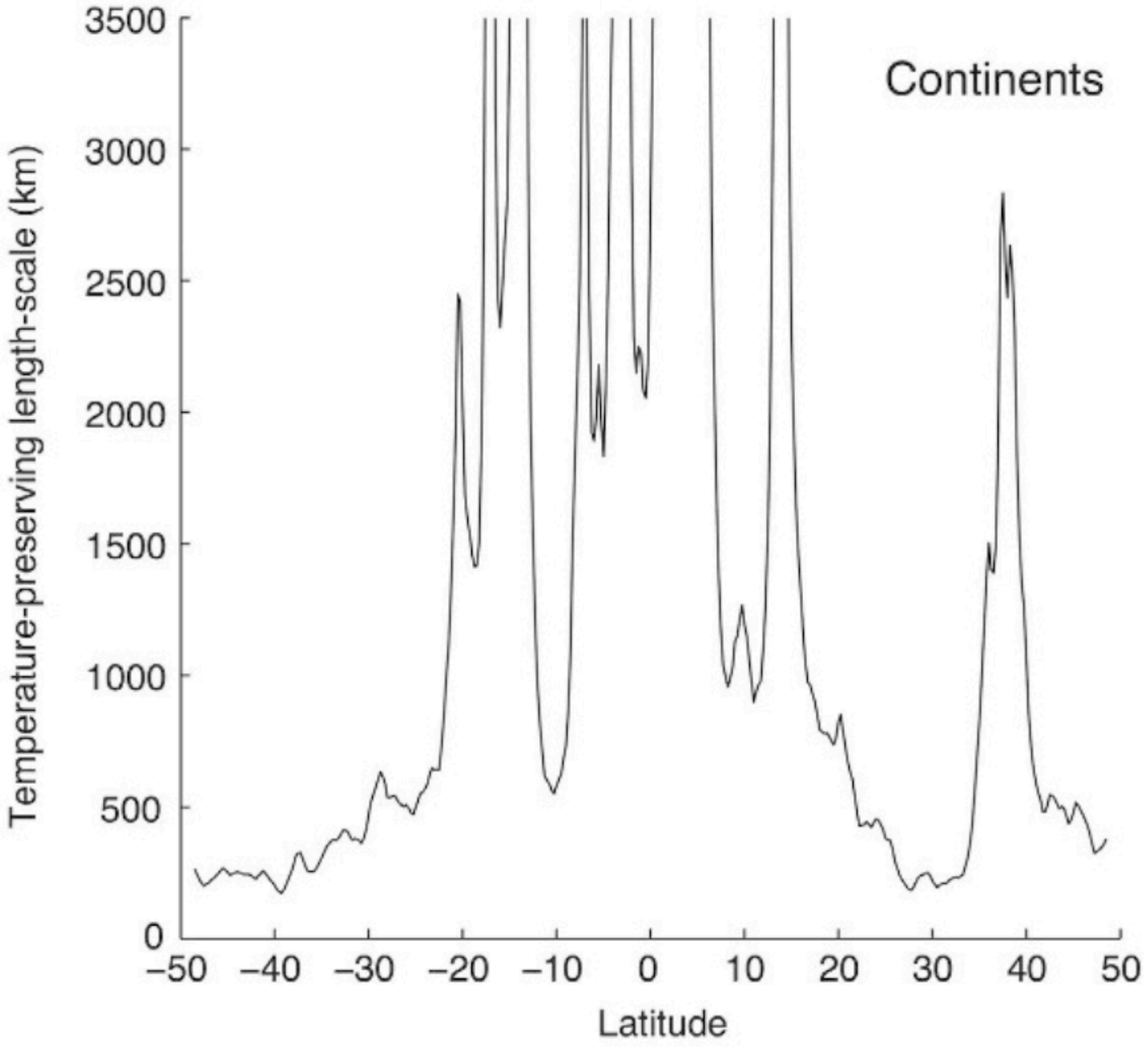

Migration distance to keep the same median temperature (IF we keep to 2C rise globally)

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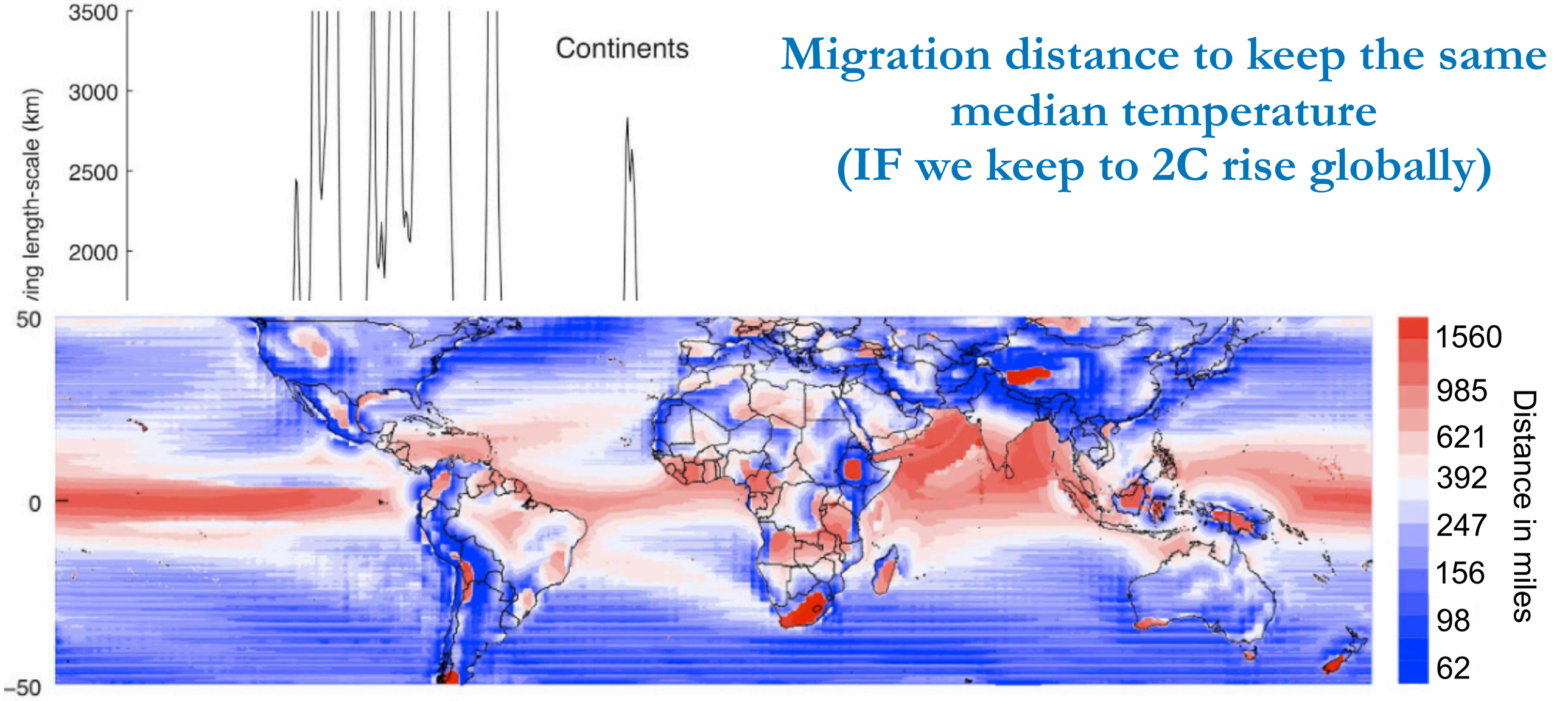
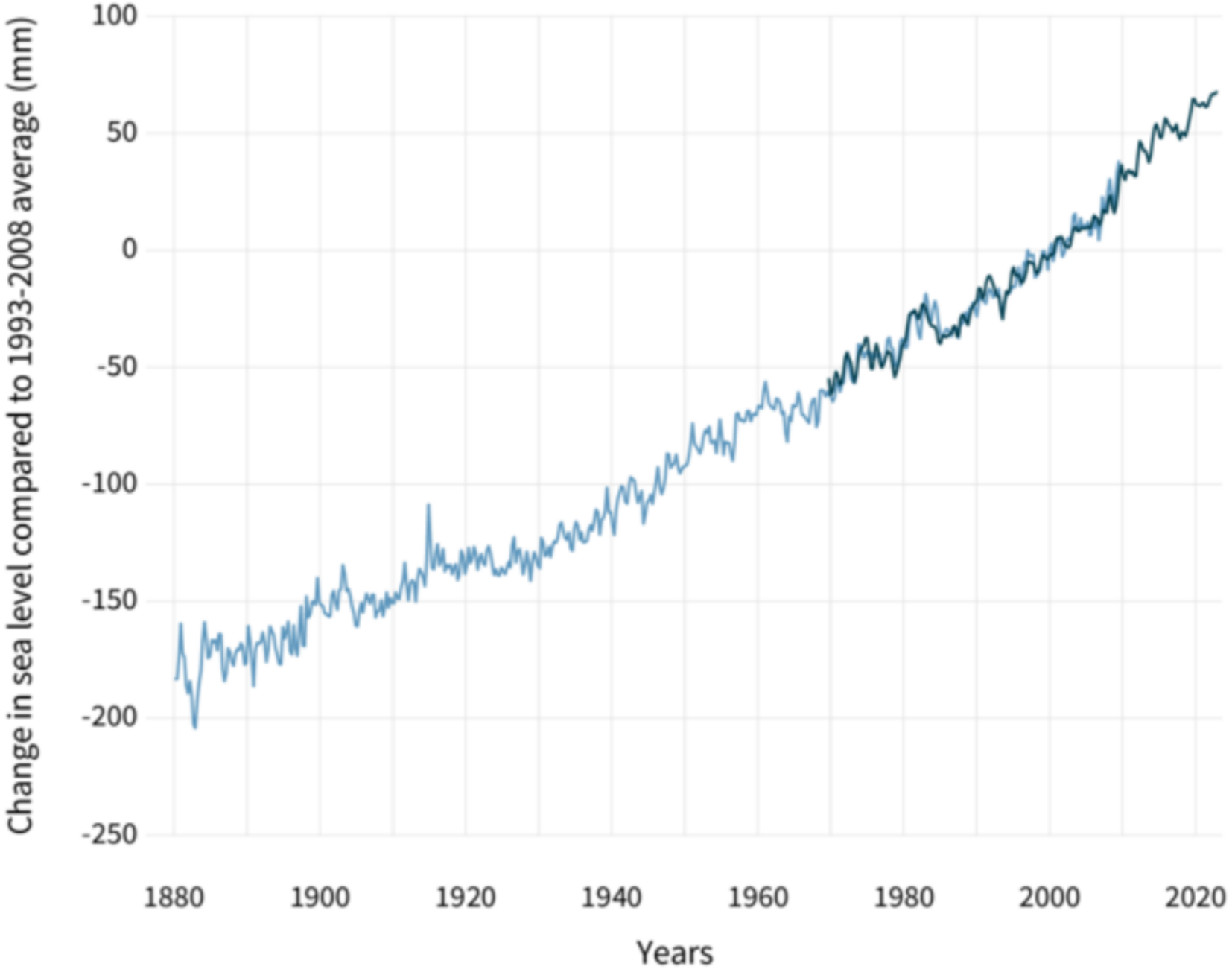


Reference: San Francisco to Fresno = 187 miles

GLOBAL SEA LEVEL



PUBLISHED APRIL 19, 2022

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Old projection for 2050

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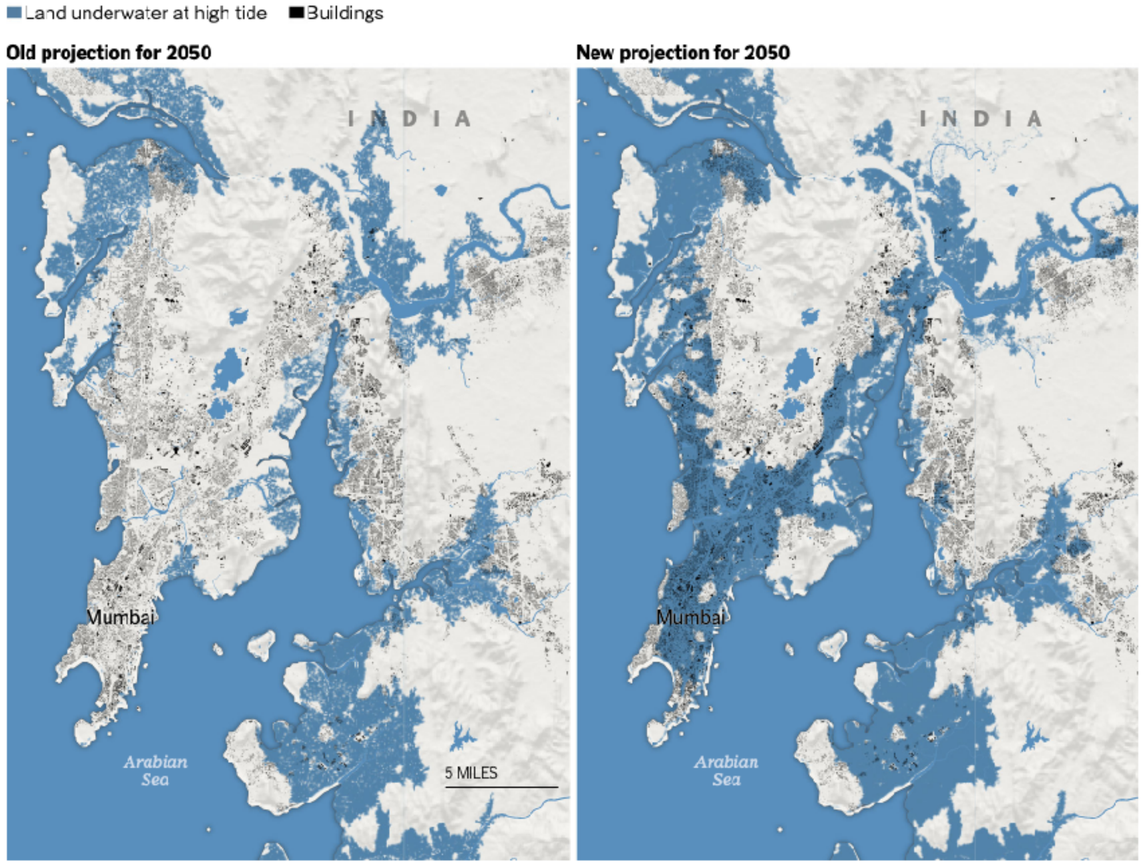

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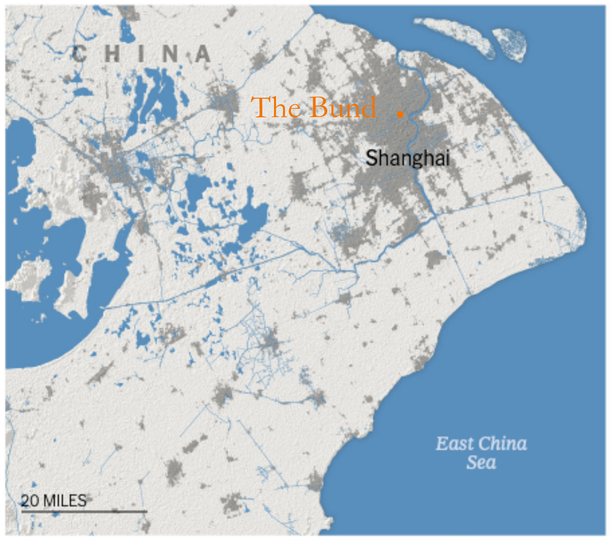
Old projection for 2050



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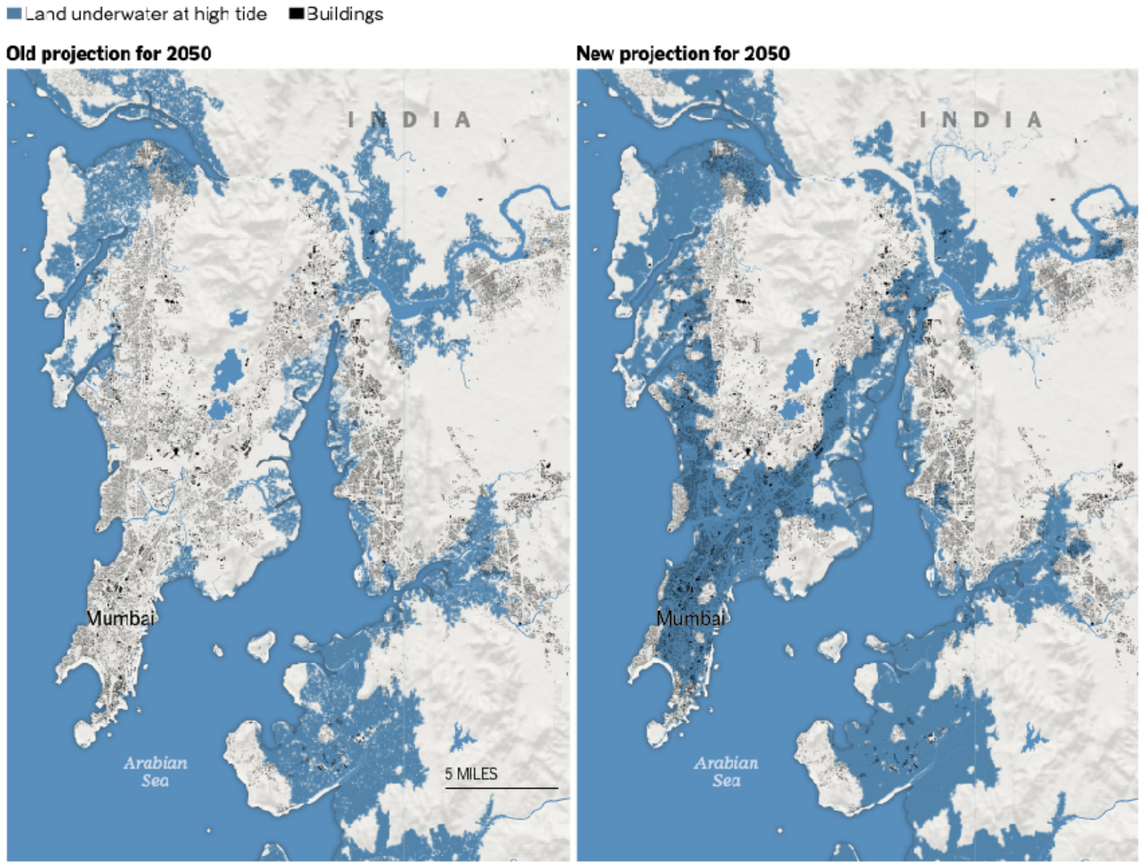

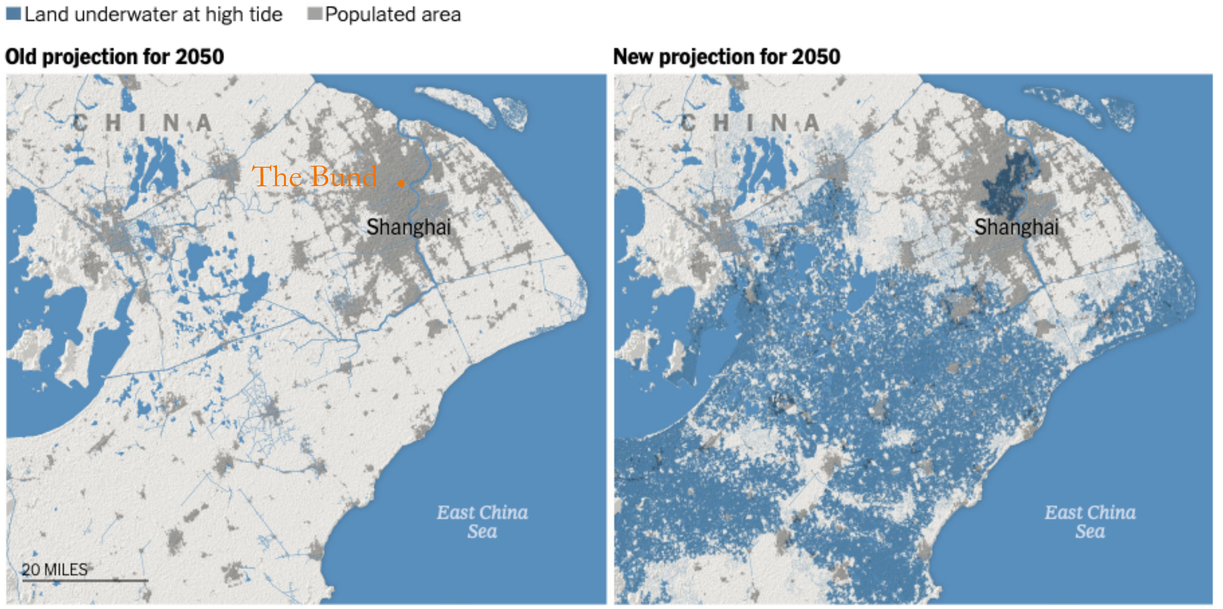

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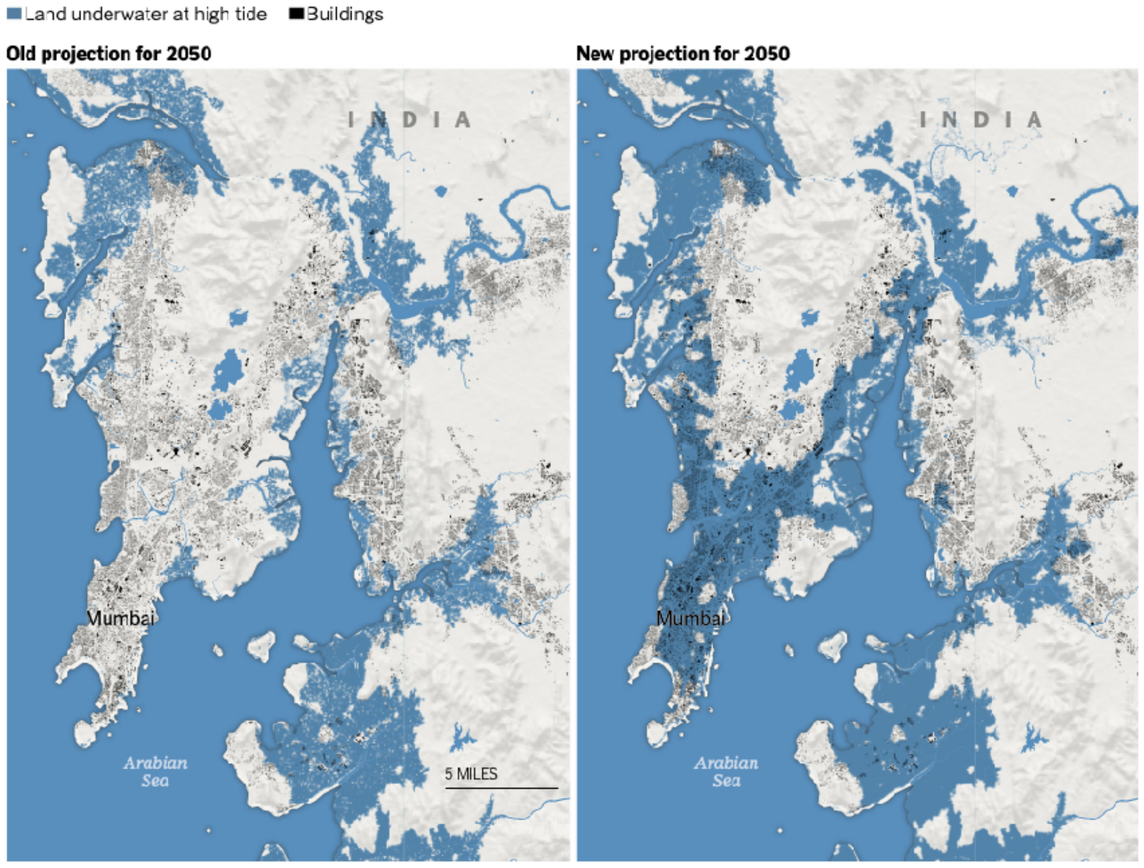

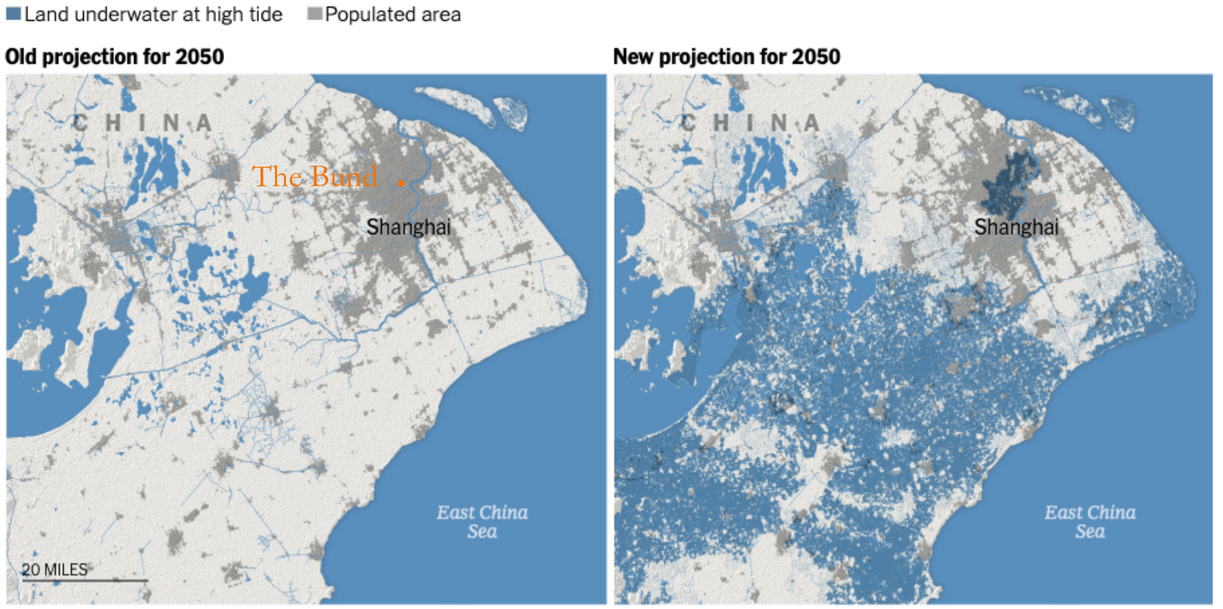

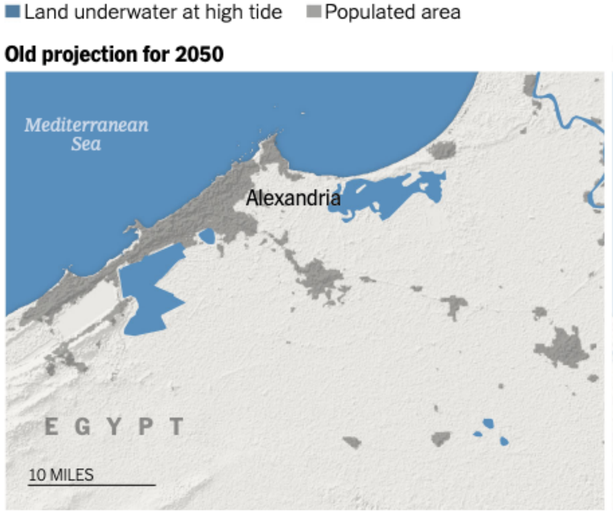

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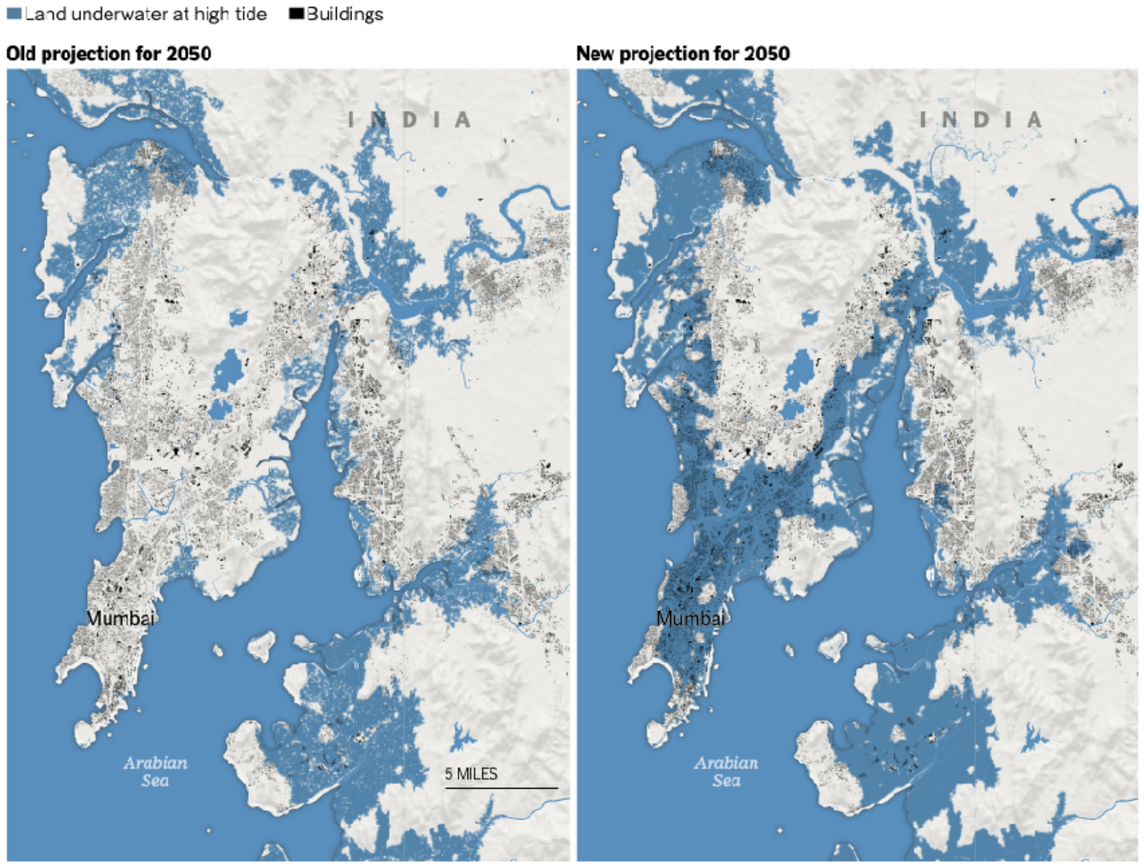

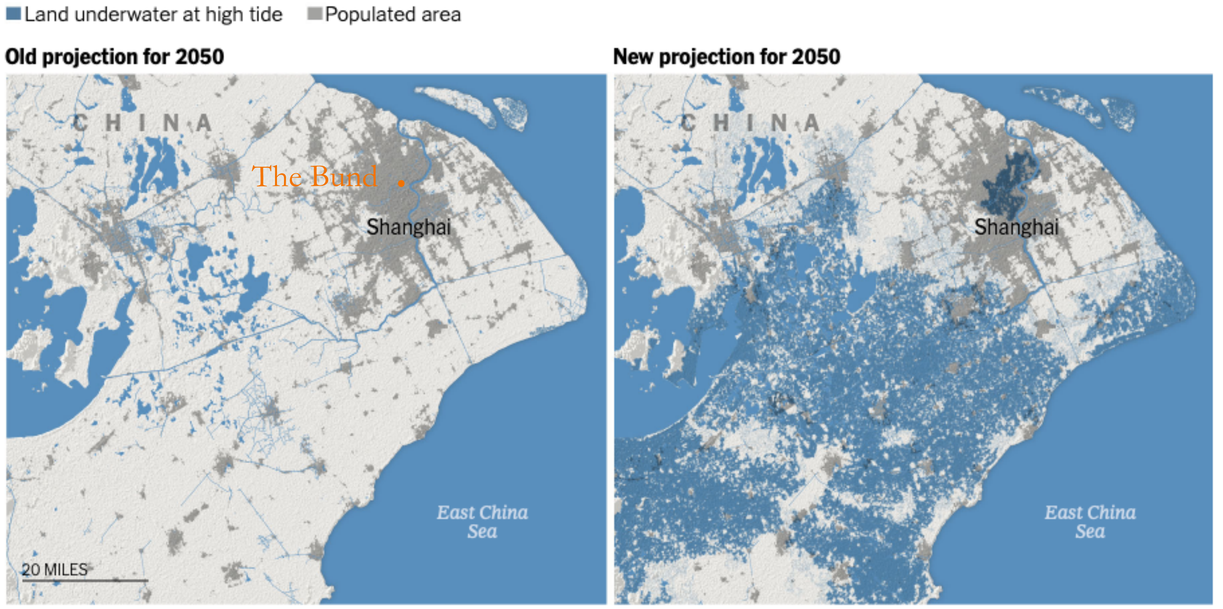

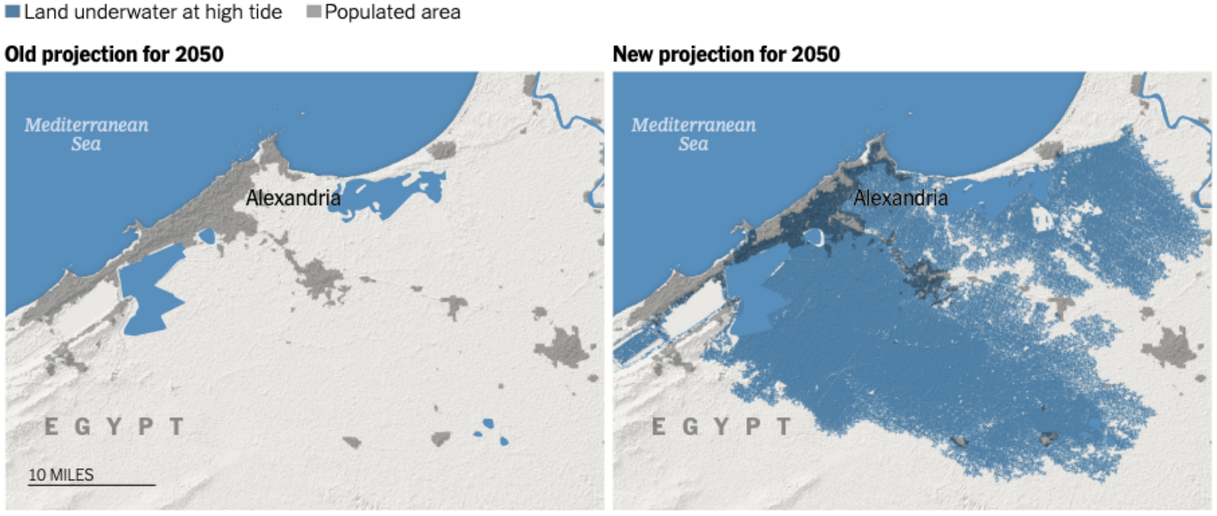

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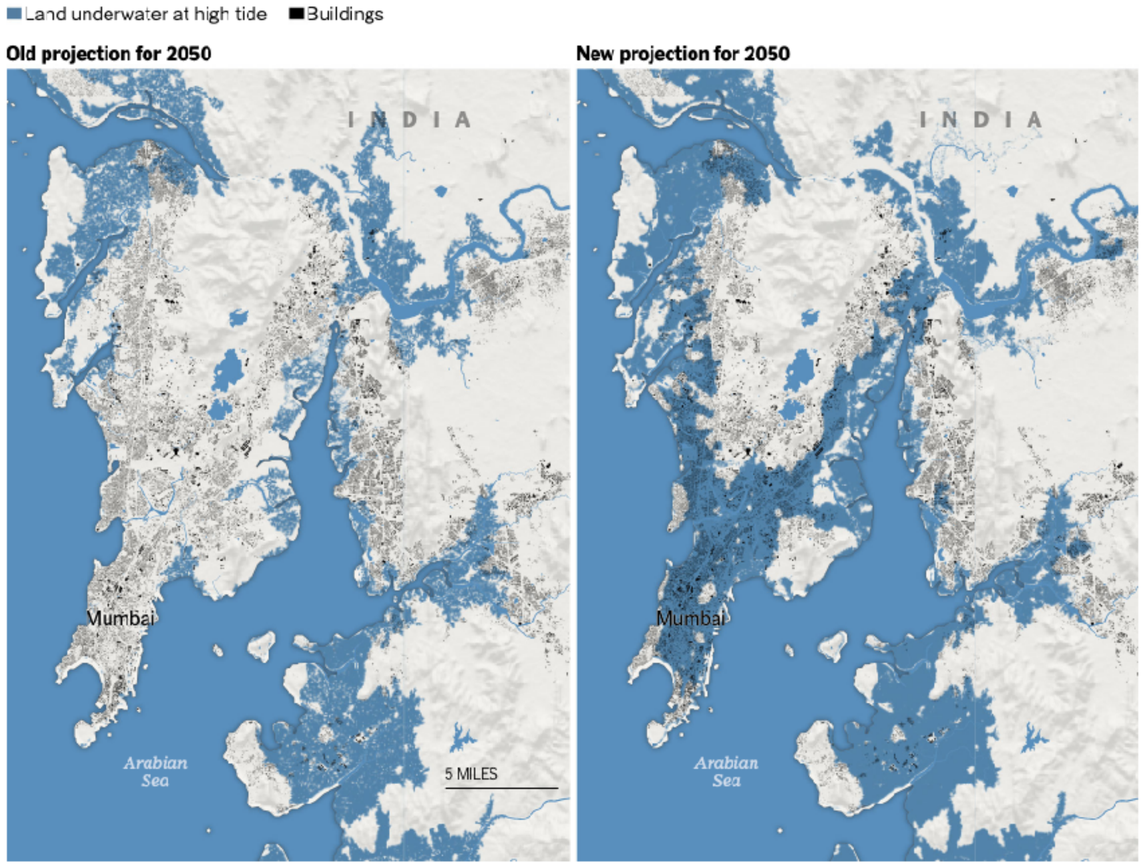

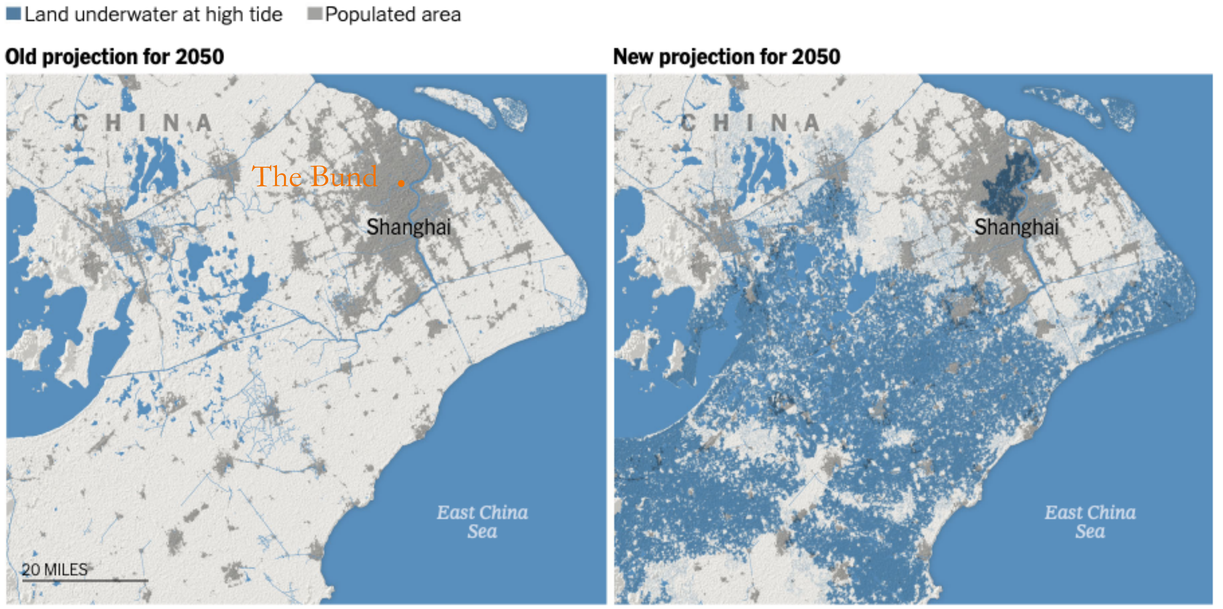

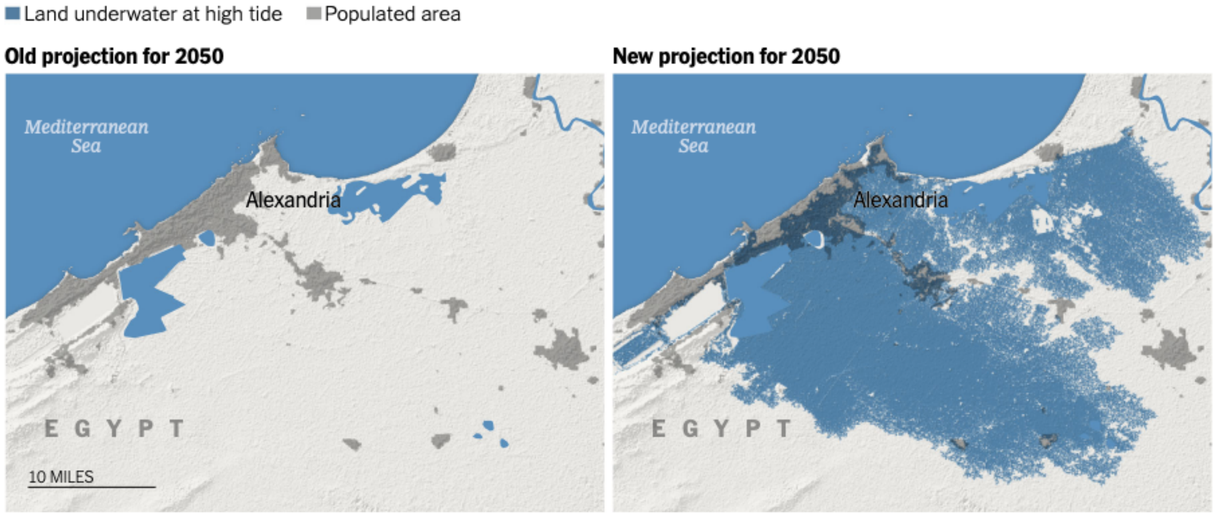

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Shanghai: 28.4 million
Alexandria: 5.6 million

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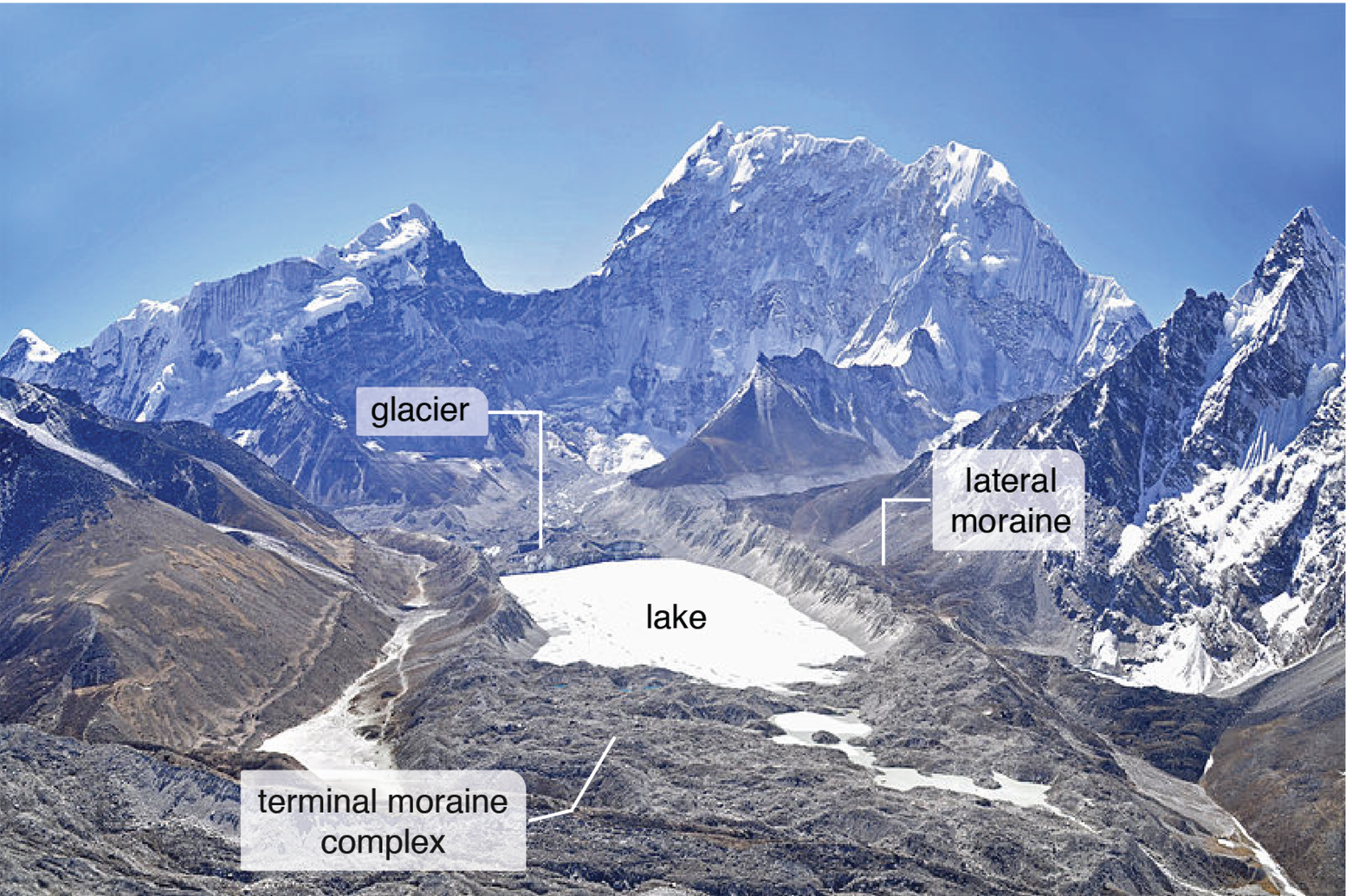
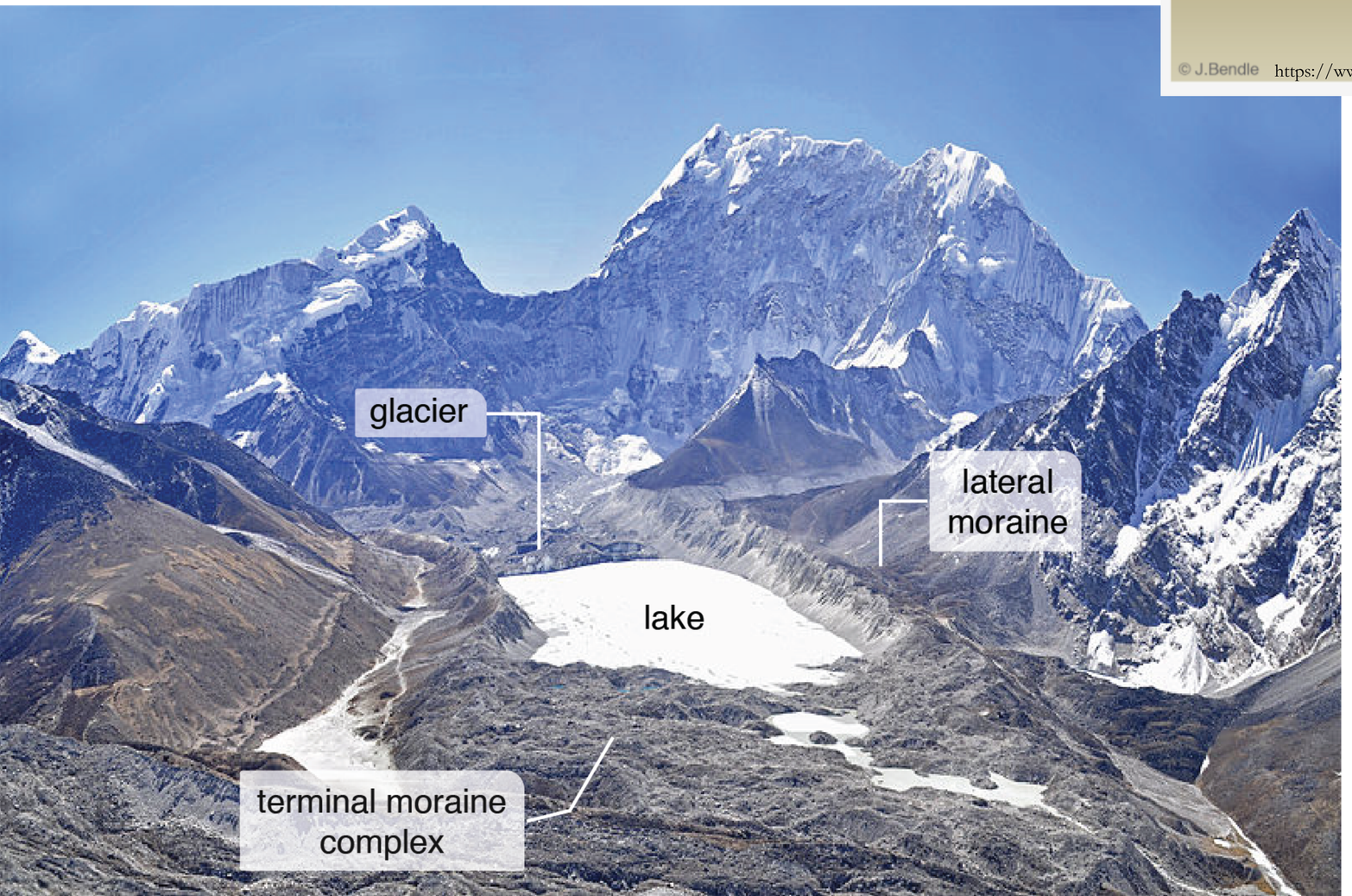
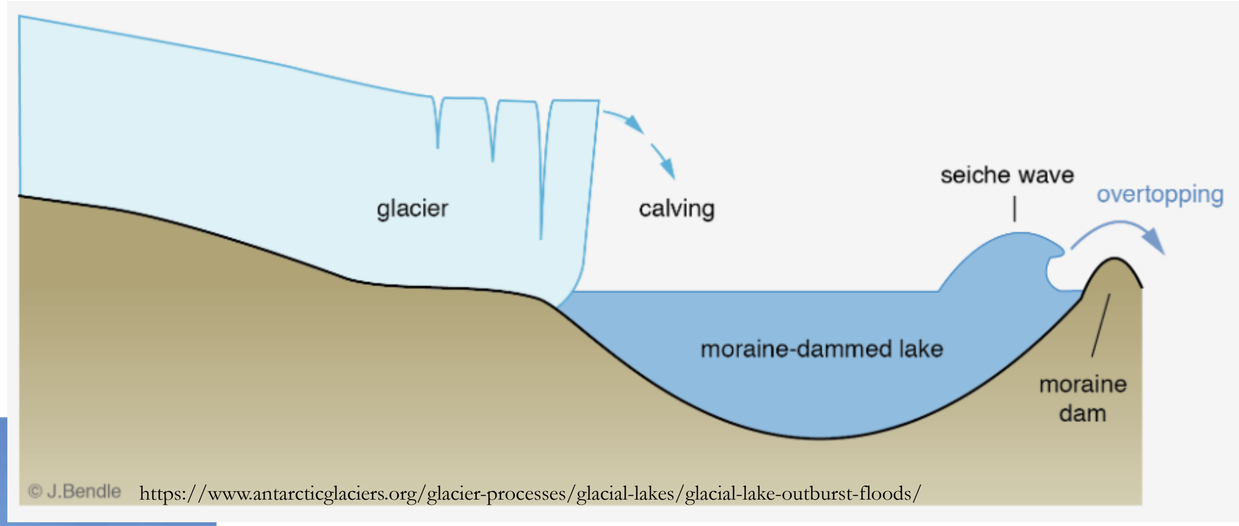
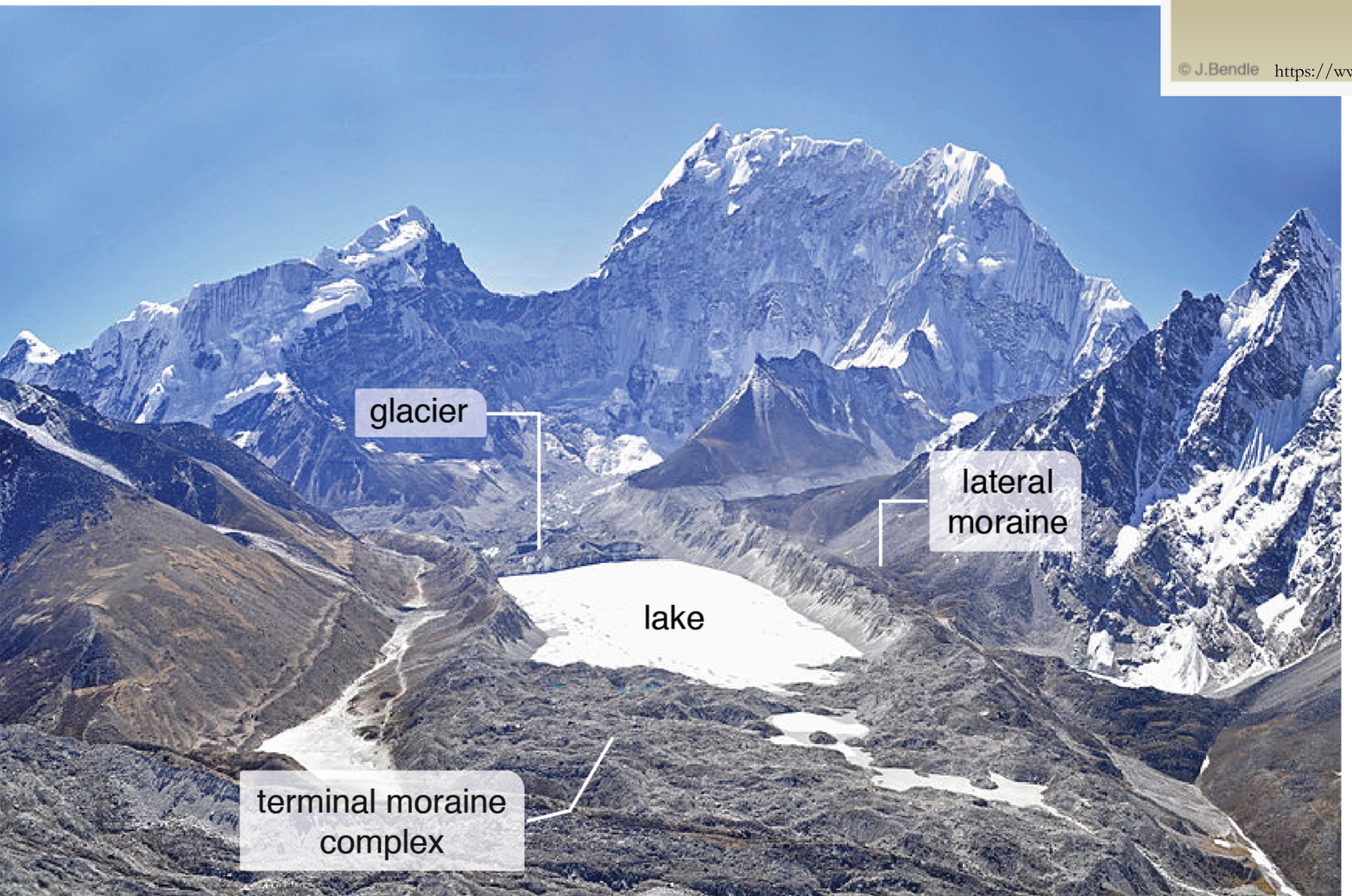
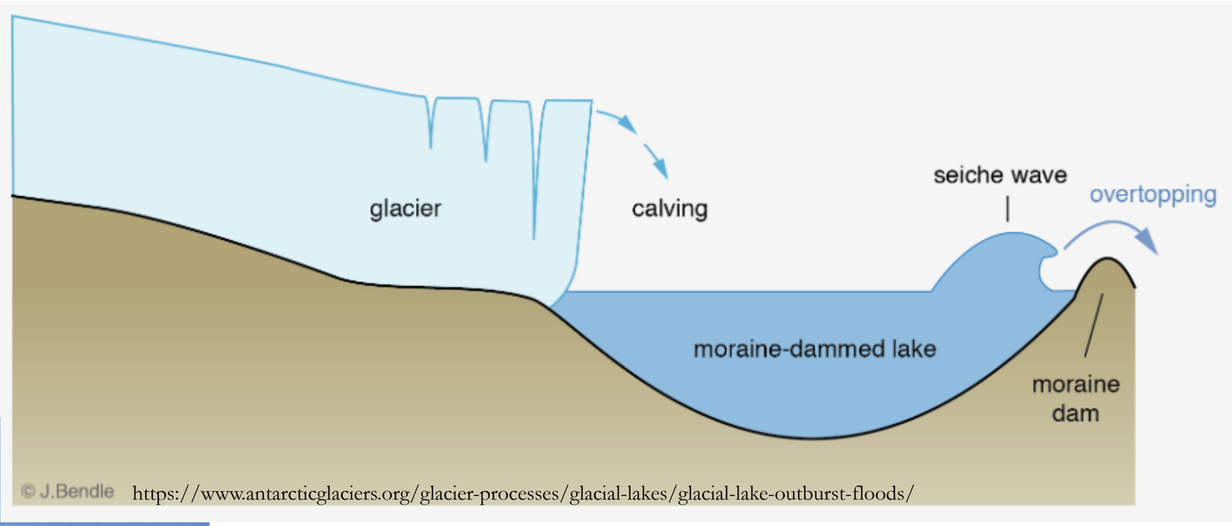

glacier
lateral moraine
lake
terminal moraine complex





https://www.antarcticglaciers.org/glacier-processes/glacial-lakes/glacial-lake-outburst-floods/





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nature communications

Article

https://doi.org/10.1038/s41467-023-36033-x

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Received: 24 February 2022

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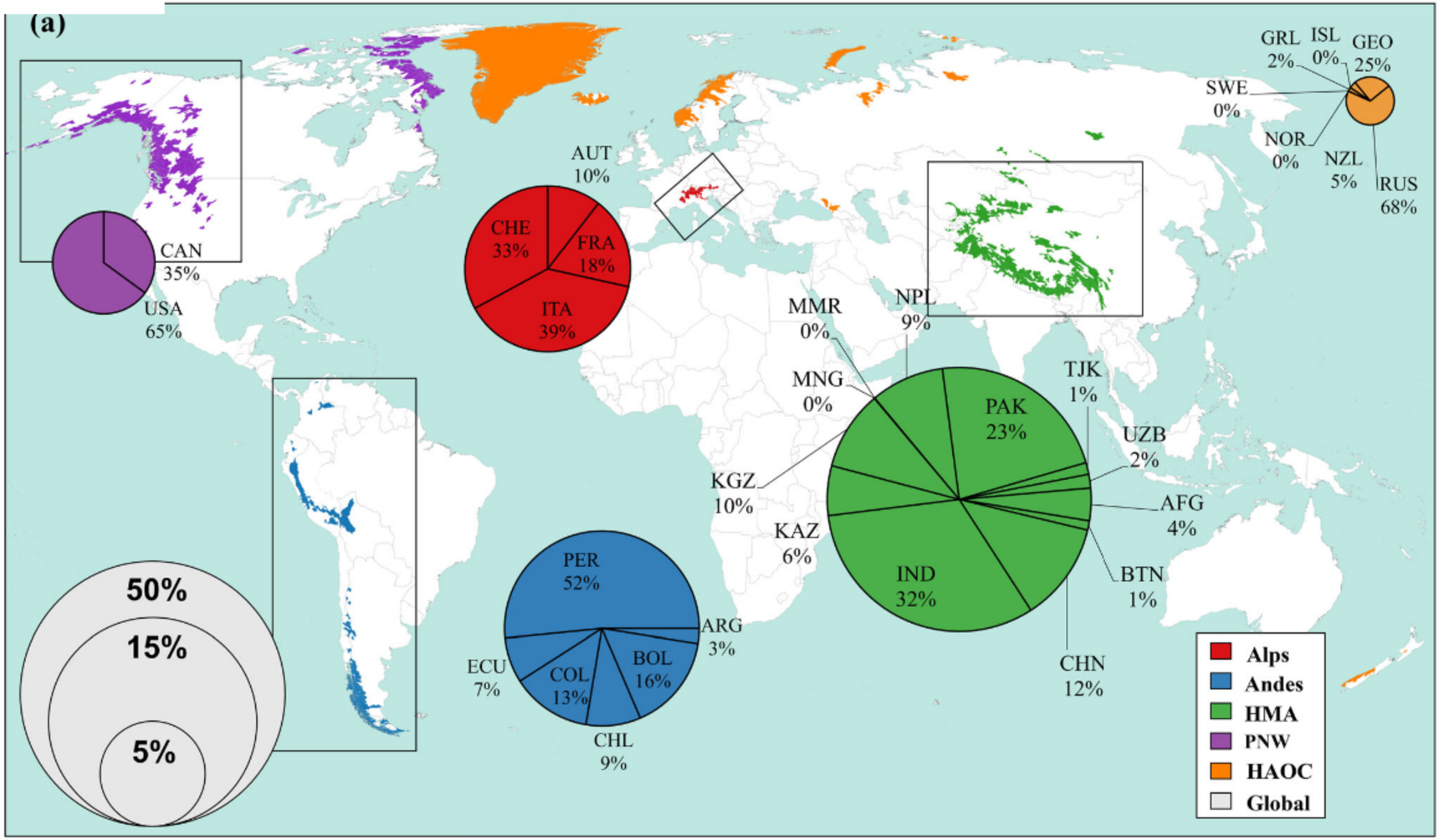

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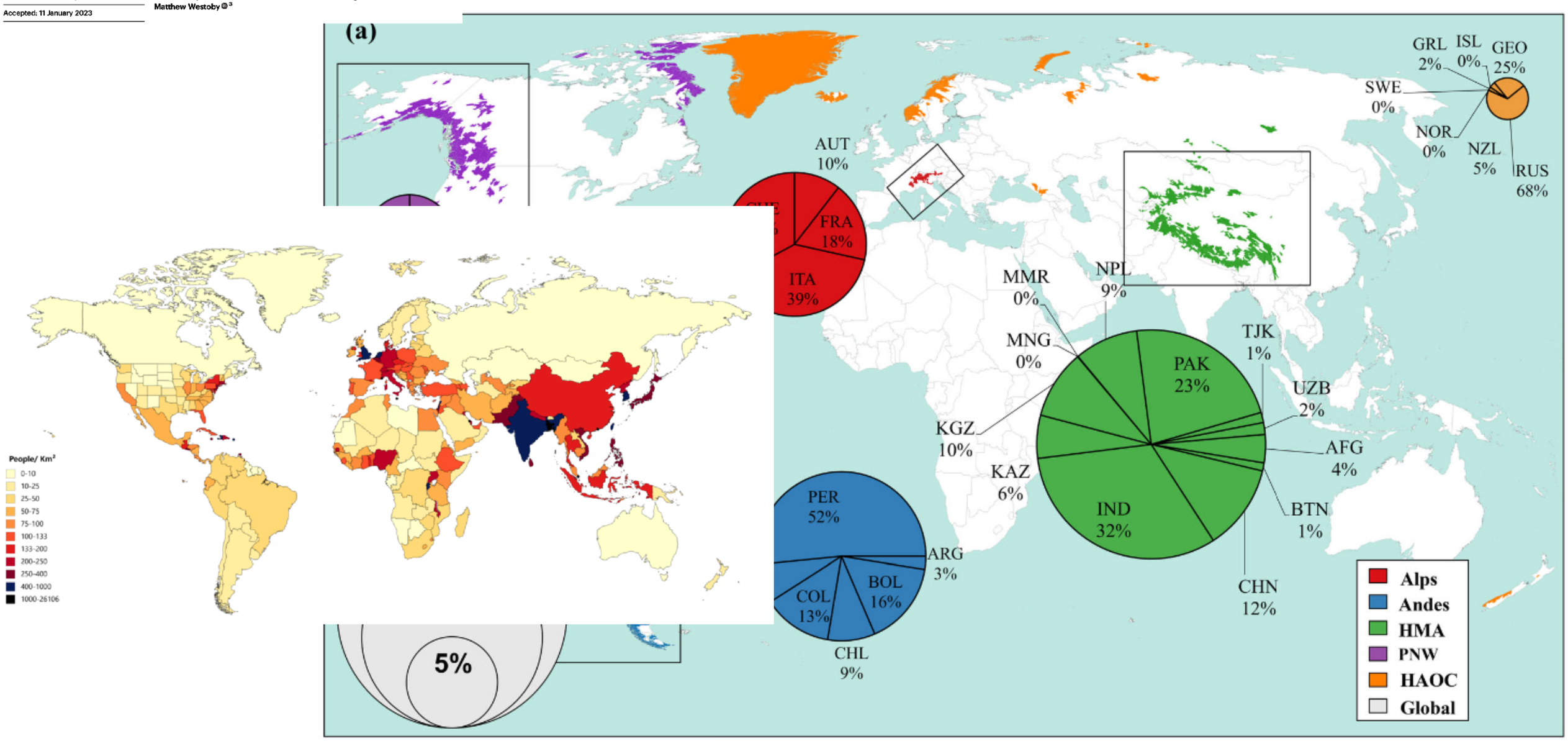

nature communications

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https://doi.org/10.1038/s41467-022-35462-4

Temperature-related mortality in China from specific injury

Received: 4 January 2022

Accepted: 5 December 2022

Published online: 03 January 2023

Check for updates

Jianxiong Hu[1,12], Guanhao He[2,12], Ruilin Meng[3,12], Weiwei Gong[4], Zhoupeng Ren[5], Heng Shi[6], Ziqiang Lin[2], Tao Liu[2], Fangfang Zeng[2], Peng Yin[7], Guoxia Bai[6], Mingfang Qin[8], Zhulin Hou[9], Xiaomei Dong[2], Chunliang Zhou[10], Zhuoma Pingcuo[6], Yize Xiao[8], Min Yu[4], Biao Huang[9], Xiaojun Xu[3], Lifeng Lin[3], Jianpeng Xiao[1], Jieming Zhong[4], Donghui Jin[10], Qinglong Zhao[9], Yajie Li[6], Cangjue Gama[6], Yiqing Xu[10], Lingshuang Lv[10], Weilin Zeng[1], Xing Li[1], Liying Luo[1], Maigeng Zhou[7], Cunrui Huang[11] & Wenjun Ma[2]

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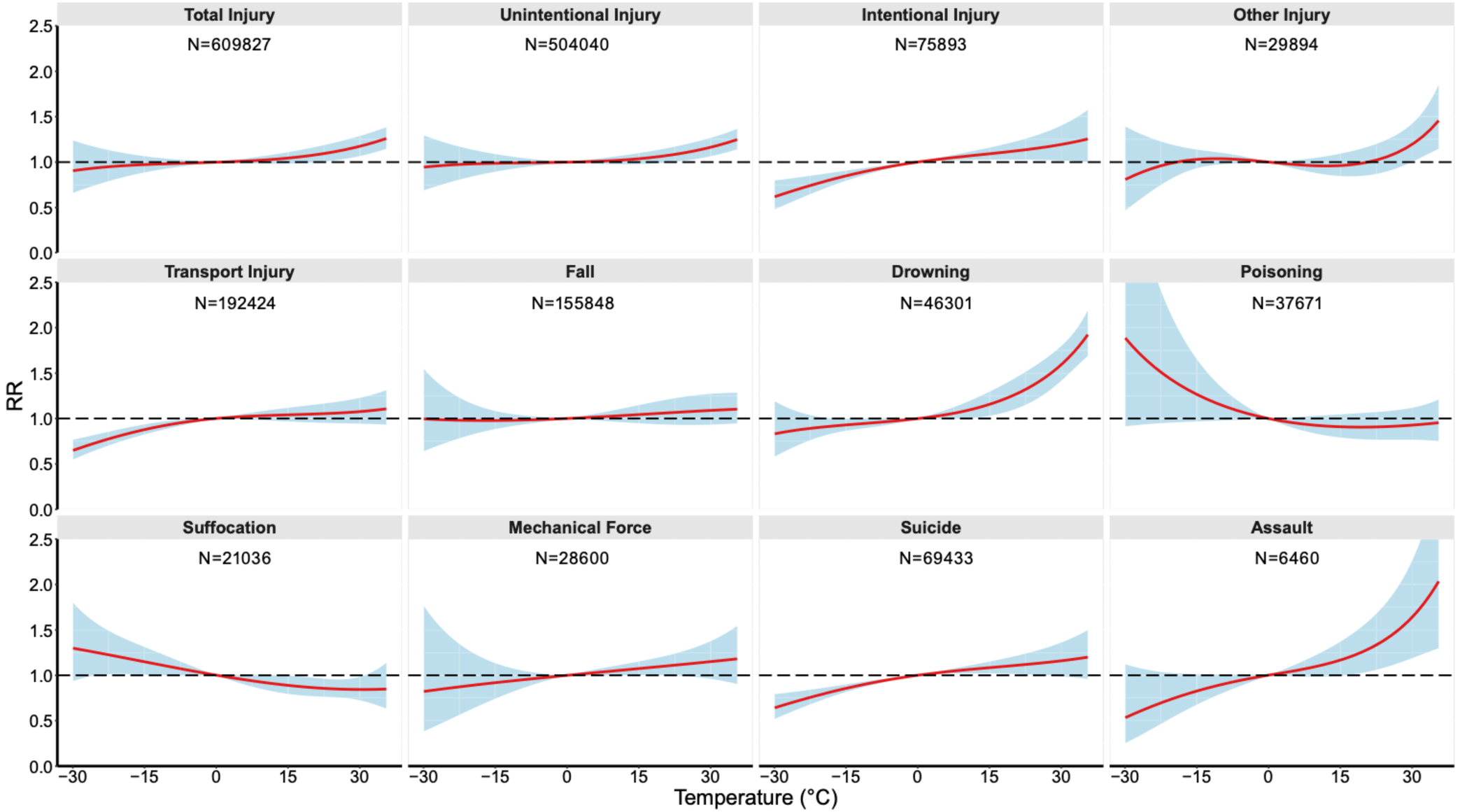

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Additional deaths due to climate change….

nature communications

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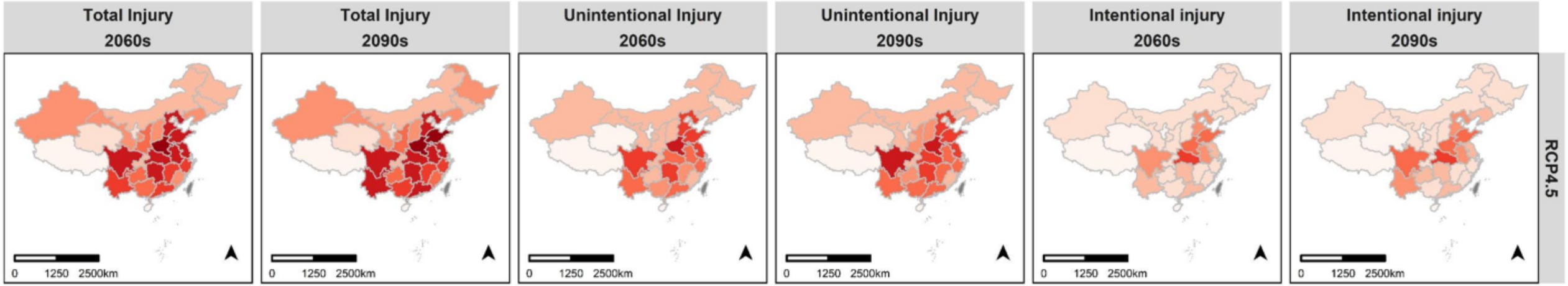

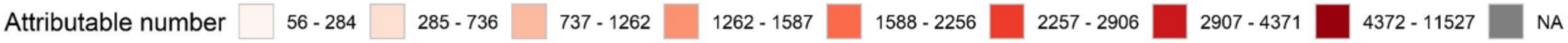

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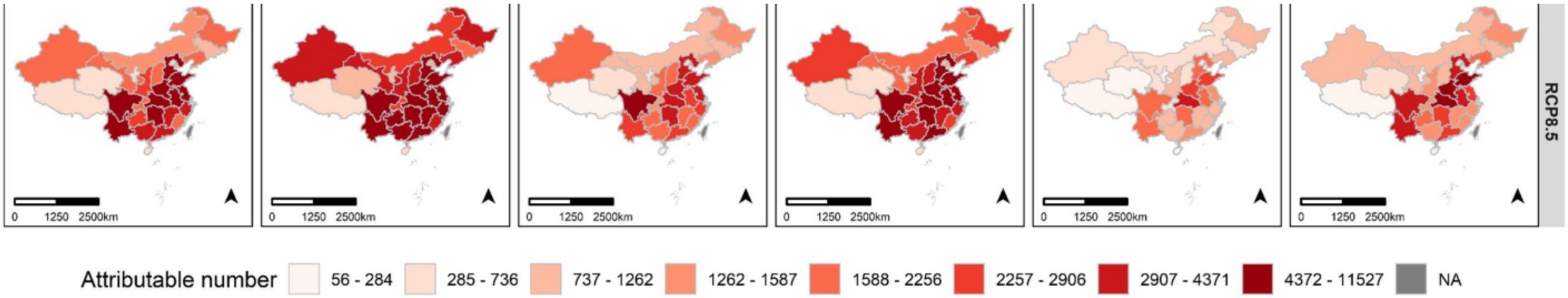

Summary

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- Average temperatures: **rising**
- Inequality: **rising**
- Sea level: **rising, flooding**
- Glaciers: **retracting, flooding**
- Behavior: **changing: violence, migration**
- Ice on the arctics: **declining**
- Extreme weather: **increasing**
- Biological consequences would take another seminar!

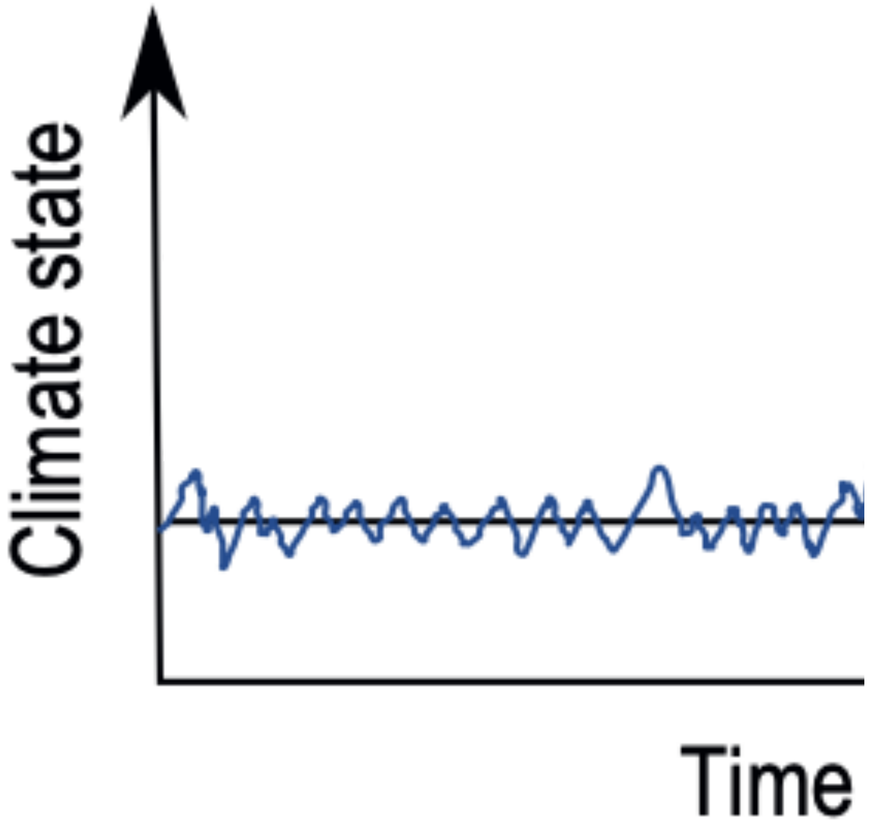
There are urgent consequences

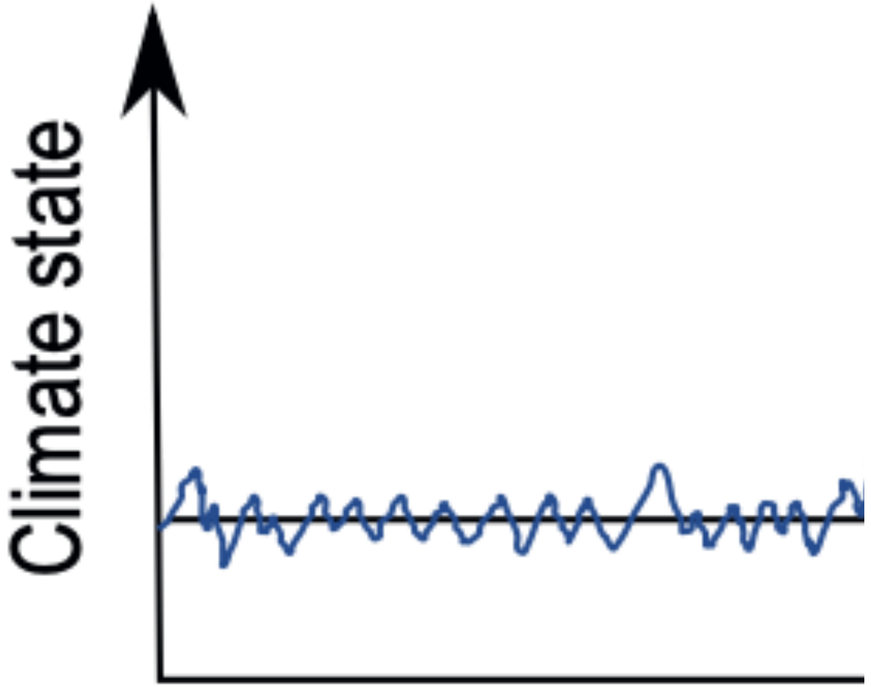
“What keeps you up at night?”

….

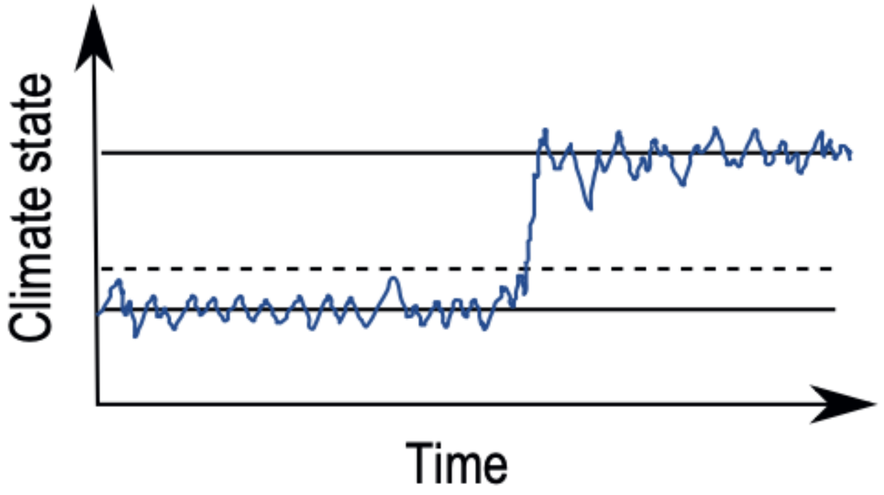
calculus

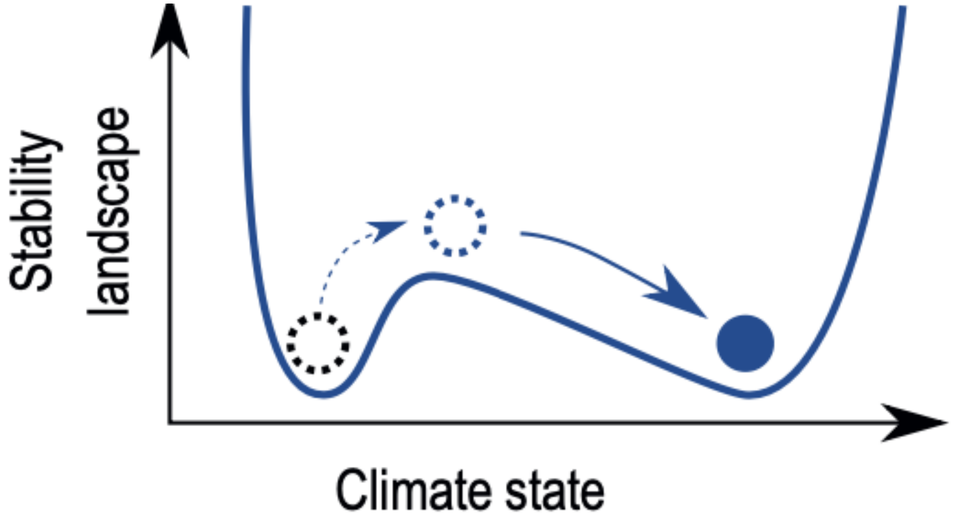
….

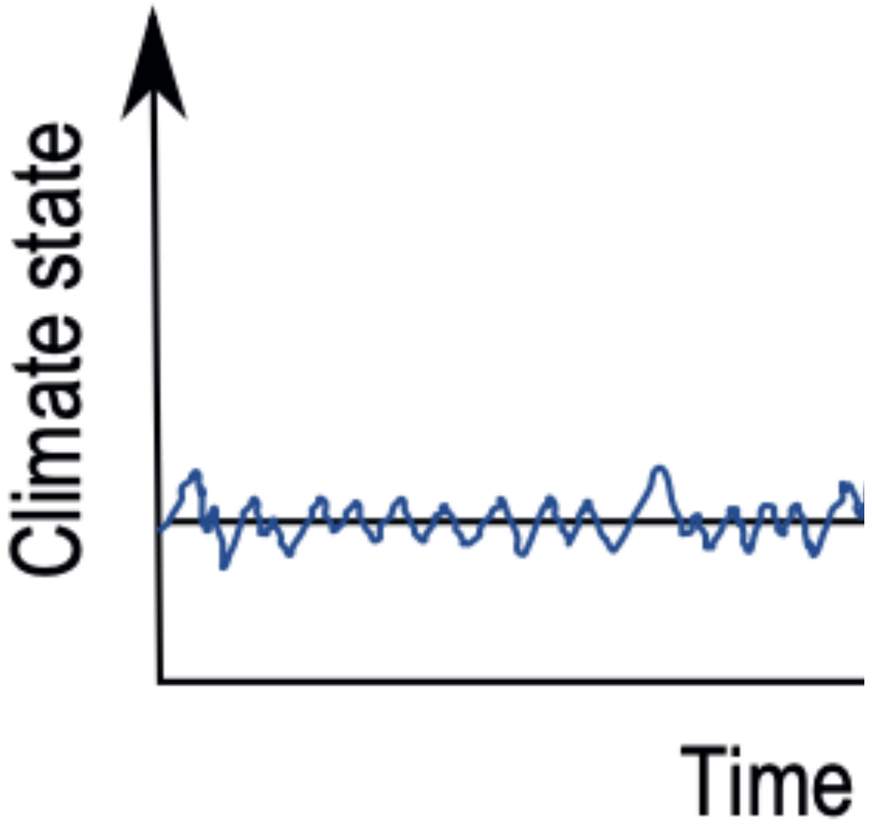

Climate state
Time



noise-induced tipping events…
for instance drought events causing sudden dieback of the Amazon rainforest….



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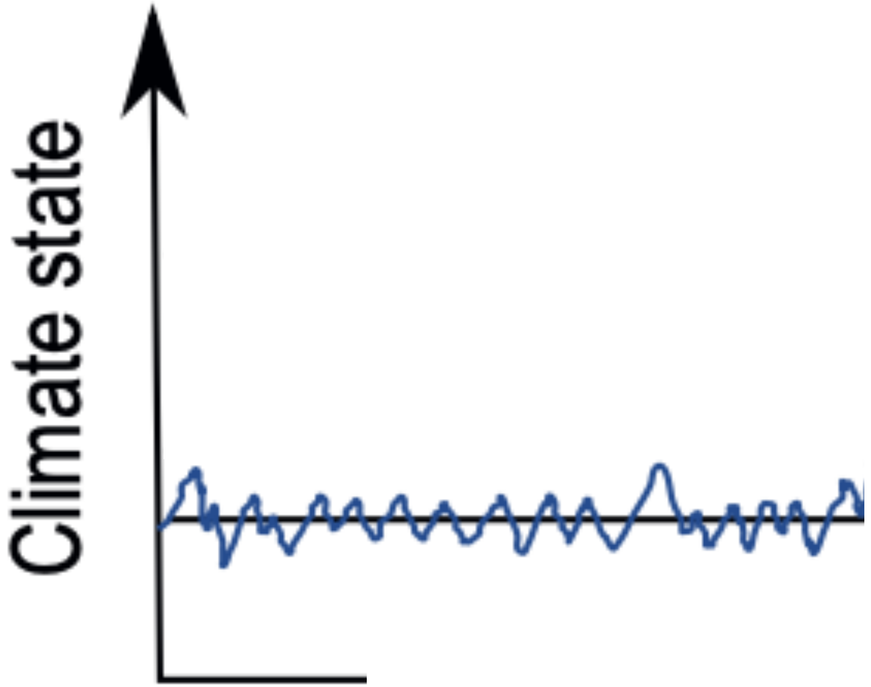
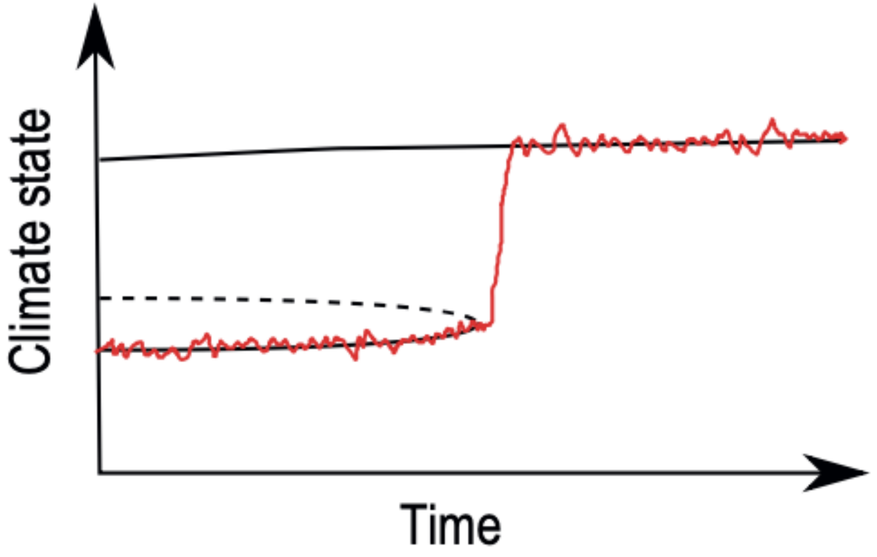
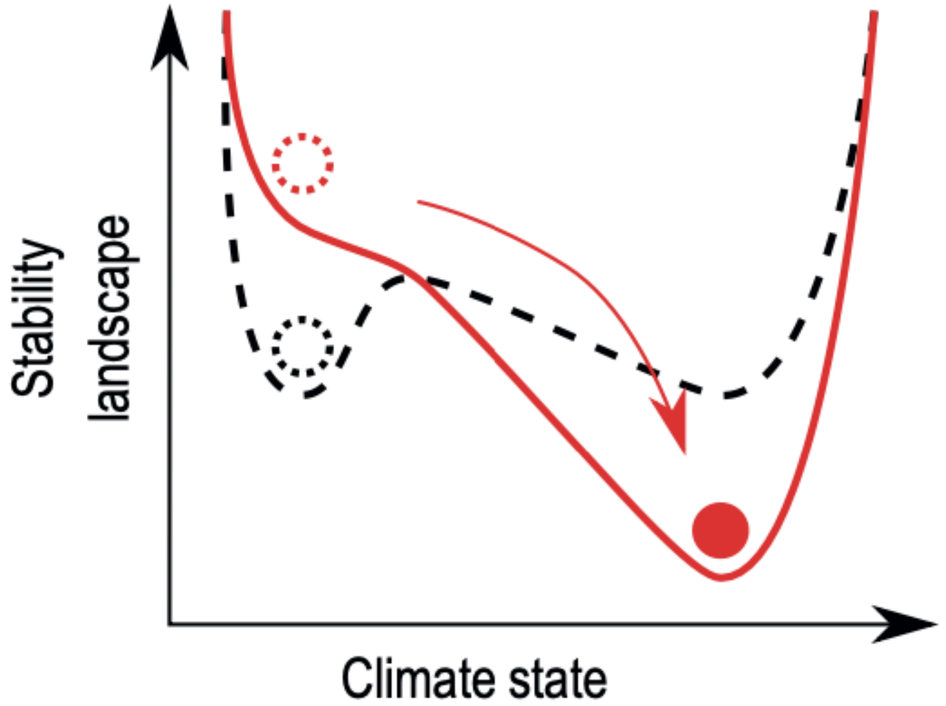


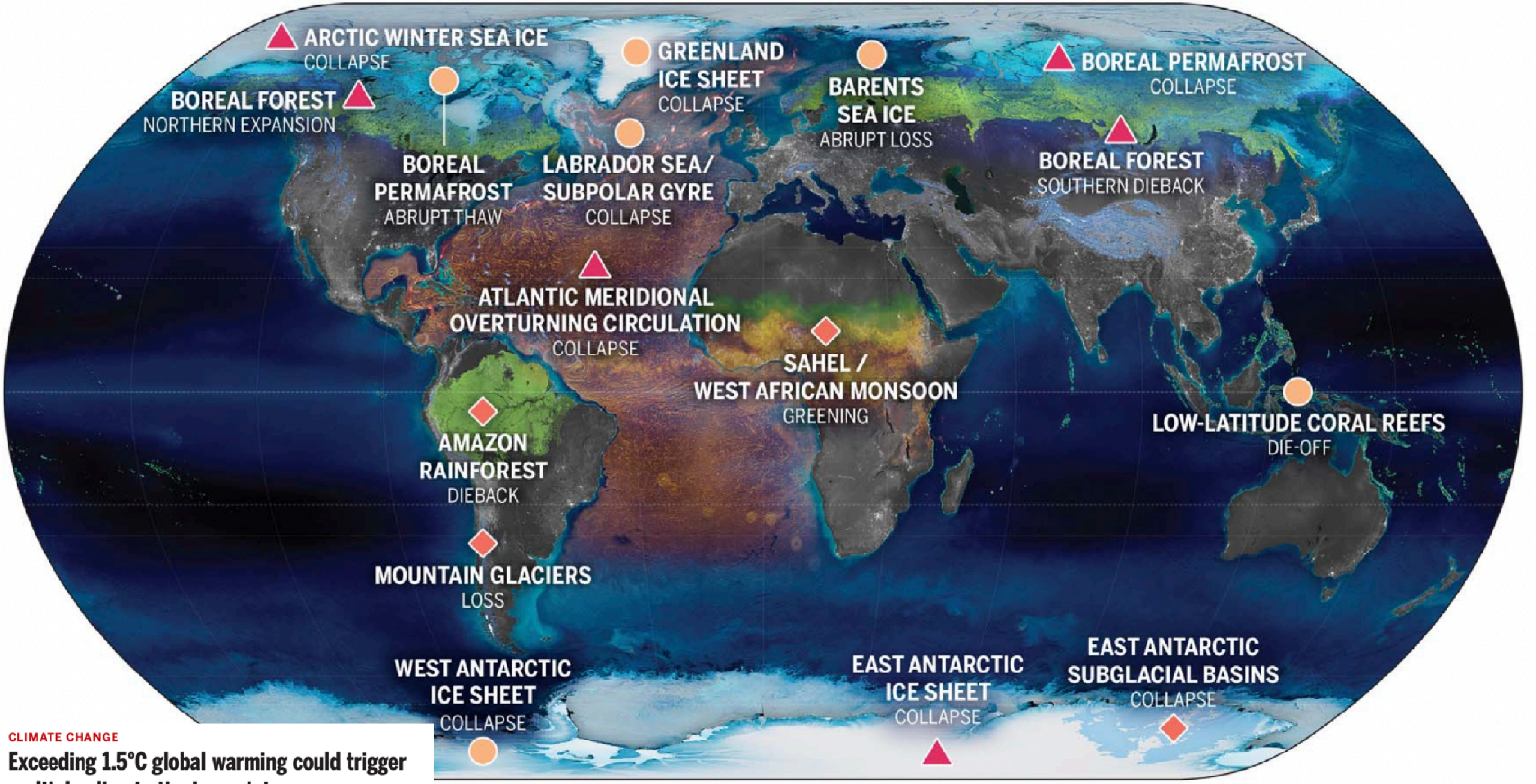
bifurcation tipping events

e.g., collapse of the thermohaline circulation in the Atlantic Ocean

…a critical level in the forcing is reached.







CLIMATE CHANGE

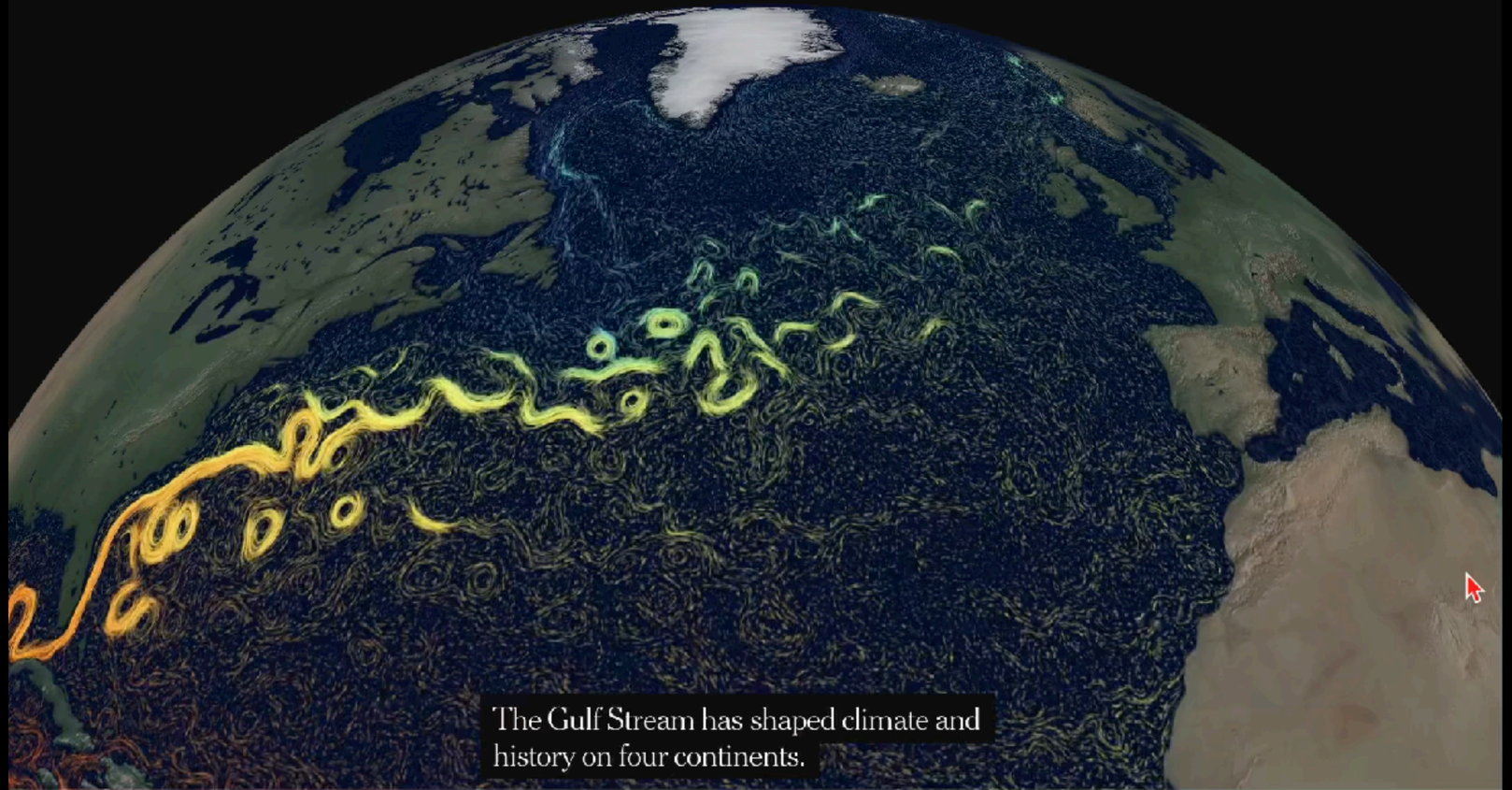
Exceeding 1.5°C global warming could trigger multiple climate tipping points

David I. Armstrong McKay[1,2,3,4]*, Arie Staal[1,2,5], Jesse F. Abrams[3], Ricarda Winkelmann[6], Boris Sakschewski[6], Sina Loriani[6], Ingo Fetzer[1,2], Sarah E. Cornell[1,2], Johan Rockström[1,6], Timothy M. Lenton[3]*

In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

The warming atmosphere is causing an arm of the powerful Gulf Stream to weaken, some scientists fear.

By MOISES VELASQUEZ-MANOFF and JEREMY WHITE



The Gulf Stream has shaped climate and history on four continents.

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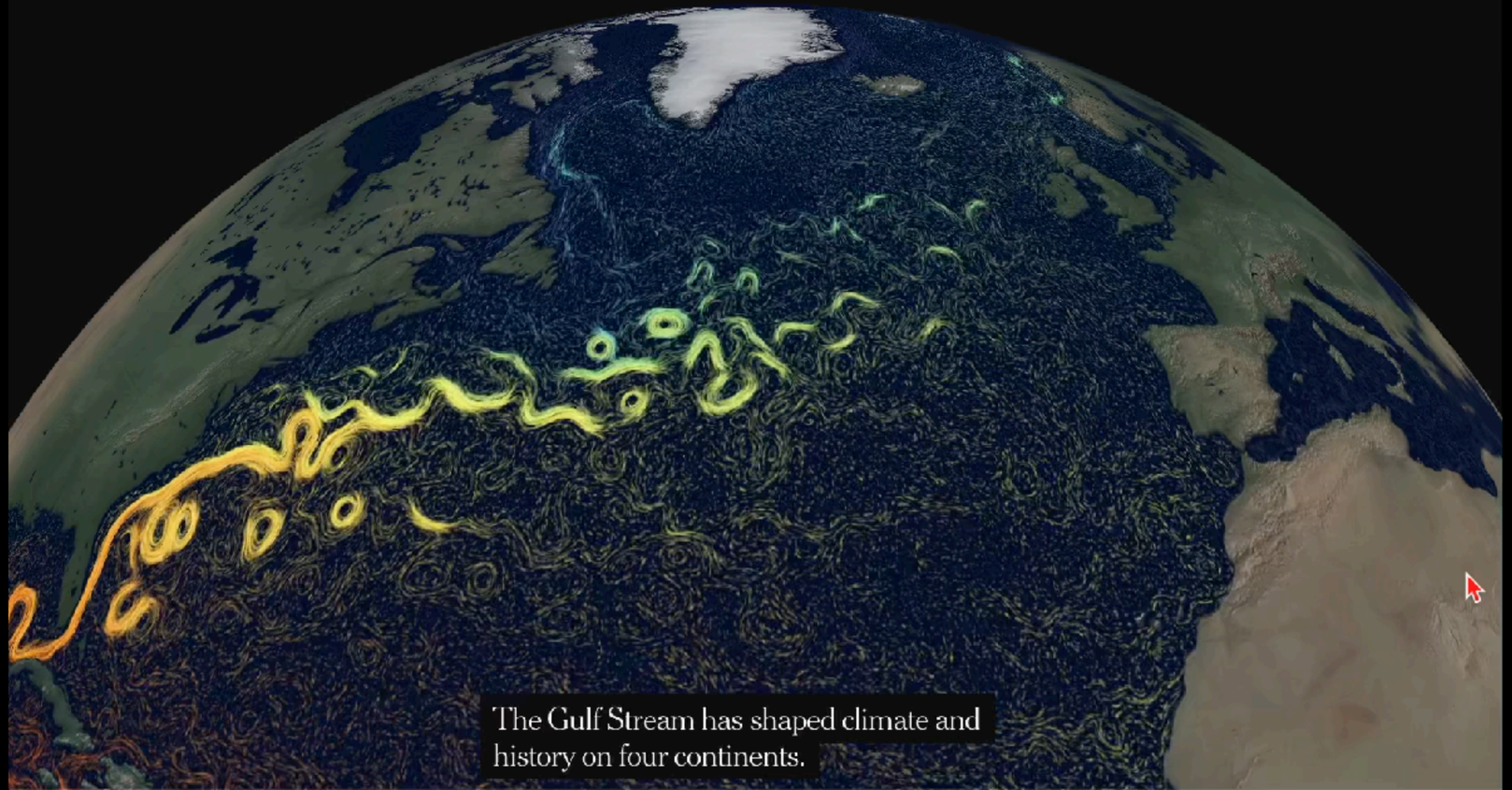

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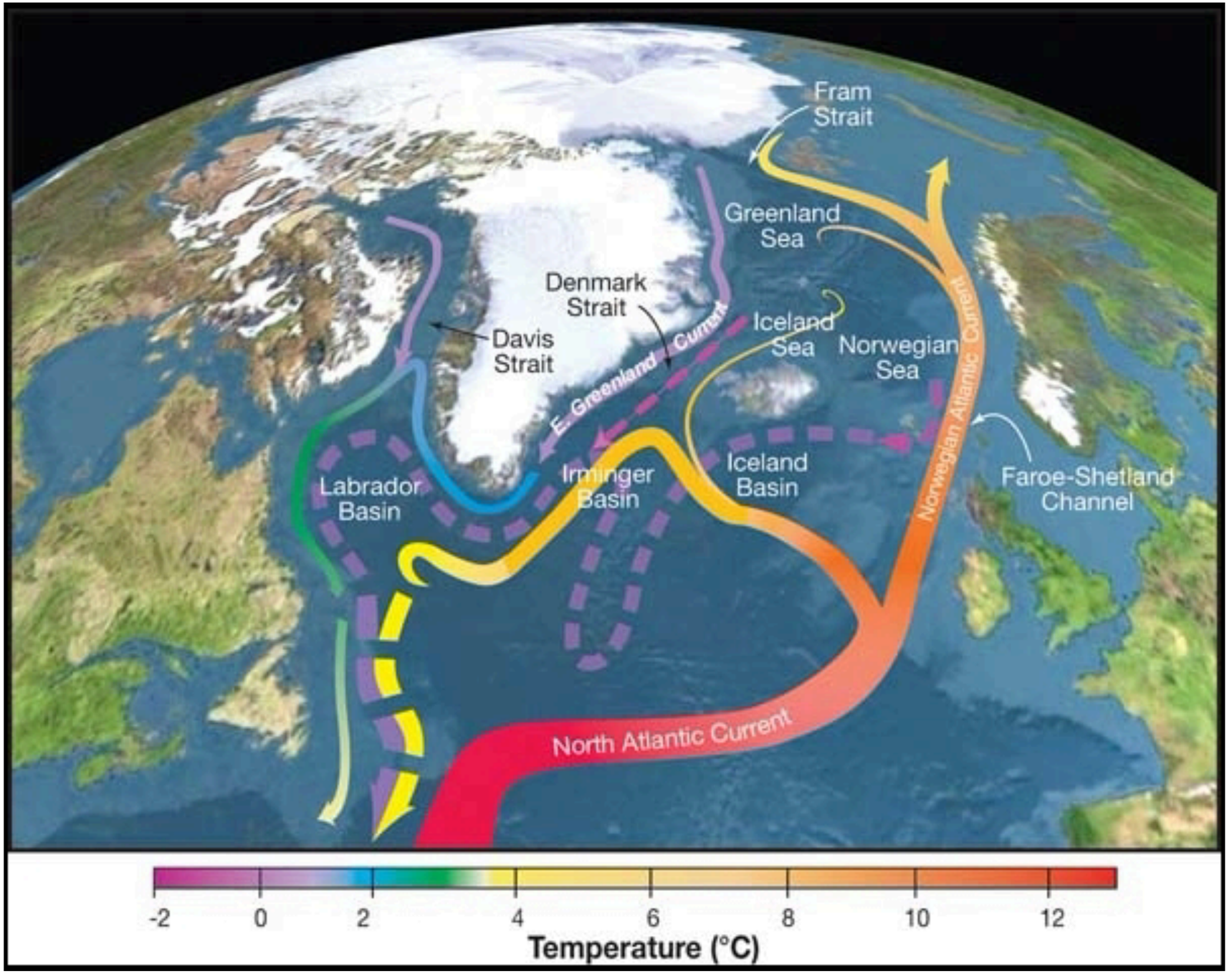
Atlantic Meridional Overturning Circulation



https://science.howstuffworks.com/environmental/earth/oceanography/amoc-news.htm

ARTICLE nature

https://doi.org/10.1038/s41586-018-0006-5

12 APRIL 2018 | VOL 556 | NATURE | 191

Observed fingerprint of a weakening Atlantic Ocean overturning circulation

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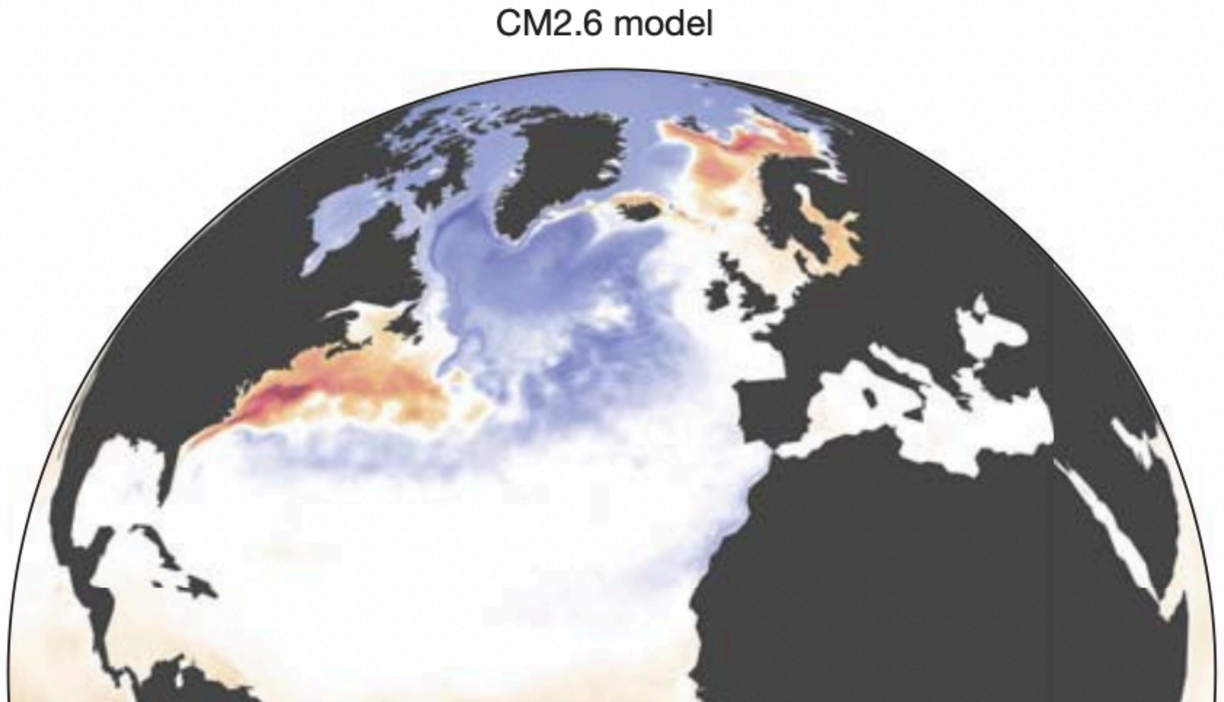

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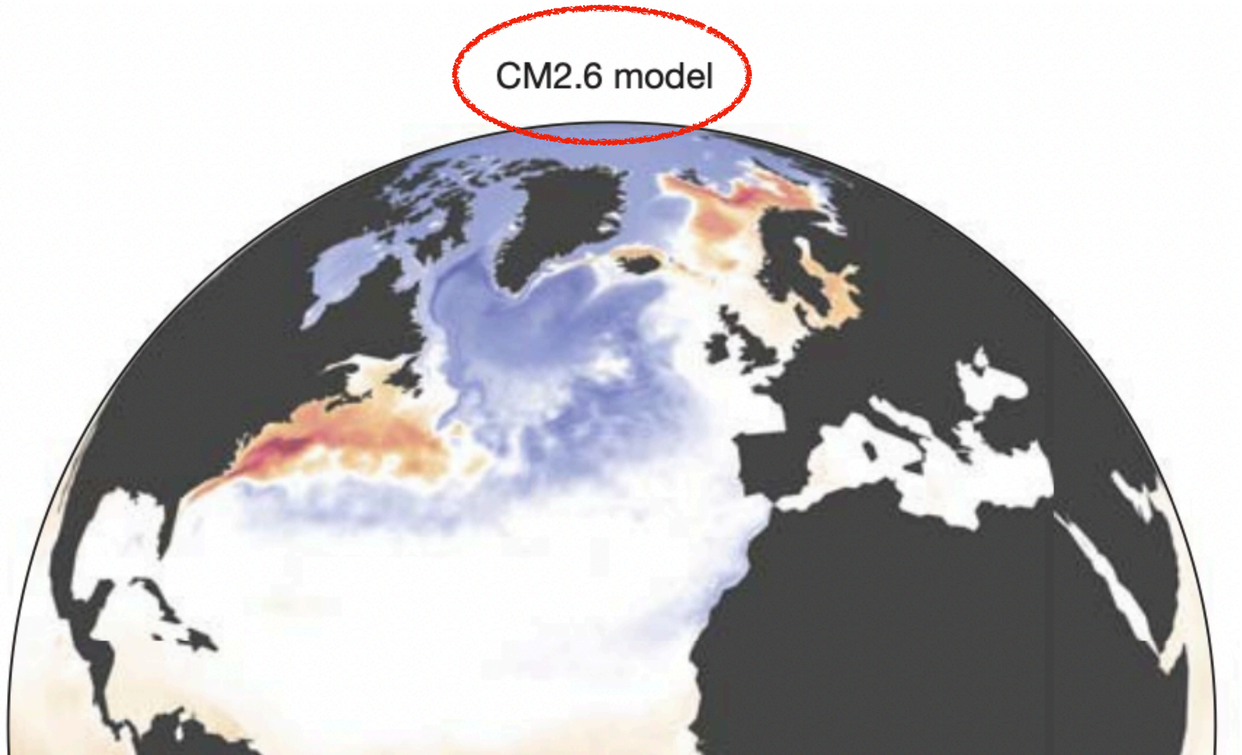

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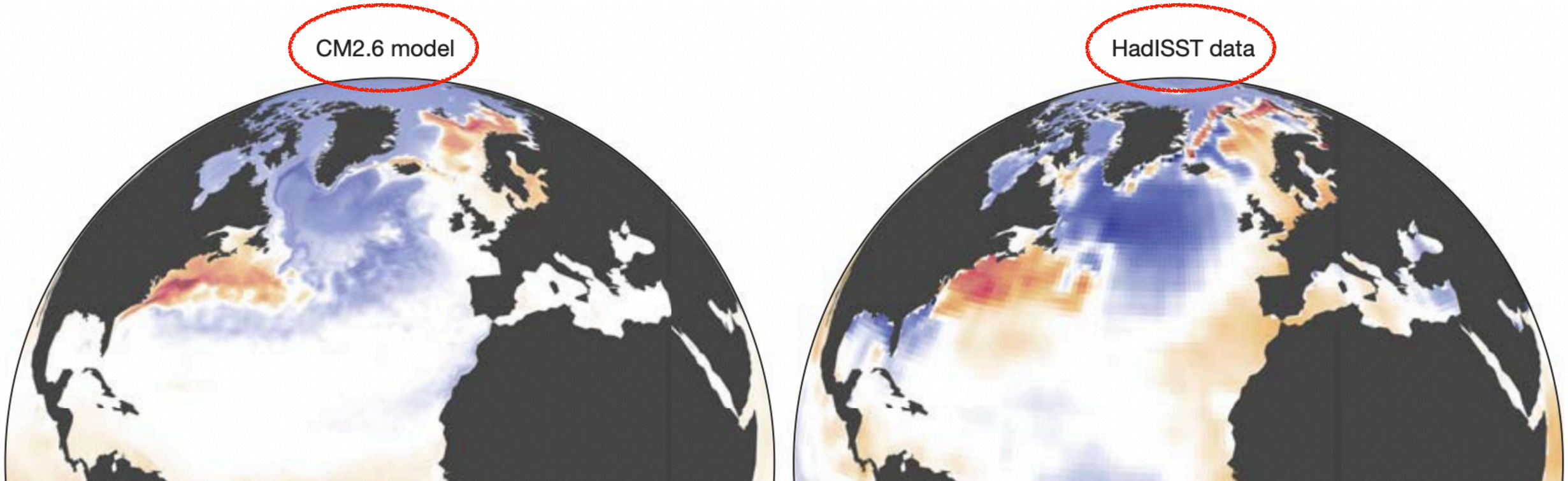

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https://doi.org/10.1038/s41558-021-01097-4
nature climate change
Check for updates

Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation

NATURE CLIMATE CHANGE | VOL 11 | AUGUST 2021 | 680–688 |

Niklas Boers[1,2,3]

BRIEF COMMUNICATION
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nature geoscience
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Current Atlantic Meridional Overturning Circulation weakest in last millennium

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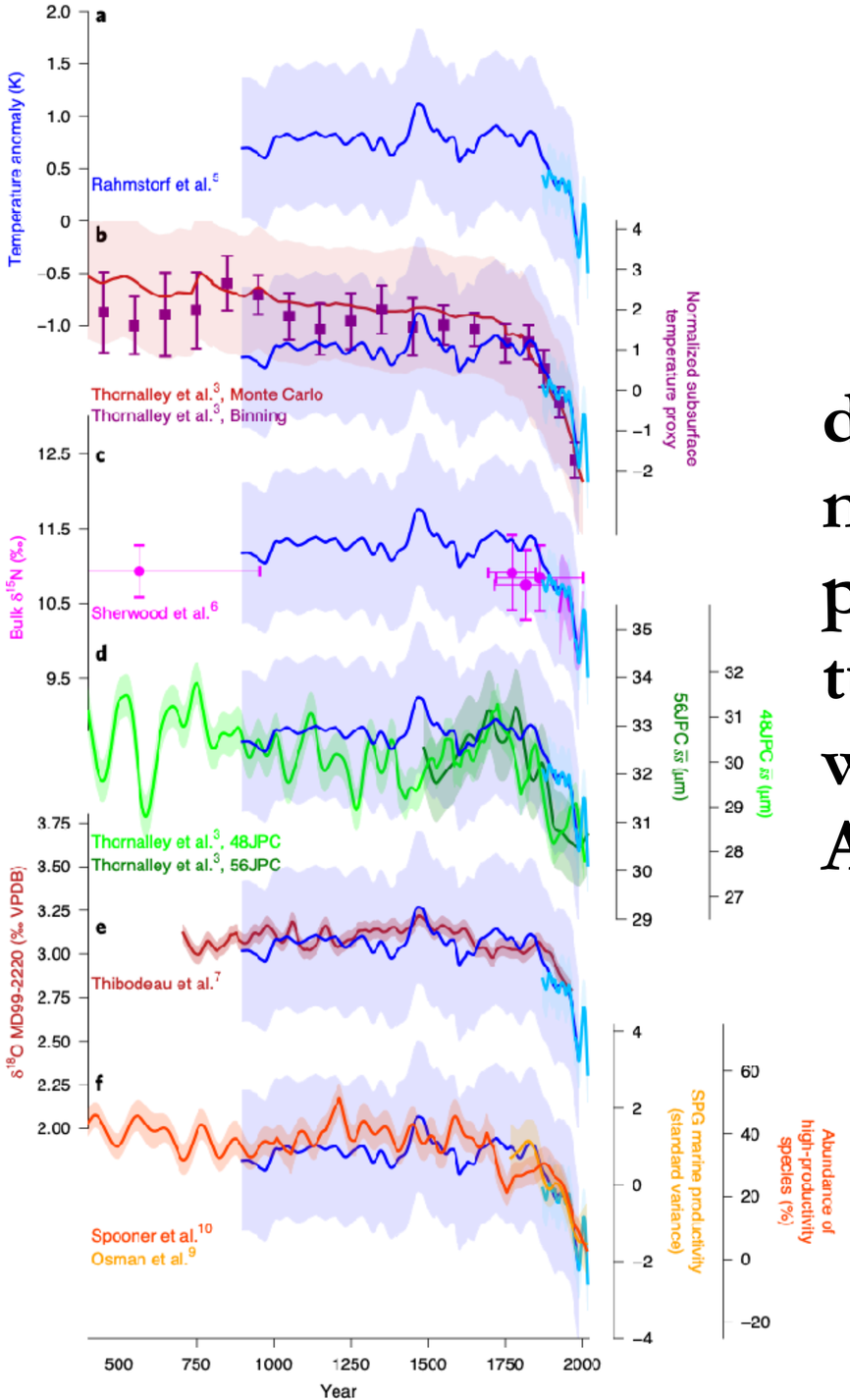
NATURE GEOSCIENCE | VOL 14 | MARCH 2021 | 118–120 | www.nature.com/naturegeoscience



data..NOT model… proxies for turnover of water in the AMOC

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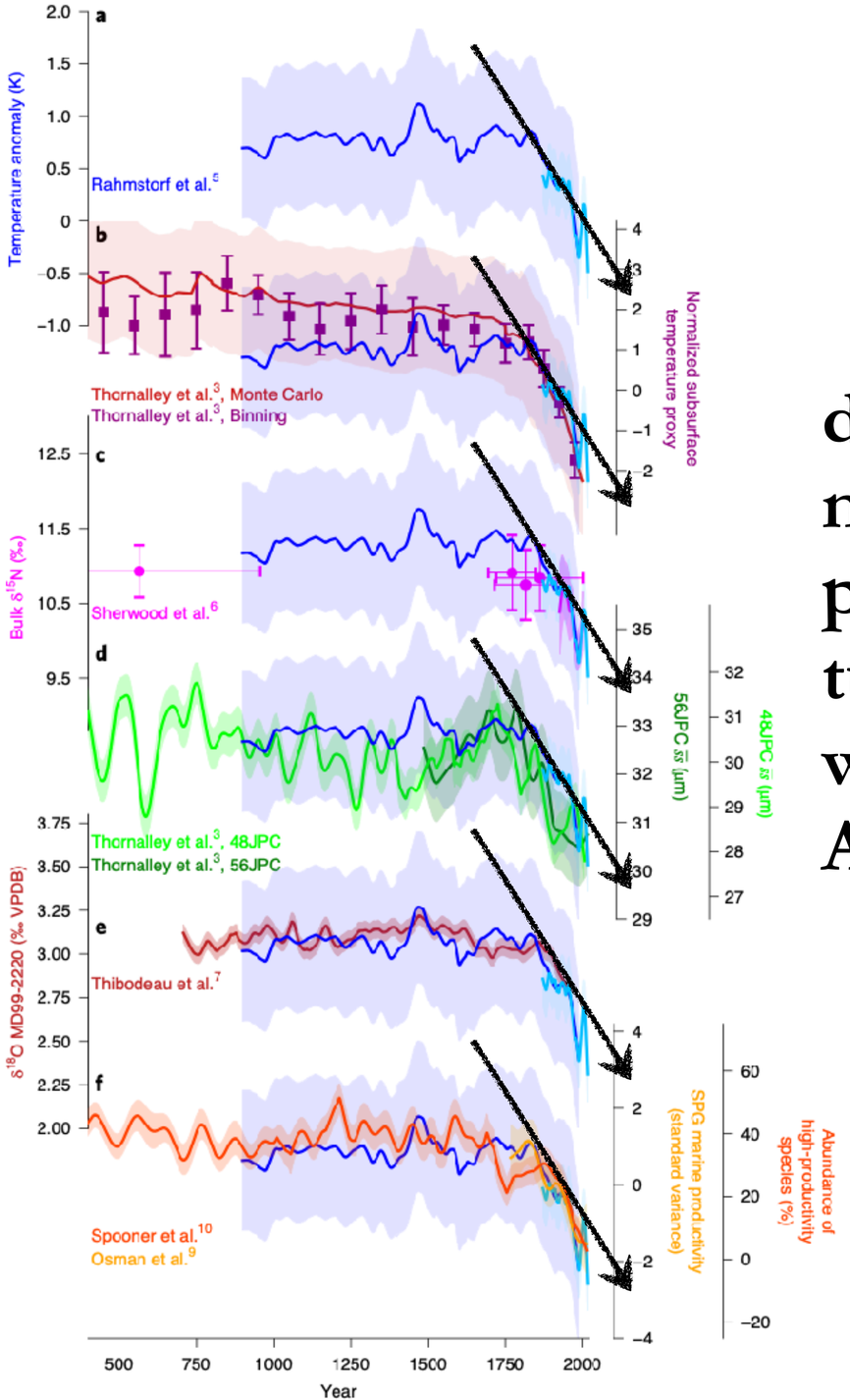

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The evolution of the North Atlantic Meridional Overturning Circulation since 1980

Laura C. Jackson[1✉], Arne Biastoch[2,3], Martha W. Buckley[4], Damien G. Desbruyères[5], Eleanor Frajka-Williams[6], Ben Moat[6] and Jon Robson[7]

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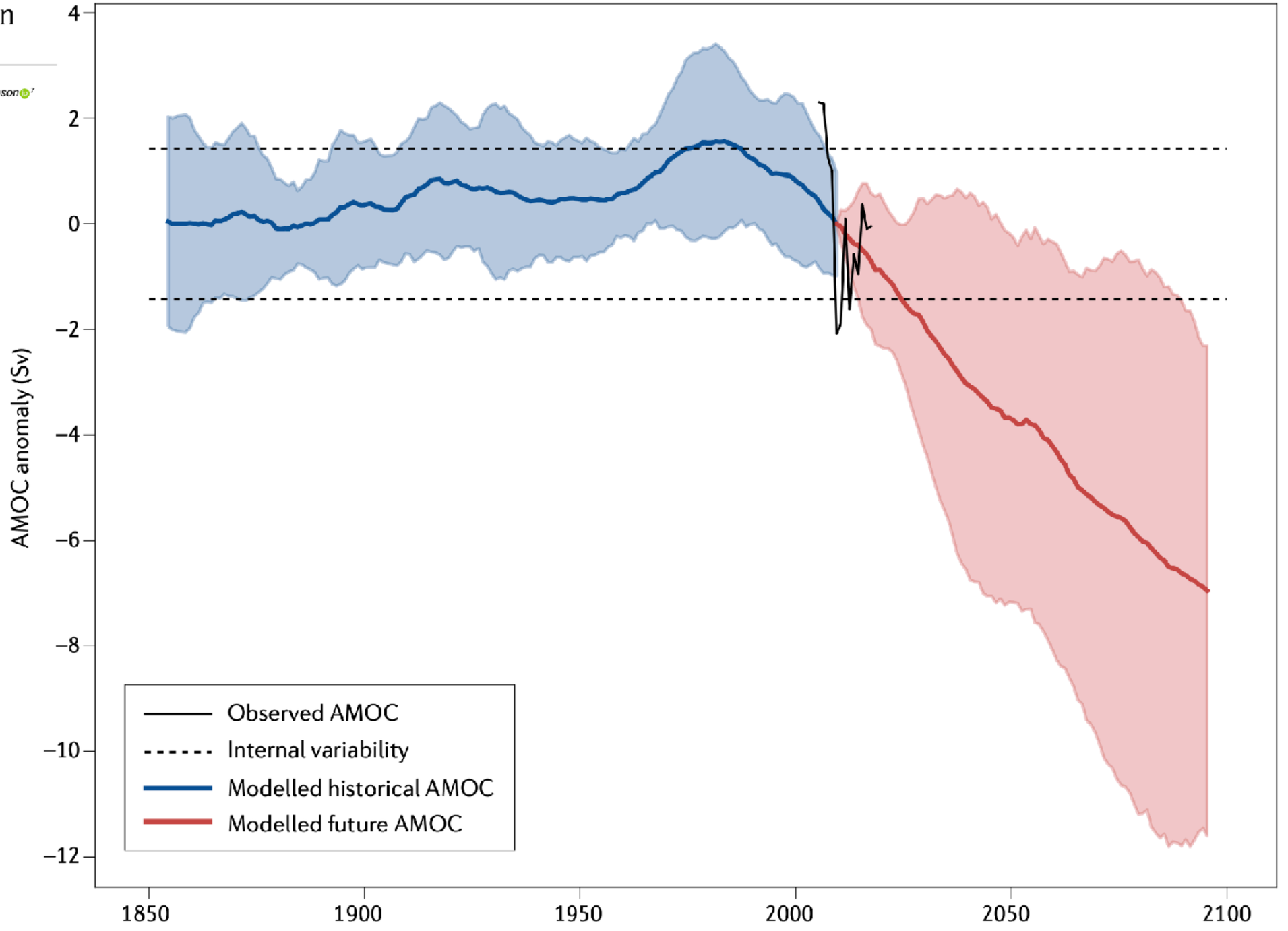
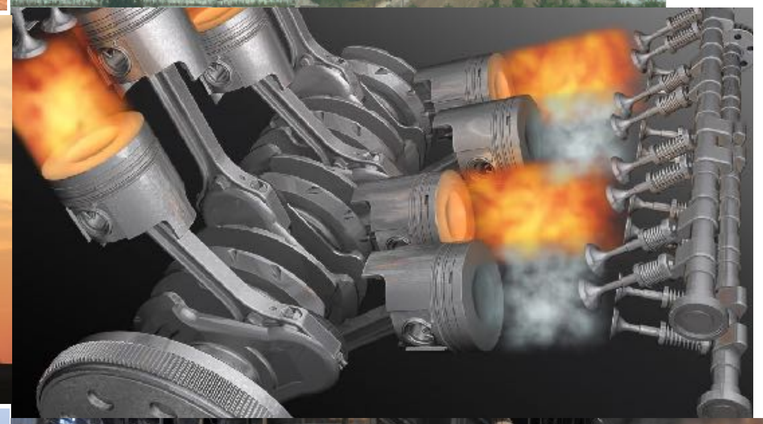
VOLUME 3 | APRIL 2022 | 241



"What keeps you up at night?"

Answer:
calculus,
and
justice

extraction



extraction

burn

extraction

burn

profit

extraction

burn

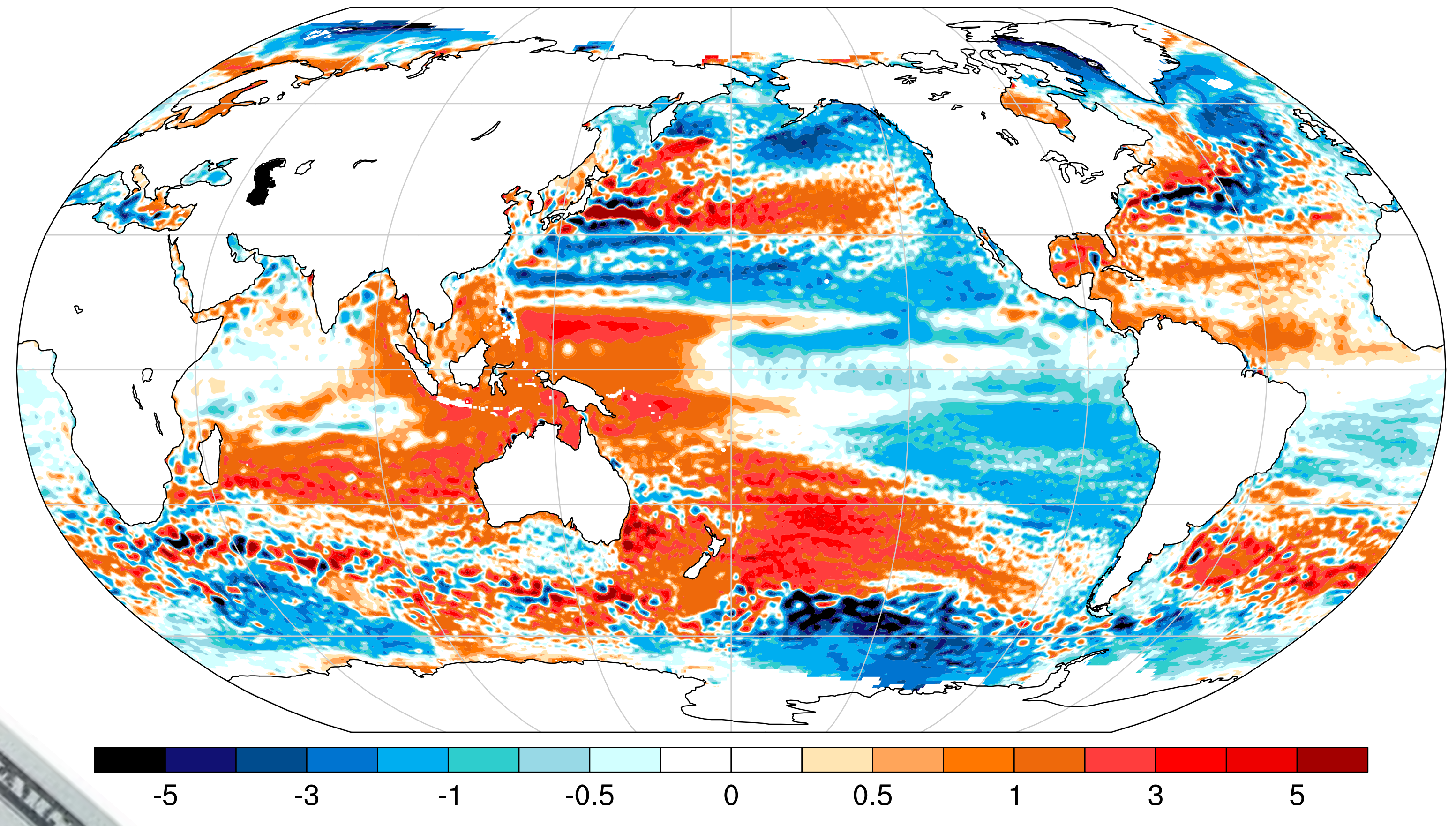
profit - environmental justice

extraction

burn

profit - environmental justice

consequences



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burn

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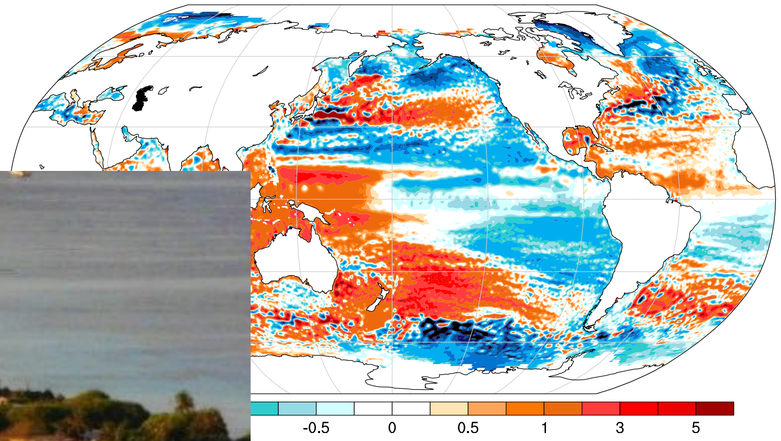

extraction

burn

profit - environmental justice

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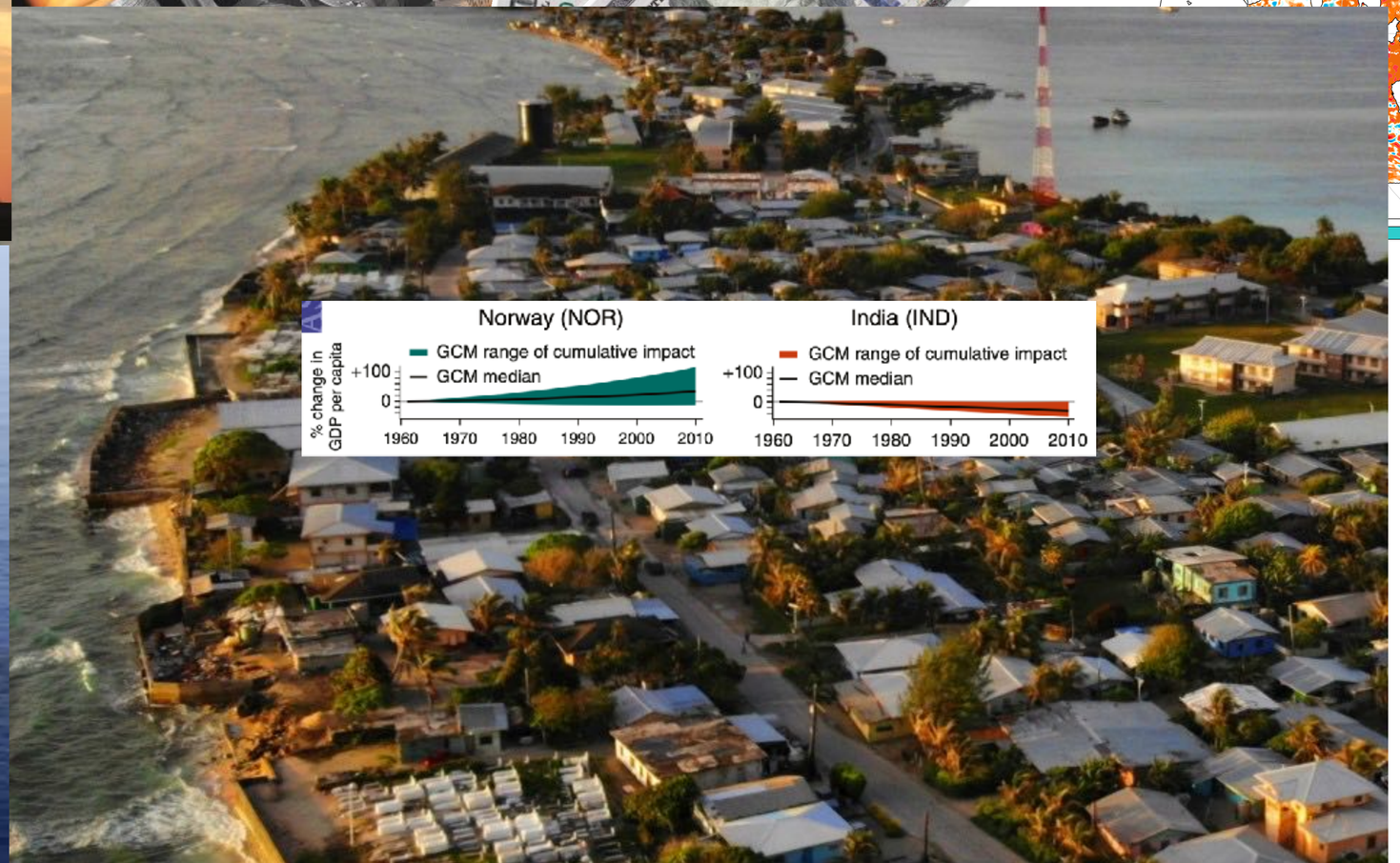

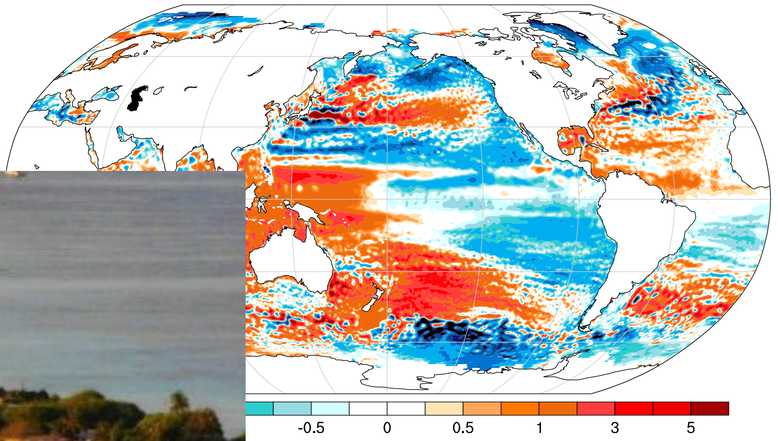

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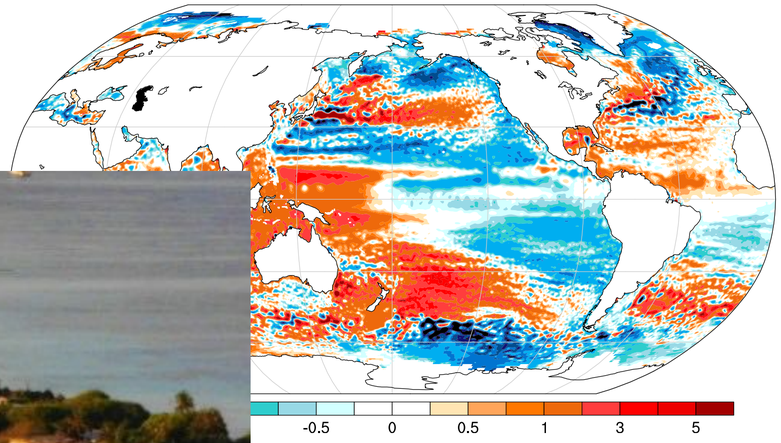
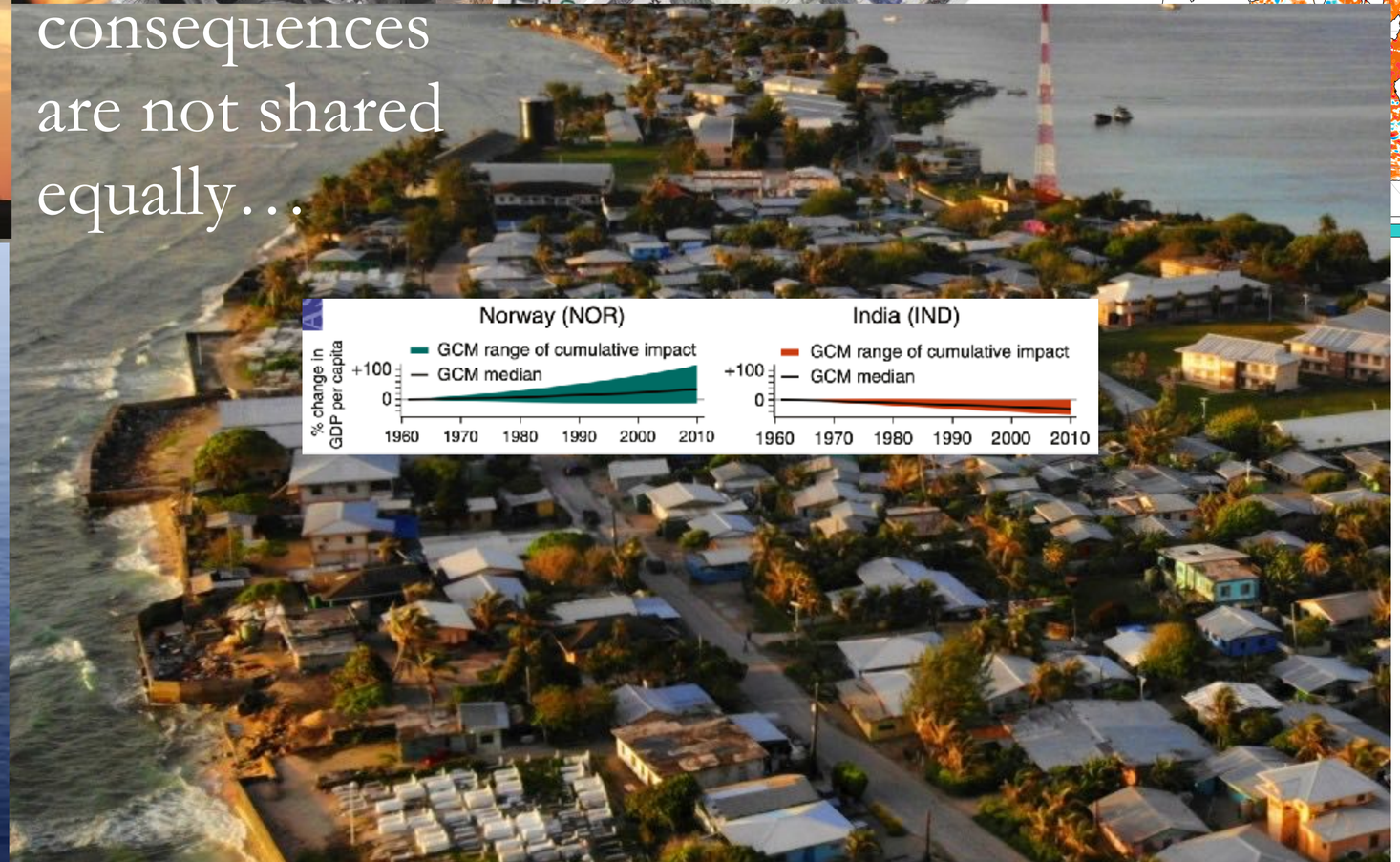


consequences are not shared equally…



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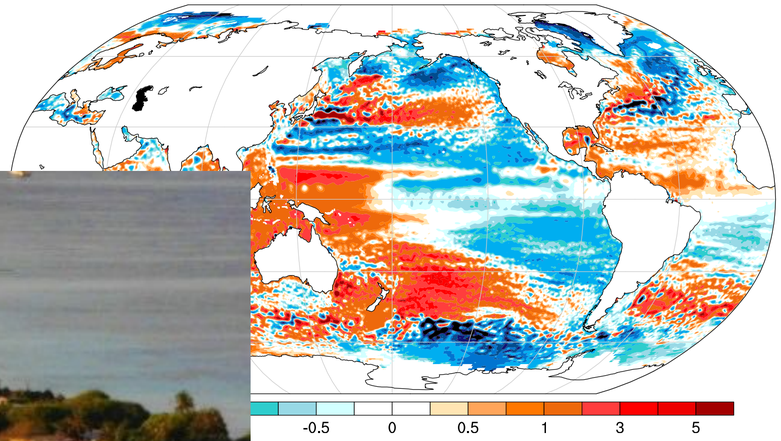
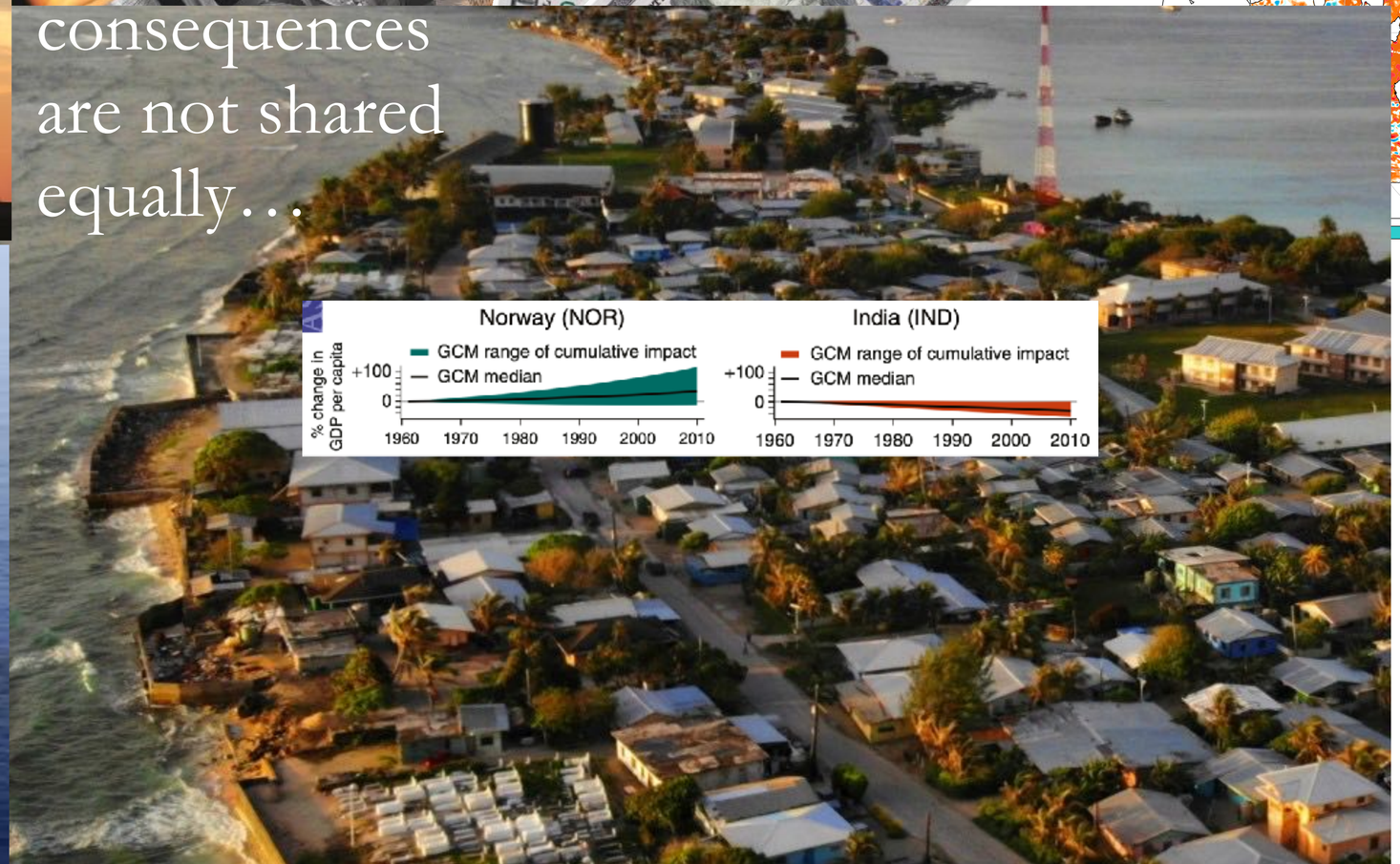
profit - environmental justice

consequences - climate justice



consequences
are not shared
equally…



What are we going to do?

Policy and Action Framework: The United Nations Sustainable Development Goals

https://sdgs.un.org/goals

Policy and Action Framework: The United Nations Sustainable Development Goals

7

Goal 7

Ensure access to affordable, reliable, sustainable and modern energy for all.

5 Targets

22 Events

33 Publications

862 Actions

More info

https://sdgs.un.org/goals

Policy and Action Framework: The United Nations Sustainable Development Goals

https://sdgs.un.org/goals

13

Goal 13

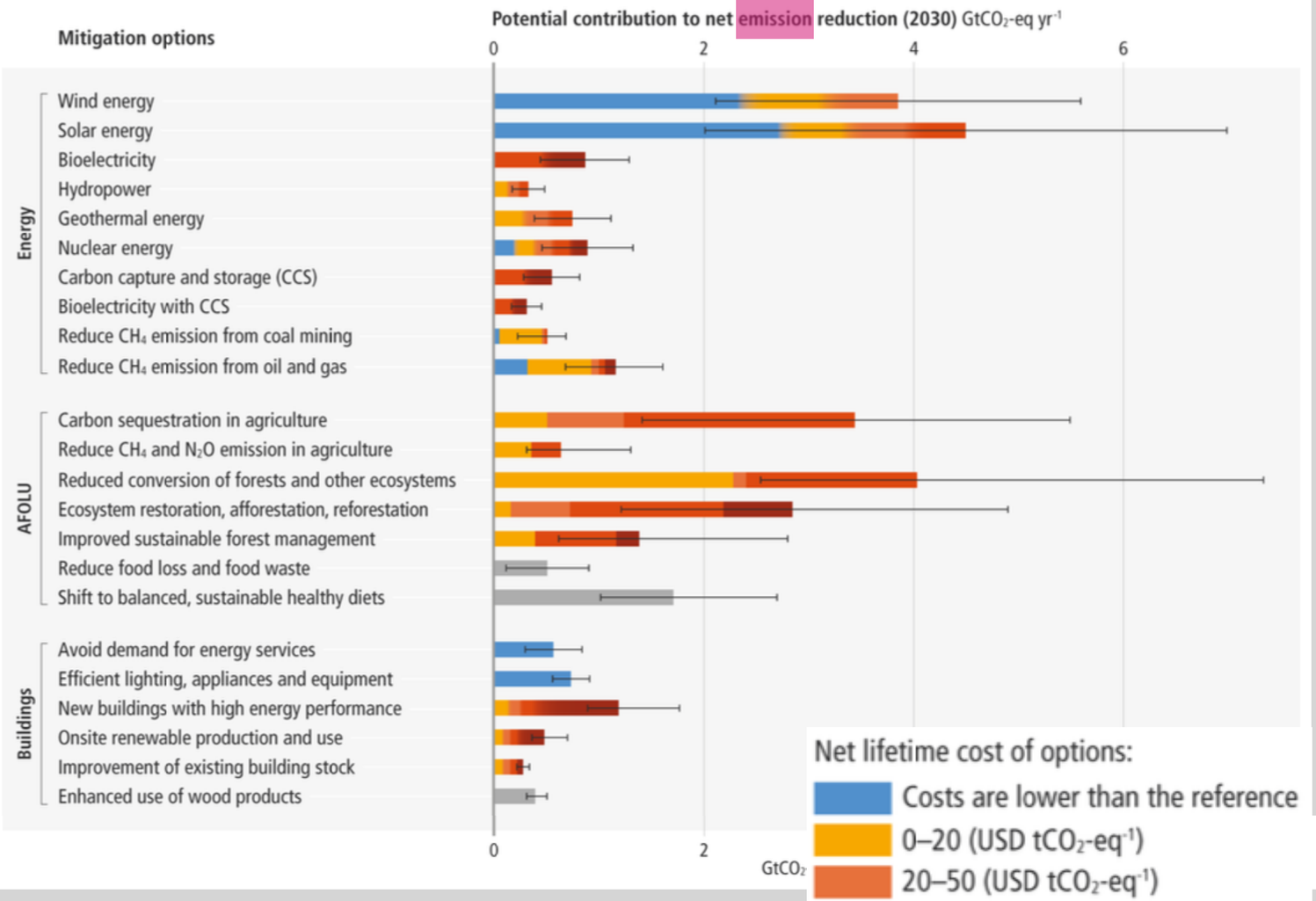
Take urgent action to combat climate change and its impacts.

5 Targets	**19** Events
33 Publications	**1568** Actions

More info

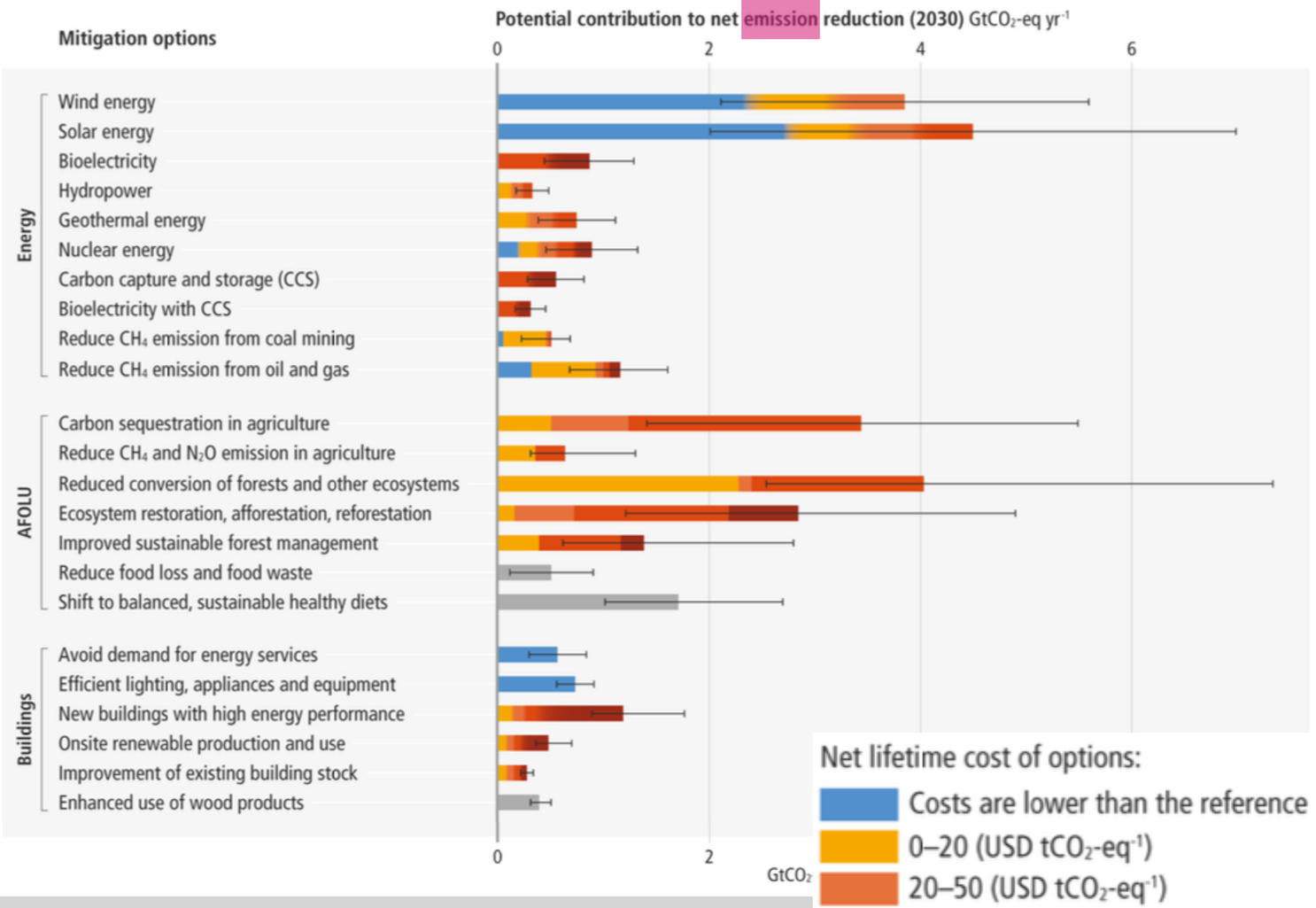
https://sdgs.un.org/goals

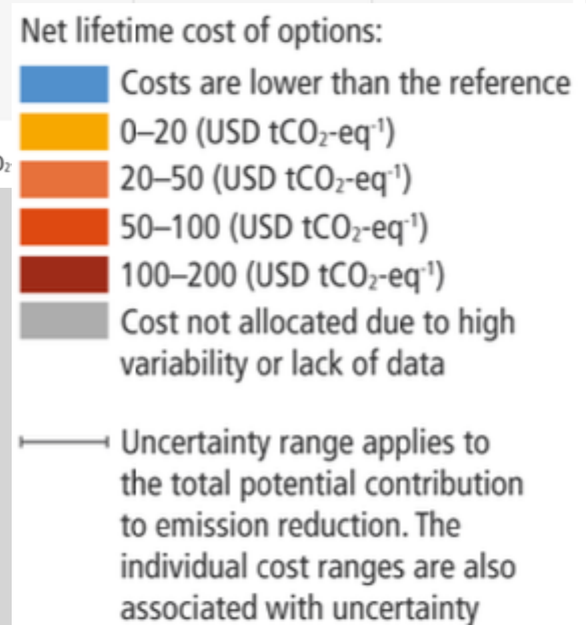
Present day technologies that provide hope

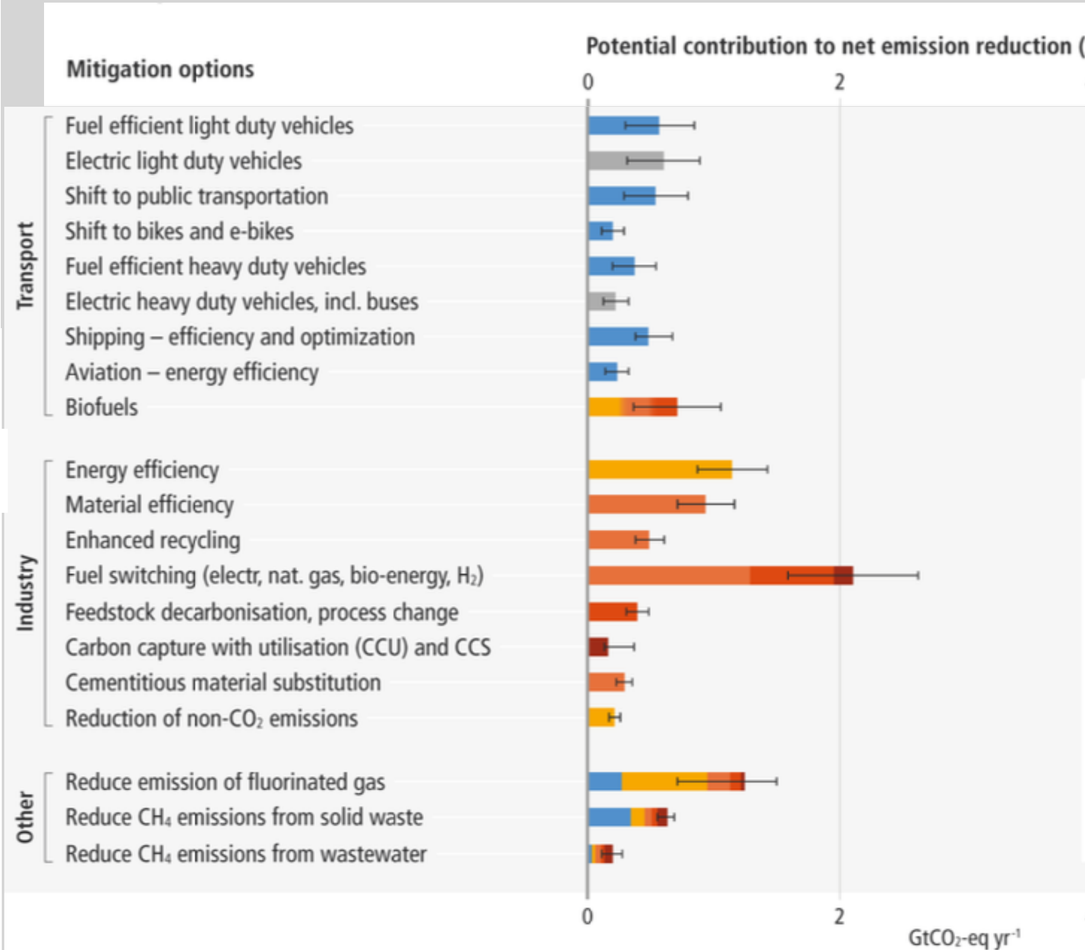


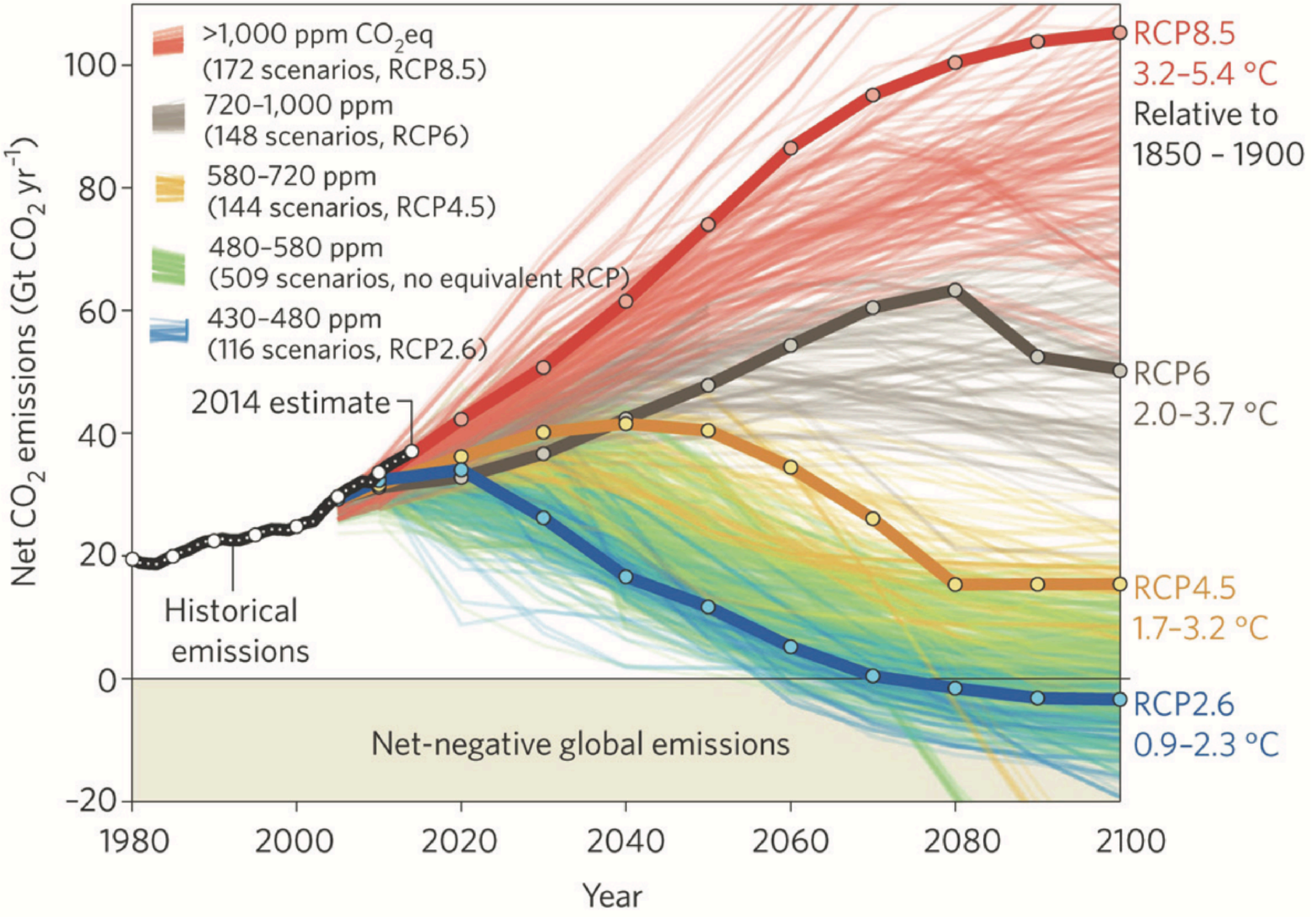
Present day technologies that provide hope

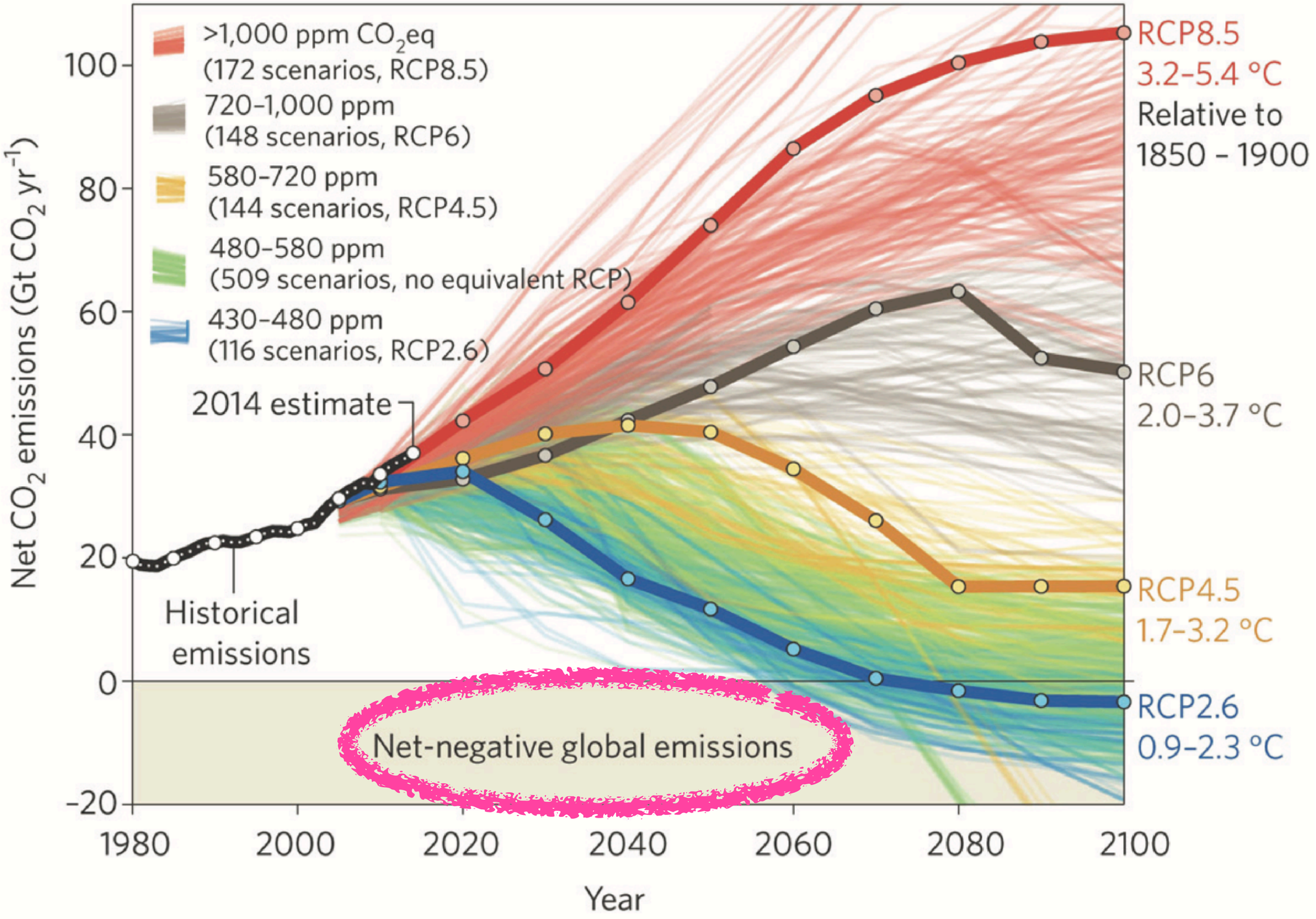
Present day technologies that provide hope








>1,000 ppm CO_2eq
(172 scenarios, RCP8.5)
720–1,000 ppm
(148 scenarios, RCP6)
580–720 ppm
(144 scenarios, RCP4.5)
480–580 ppm
(509 scenarios, no equivalent RCP)
430–480 ppm
(116 scenarios, RCP2.6)
2014 estimate
Historical emissions
Net-negative global emissions
RCP8.5
3.2–5.4 °C
Relative to
1850 – 1900
RCP6
2.0–3.7 °C
RCP4.5
1.7–3.2 °C
RCP2.6
0.9–2.3 °C
Net CO_2 emissions (Gt CO_2 yr^{-1})
100
80
60
40
20
0
-20
1980
2000
2020
2040
2060
2080
2100
Year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Year

Wednesday

9:00 am - 12:30 pm	**Learning from Deployment** Discussion Leader: **Frauke Kracke** (Frontier, United States)
6:00 pm - 8:00 pm	**Greenhouse Gas Removal Harnessing Ocean, Land and Forests** Discussion Leader: **Yiwen Pan** (Institute of Marine Chemistry and Environment, Ocean College, Zhejiang University, China, China)

Thursday

9:00 am - 12:30 pm	**Permanently Storing CO_2 in Minerals and Underground** Discussion Leader: **Greeshma Gadikota** (Cornell University, United States)
6:00 pm - 8:00 pm	**Unlocking Value Chains for Negative Emissions** Discussion Leader: **Sandra Osk Snaebjornsdottir** (Carbfix, Iceland)

Transformative Science for the New Carbon Economy

May 28 - June 2, 2023

Conference Program

Sunday

7:40 pm - 9:30 pm	**Fast-Tracking CCUS from Lab to Innovation** Discussion Leader: **Andrea Ramirez Ramirez** (Delft University of Technology, The Netherlands)

Monday

9:00 am - 12:30 pm	**Converting CO_2 into Products** Discussion Leader: **Christoph Guertler** (COVESTRO, Germany)
6:00 pm - 8:00 pm	**Moving from Technical Feasibility to Societal Impact** Discussion Leader: **Holly Buck** (University at Buffalo, SUNY, United States)

Tuesday

9:00 am - 12:30 pm	**Innovation in CO_2 Capture** Discussion Leader: **Kristin Jordal** (SINTEF, Norway)
6:00 pm - 8:00 pm	**The Systems Challenge of the Carbon Transition** Discussion Leader: **Heleen de Coninck** (Eindhoven University of Technology, The Netherlands)