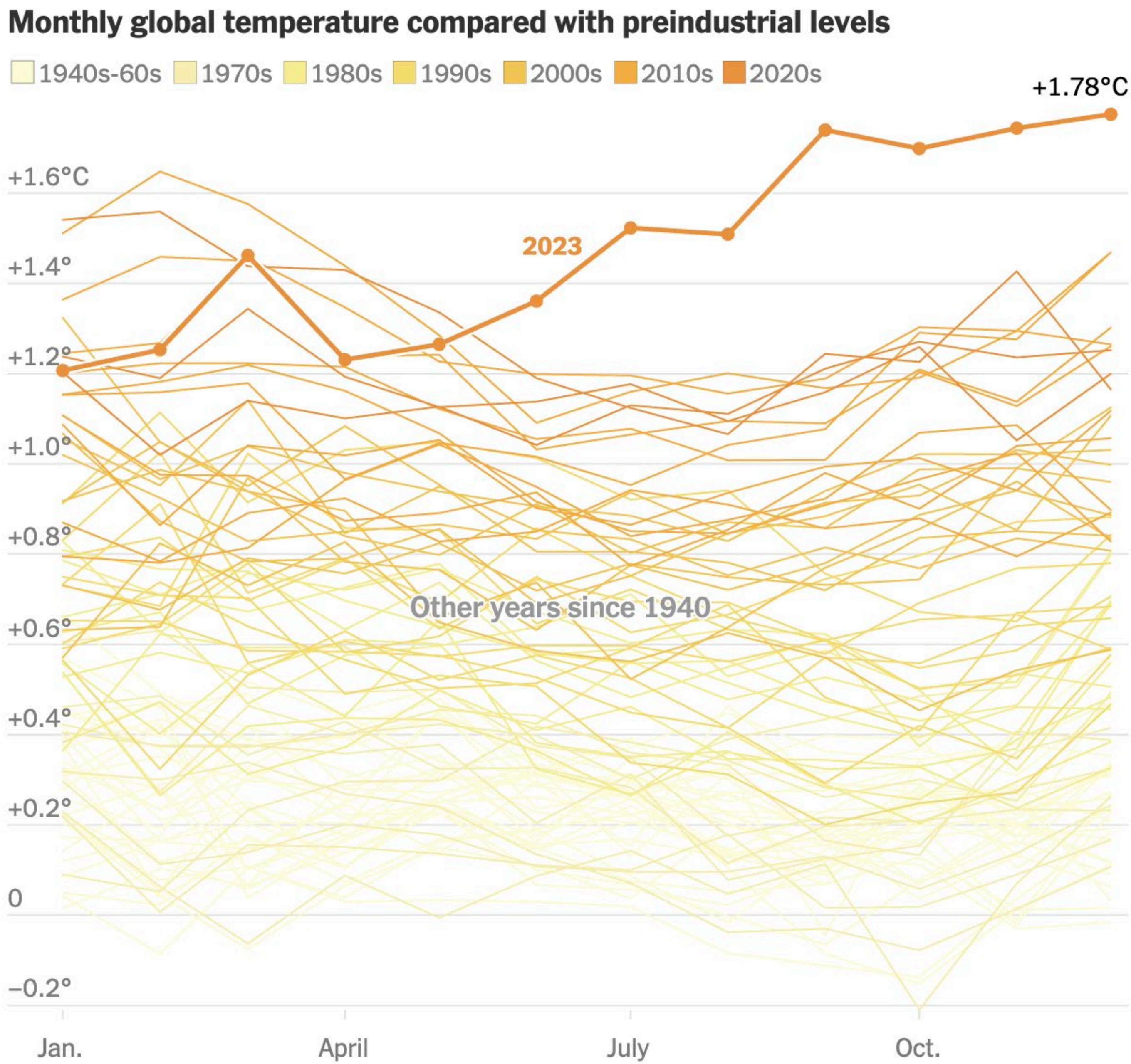
2023 was the hottest year on record



The world has just experienced the hottest summer on record – by a significant margin

CNN — none

As heat waves continue to bake parts of the world, scientists are reporting that this blistering, deadly summer was the hottest on record – and by a significant margin.

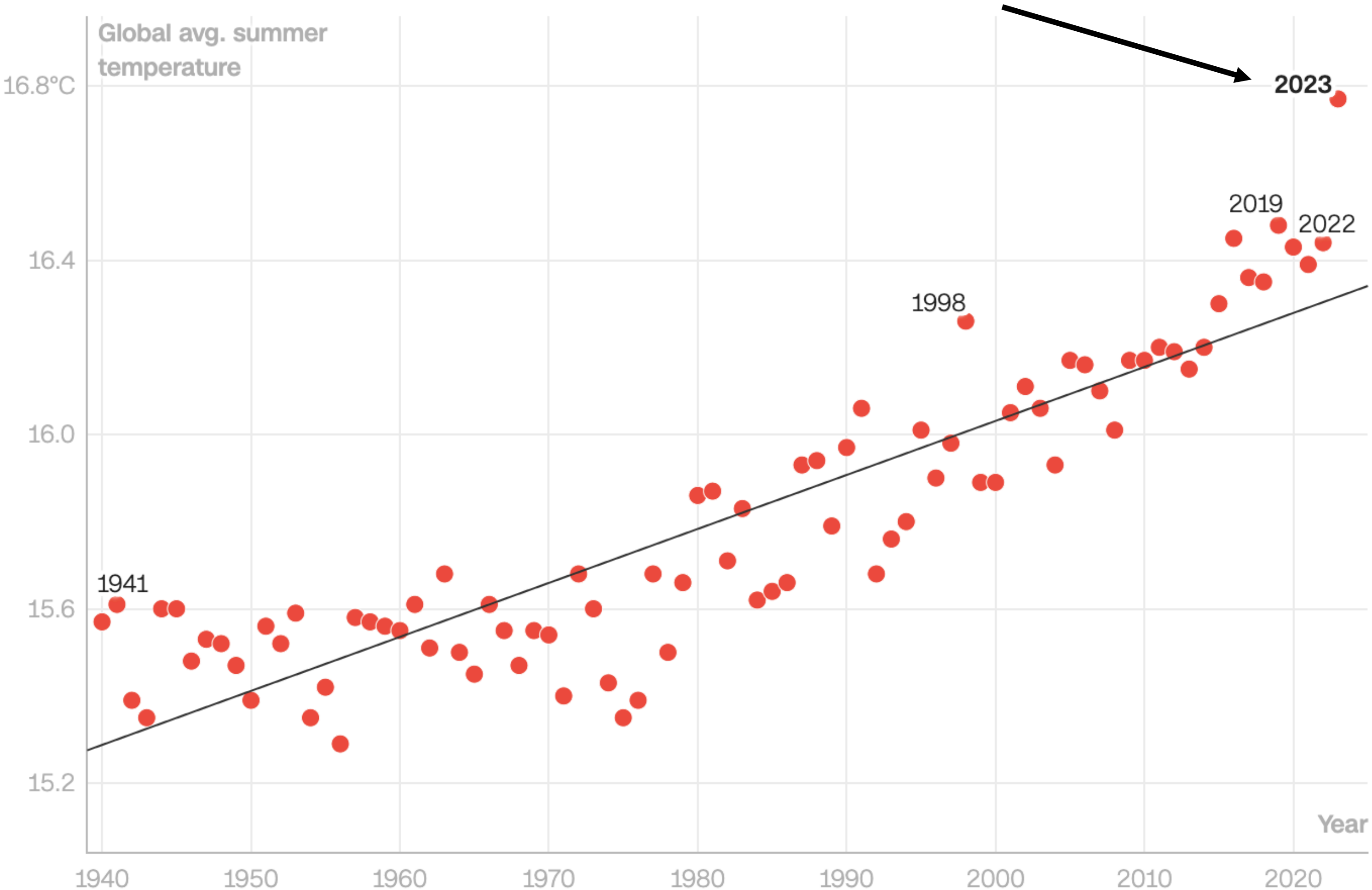
June to August was the planet's warmest such period since records began in

Kevin Frayer/Getty Images

Unstable Jet Stream – Extreme weather

This summer was the hottest on record — by a significant margin

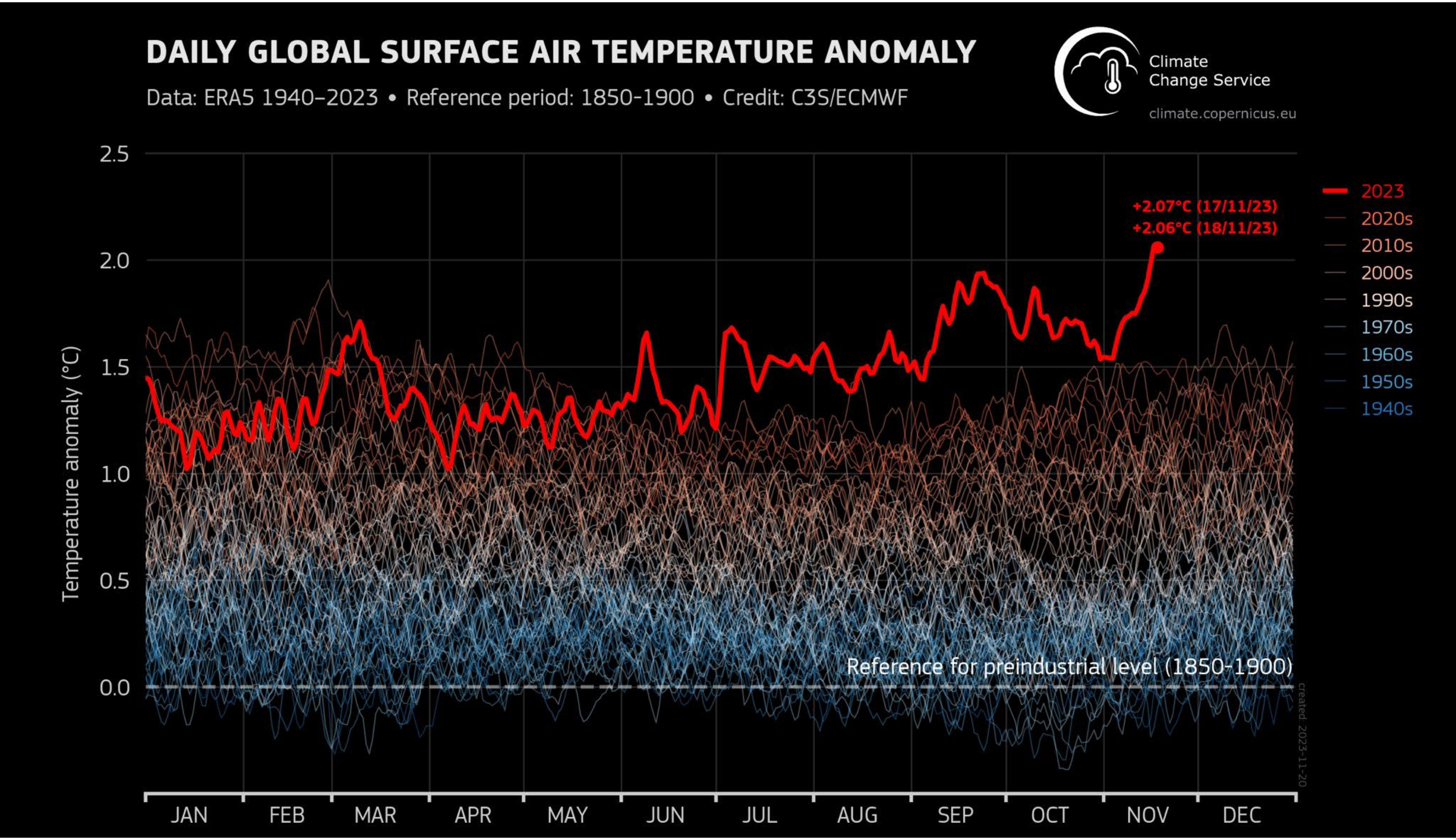
Summers have been trending hotter since at least the 1940s, and especially the past decade. Global temperature for June, July and August this year has surpassed that of summer 2019 — the previous record — by nearly a third of a degree Celsius.



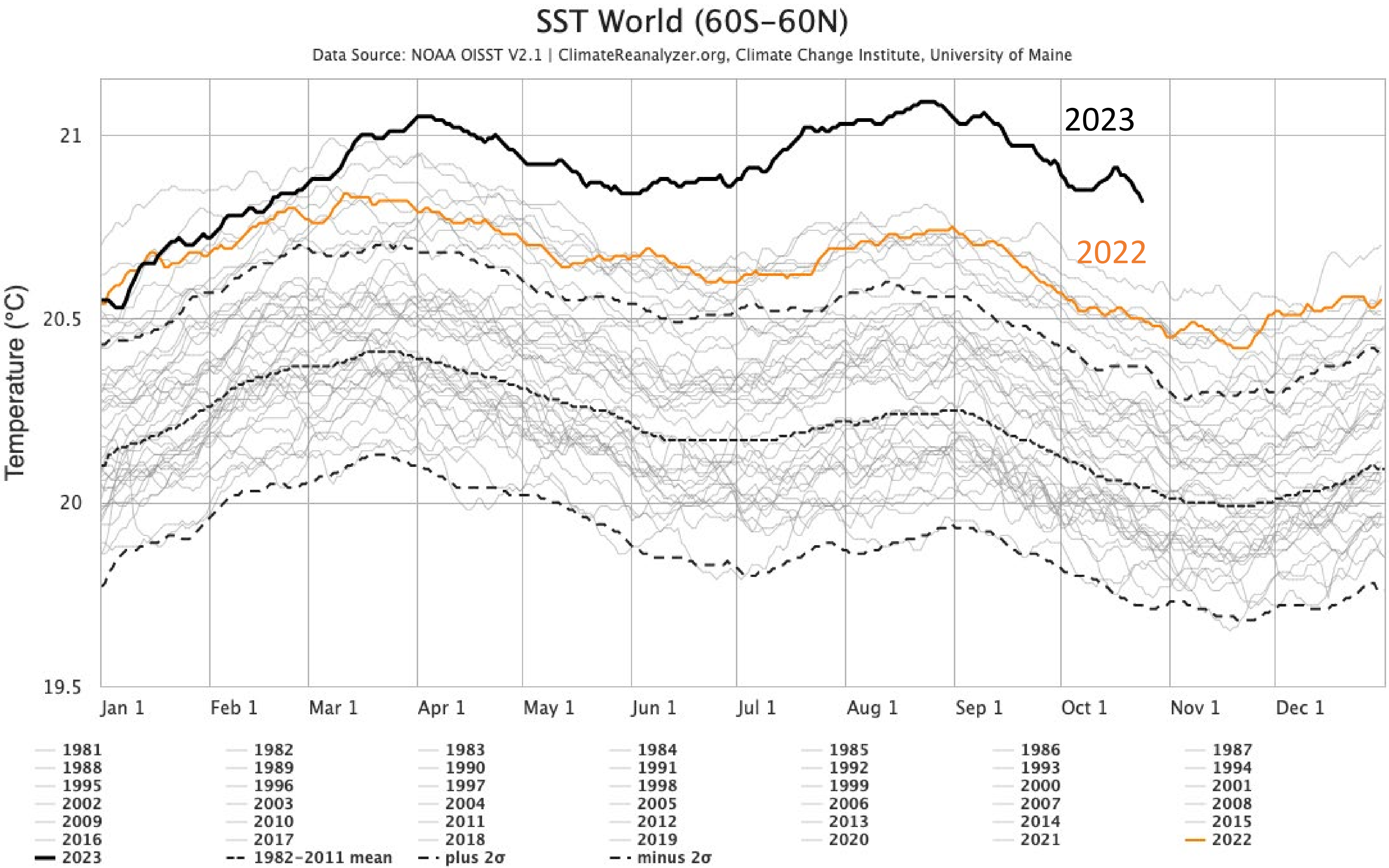
Note: Summer temperature includes all days in June, July, and August.

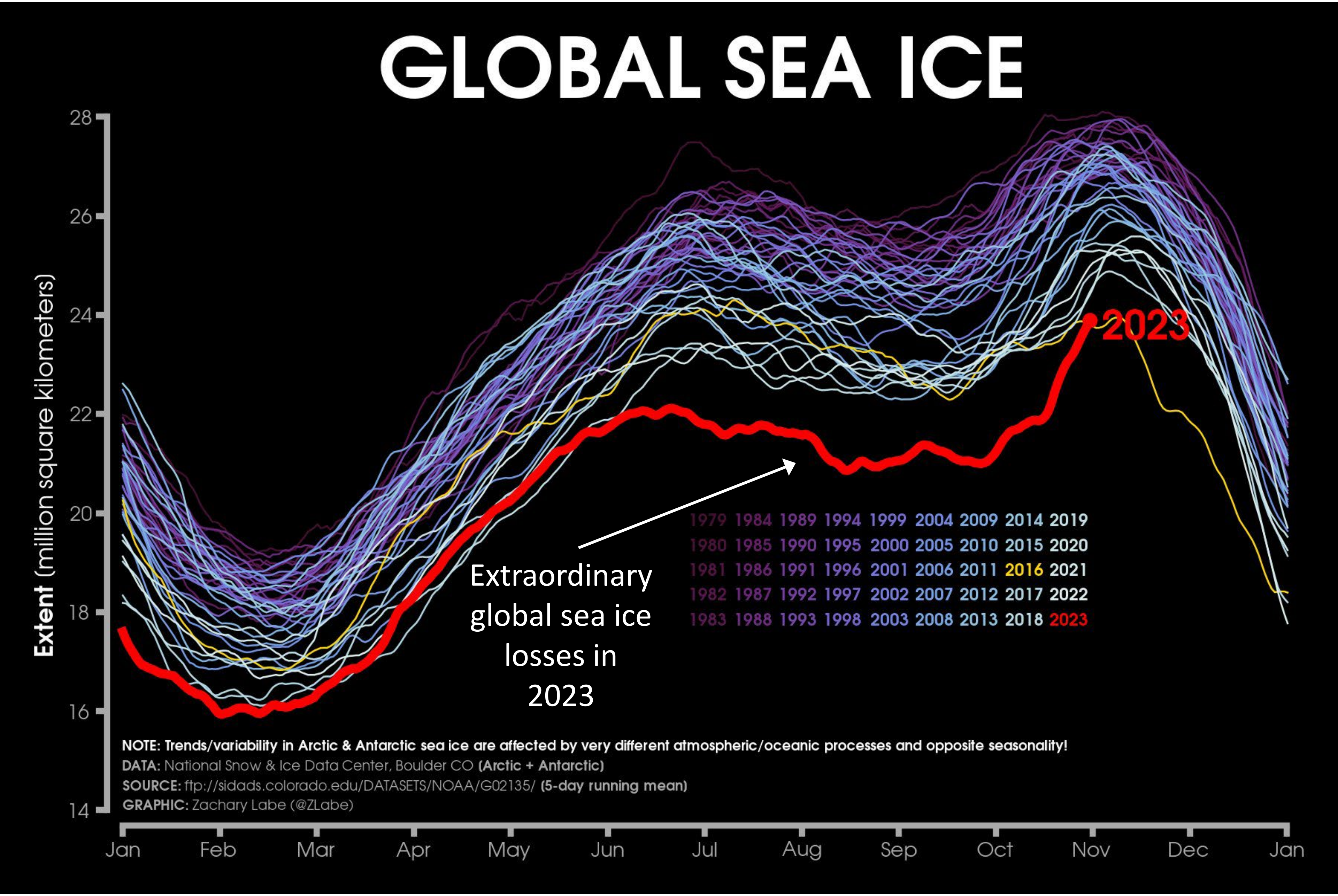
Source: Copernicus Climate Change Service
Graphic: Krystina Shveda, CNN

Global surface temperatures have set records virtually every day since mid-June

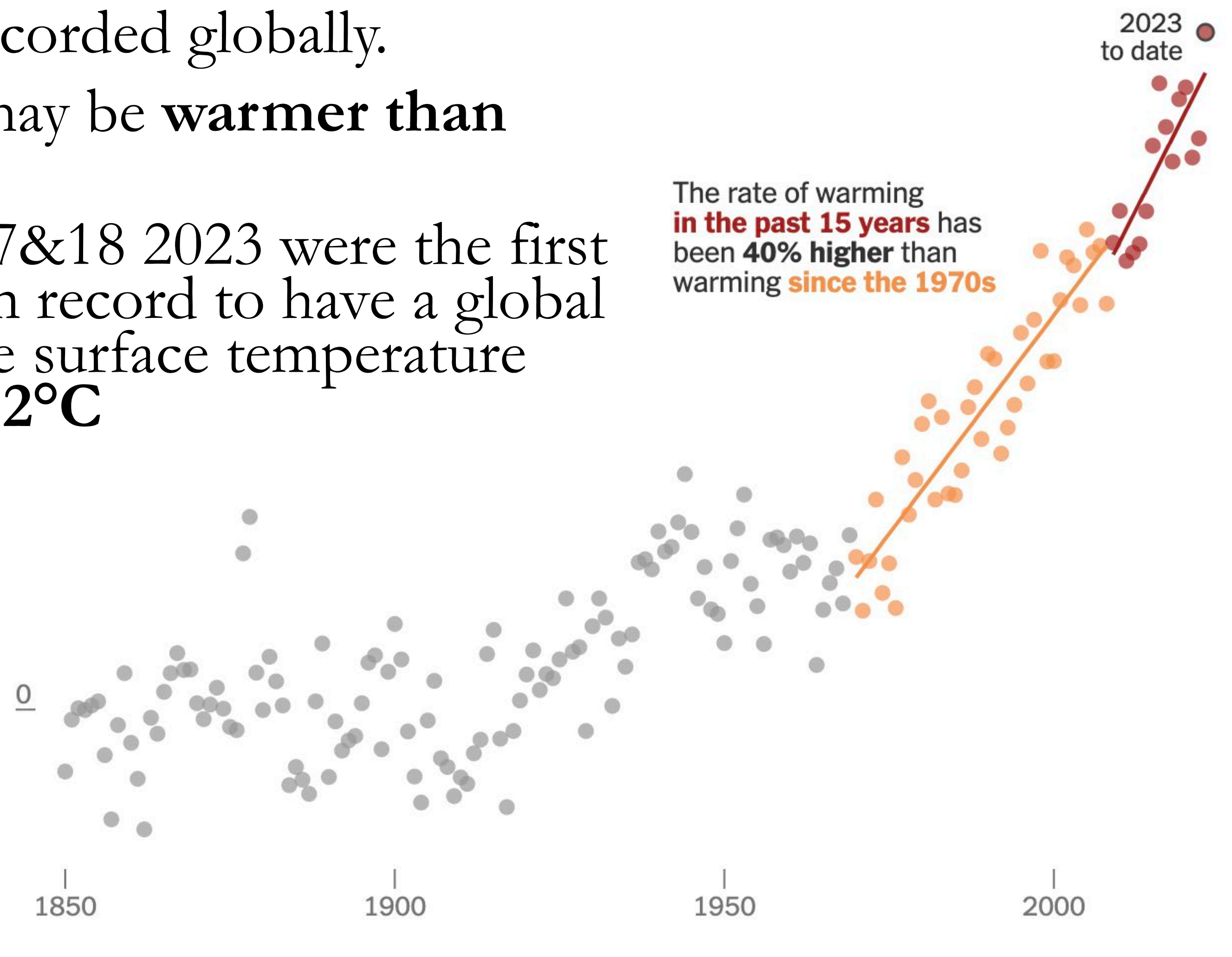


Since April, the hottest SSTs ever measured




GLOBAL SEA ICE
Extent (million square kilometers)
28
26
24
22
20
18
16
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2023
Extraordinary global sea ice losses in 2023
1979 1984 1989 1994 1999 2004 2009 2014 2019
1980 1985 1990 1995 2000 2005 2010 2015 2020
1981 1986 1991 1996 2001 2006 2011 2016 2021
1982 1987 1992 1997 2002 2007 2012 2017 2022
1983 1988 1993 1998 2003 2008 2013 2018 2023
NOTE: Trends/variability in Arctic & Antarctic sea ice are affected by very different atmospheric/oceanic processes and opposite seasonality!
DATA: National Snow & Ice Data Center, Boulder CO (Arctic + Antarctic)
SOURCE: ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/ (5-day running mean)
GRAPHIC: Zachary Labe (@ZLabe)

- The rate of global warming has **accelerated**
- Every month from **June to November was the hottest** ever recorded globally.
- 2023 may be **warmer than 1.5ºC**
- Nov 17&18 2023 were the first days on record to have a global average surface temperature **above 2°C**

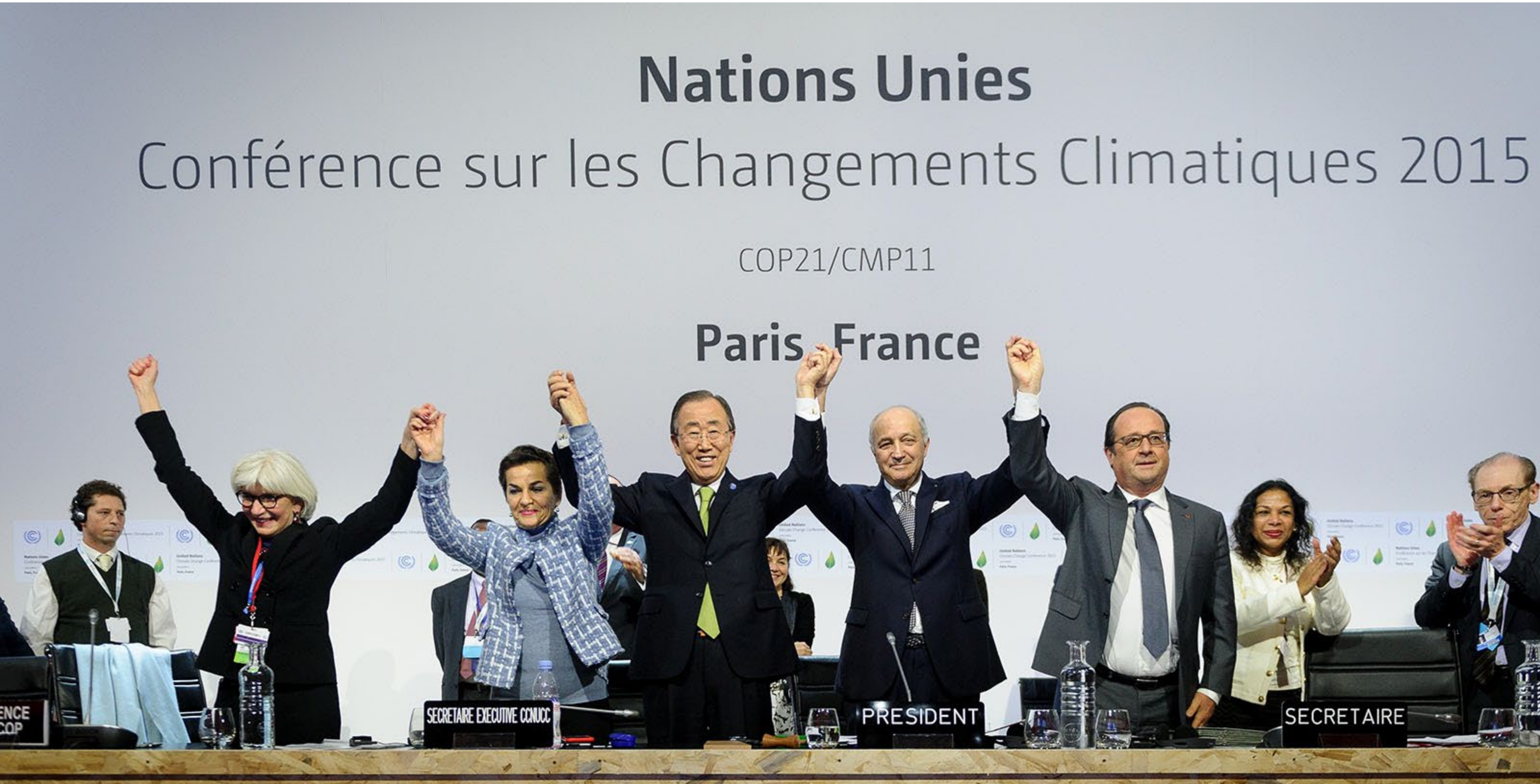


Paris Agreement, 2015

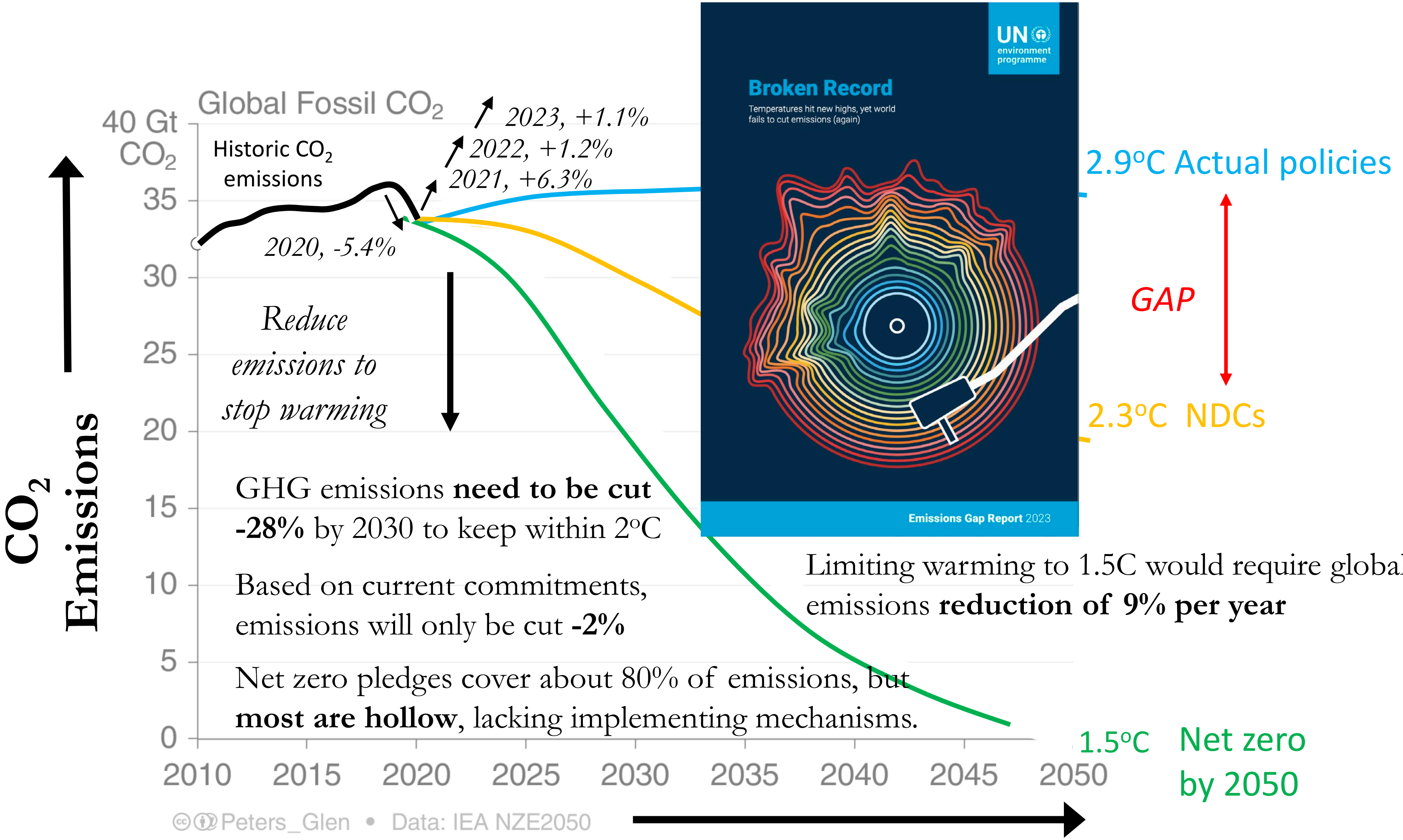
United Nations Framework Convention on Climate Change

Stop global warming before *2°C (3.6°F)*

Pursue efforts to end warming before *1.5°C (2.7°F)*



Progress on Stopping Warming at 1.5°C

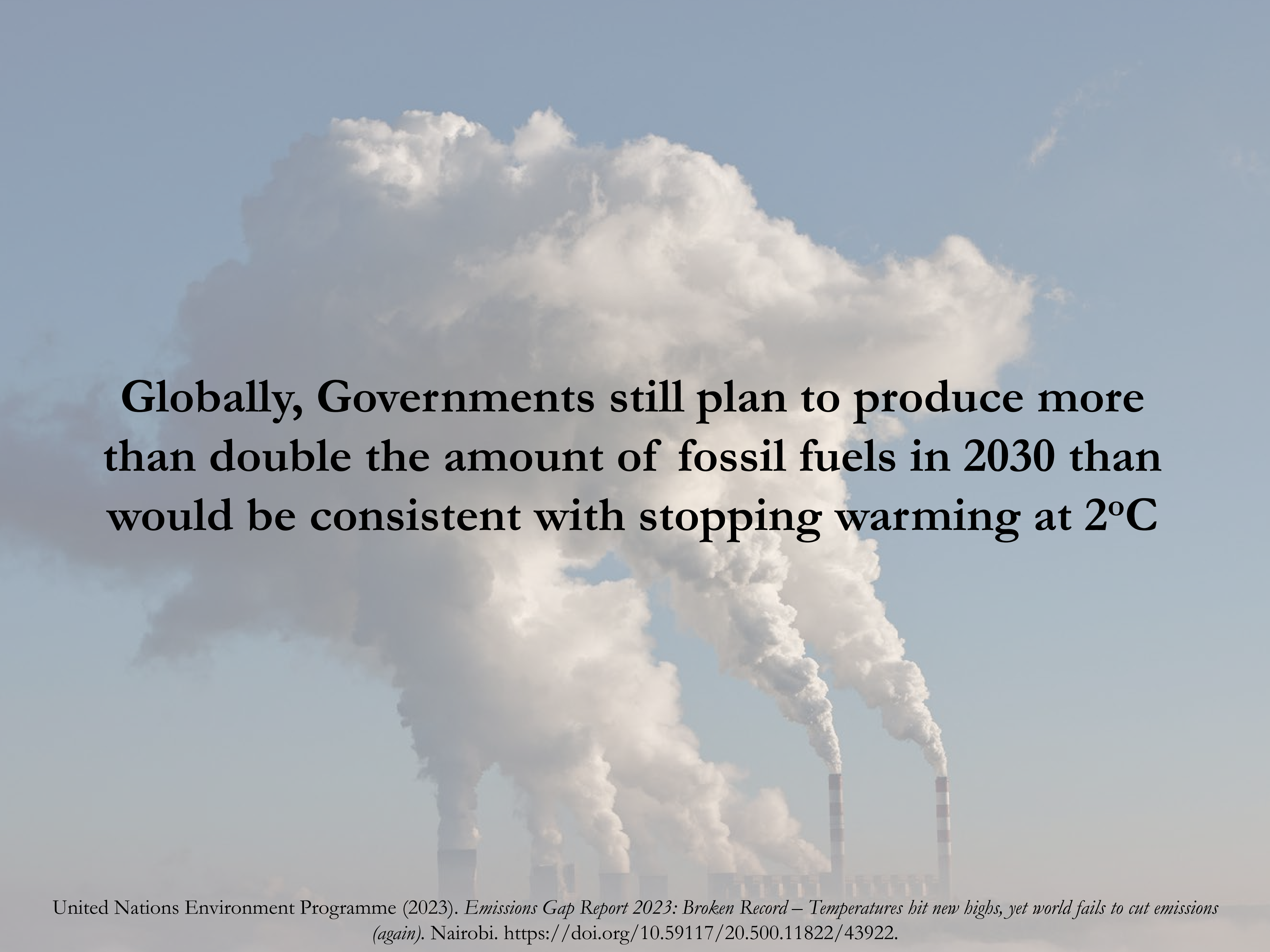


Climate Action Tracker (2022) https://climateactiontracker.org/documents/1055/CAT_2022-06-08_Briefing_EnergyCrisisReaction.pdf

Grant, N. (2022) The Paris Agreement's ratcheting mechanism needs strengthening 4-fold to keep 1.5°C alive, Joule, v. 6, p. 703-708, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2022.02.017

Meinshausen, M., Lewis, J., McGlade, C. *et al.* (2022) Realization of Paris Agreement pledges may limit warming just below 2 °C. *Nature* 604, 304–309 https://doi.org/10.1038/s41586-022-04553-z

United Nations Environment Programme (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). Nairobi. https://doi.org/10.59117/20.500.11822/43922.



Globally, Governments still plan to produce more than double the amount of fossil fuels in 2030 than would be consistent with stopping warming at 2^{o}C

United Nations Environment Programme (2023). *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again).* Nairobi. https://doi.org/10.59117/20.500.11822/43922.

Fate of anthropogenic CO_2 emissions (2010–2019)

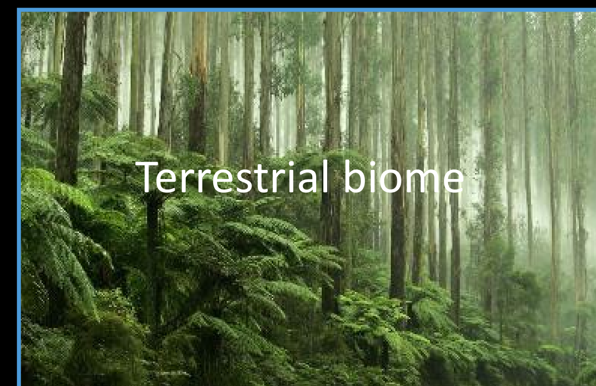
Sources = Sinks

35.3 $GtCO_2/yr$
88%

18.9 $GtCO_2/yr$
47%

12%
4.7 $GtCO_2/yr$

~~31%~~
~~12.3 $GtCO_2/yr$~~



Budget Imbalance:
(the difference between estimated sources & sinks)

3%
-1.2
$GtCO_2/yr$

26%
10.4 $GtCO_2/yr$

Source: Friedlingstein et al 2023; Global Carbon Project 2023

- Plant *photosynthesis* removes CO_2 from the air
- Plant *respiration* releases CO_2 to the air
- Photosynthesis has a heat limit, past which:
  - Photosynthesis sharply **declines**
  - Respiration continues to **increase**
  - Carbon uptake by land plants is degraded
- With continued emissions,
  - **Carbon uptake may be degraded nearly 50% as early as 2040**
- This effect is **not accounted for** in National Policies


SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

How close are we to the temperature tipping point of the terrestrial biosphere?

Katharyn A. Duffy[1,2]*, Christopher R. Schwalm[2,3], Vickery L. Arcus[4], Liyin L. Liang[4,5], Louis A. Schipper[4]

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The temperature dependence of global photosynthesis and respiration d… While the land sink currently mitigates ~30% of anthropogenic carbon emi… system service will persist and, more specifically, what hard temperature l… Here, we use the largest continuous carbon flux monitoring network to cons… temperature response curves for global land carbon uptake. We show that t… quarter (3-month period) passed the thermal maximum for photosynthes… temperatures, respiration rates continue to rise in contrast to sharply decl… business-as-usual emissions, this divergence elicits a near halving of the lan…

forests MDPI

Article

Temperate and Tropical Forest Canopies are Already Functioning beyond Their Thermal Thresholds for Photosynthesis

…u [1], Sasha C. Reed [2], Tana E. Wood [3] and Molly A. Cavaleri [1,*]

…Forest Resources & Environmental Science, Michigan Technological University, 1400 Townsend Dr., …n, MI 49931, USA; acmau@mtu.edu

…logical Survey, Southwest Biological Science Center, 2290 S. West Resource Blvd, Moab, UT 84532,

JOURNAL OF GEOPHYSICAL RESEARCH
Biogeosciences
AN AGU JOURNAL

Free Access

Are tropical forests near a high temperature threshold?

Christopher E. Doughty, Michael L. Goulden

First published: 17 October 2008 | https://doi.org/10.1029/2007JG000632 | Citations: 162

SECTIONS PDF TOOLS

Abstract

[1] We used leaf gas exchange, sap flow, and eddy covariance measurements to investigate whether high temperature substantially limits CO_2 uptake at the LBA (Large-scale Biosphere-Atmosphere) km-83 tropical forest site in Brazil. Leaf-leve… temperature-photosynthesis curves, and comparisons of whole-canopy net ecos… CO_2 exchange (NEE) with air temperature, showed that CO_2 uptake declined sha… during warm periods. Observations of ambient leaf microclimate showed that le… oscillate between two states: a cool, dimly lit stage and a hot, brightly illuminated… where leaf temperatures are often greater than 35°C. The leaf-level rates of photosynthesis decreased when shaded leaves (~ambi… μmol m^{-2} s^{-1}) were transferred into a prewa… 38°C and 1000 μmol m^{-2} s^{-1}), coincide… evaporative demand, and stomata… calculated at 5-min intervals in… followed extended cloudy pe… temperature and evaporati… The forest at km-83 appea… CO_2 uptake drops sharply… leaf temperature and leaf… disproportionately to canop… exchange is curtailed.

1\. Introduction

[2] Researchers have hypothesized that increasing te… on tropical forest production [Clark, 2004], resulting in a positive feedback that amp… global climate change [Cox et al., 2000]. High temperatures reduce CO_2 uptake by C… through reversible, short-term increases in photorespiration, respiration and stoma… closure, and, in extreme cases, irreversible damage to biochemical machinery [Berr… Björkman, 1980]. Increases in temperature that increase photorespiration, total eco… respiration, or the incidence of stomatal closure would be expected to decrease tro… forest primary production. The Amazon Forest contains 93 (±23) PgC (10^{15} g) of live aboveground, and tropical forest accounts for at least 30% of global terrestrial prim…

PNAS RESEARCH ARTICLE ECOLOGY ENVIRONMENTAL SCIENCES

No evidence of canopy-scale leaf thermoregulation to cool leaves below air temperature across a range of forest ecosystems

Edited by James Clark, Duke University, Durham, NC; received March 31, 2022; accepted June 28, 2022

Significance

Leaf temperature has long been recognized as important for plant function, and climate warming may lead to outsized impacts on leaf temperature and function. This includes carbon assimilation, as numerous studies suggest that a variety of ecosystems are operating at or near thermal thresholds. However, sustained, high-frequency measurements of canopy-scale leaf temperature across a range of ecosystems and conditions are rare. We show that daytime canopy leaf temperatures do not cool below air as predicted by the leaf homeothermy hypothesis. Leaves are typically warmer than air and the magnitude of this departure varies with leaf size and canopy structure. Almost all ecosystem photosynthesis occurs when leaf temperature exceeds air temperature. Future warming is unlikely to be mitigated by leaf cooling.

PNAS 2022 Vol. 119 No. 38 e2205682119 https://doi.org/10.1073/pnas.2205682119 1 of 8

CLIMATOLOGY

Deadly heat waves projected in the densely populated agricultural regions of South Asia

Eun-Soon Im,[1]* Jeremy S. Pal,[2]* Elfatih A. B. Eltahir[3]†

The risk associated with any climate change impact reflects intensity of natural hazard and level of human vulnerability. Previous work has shown that a wet-bulb temperature of 35°C can be considered an upper limit on human survivability. On the basis of an ensemble of high-resolution climate change simulations, we project that extremes of wet-bulb temperature in South Asia are likely to approach and, in a few locations, exceed this critical threshold by the late 21st century under the business-as-usual scenario of future greenhouse gas emissions. The most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins. Climate change, without mitigation, presents a serious and unique risk in South Asia, a region inhabited by about one-fifth of the global human population, due to an unprecedented combination of severe natural hazard and acute vulnerability.

INTRODUCTION

The risk of human illness and mortality increases in hot and humid weather associated with heat waves. Sherwood and Huber (*1*) proposed the concept of a human survivability threshold based on wet-bulb temperature (*TW*). *TW* is defined as the temperature that an air parcel would attain if cooled at constant pressure by evaporating water within it until saturation. It is a combined measure of temperature [that is, dry-bulb temperature (*T*)] and humidity (*Q*) that is always less than or equal to *T*. High values of *TW* imply hot and humid conditions and vice versa. The increase in *TW* reduces the differential between human body skin temperature and the inner temperature of the human body, which reduces the human body's ability to cool itself (*2*). Because normal human body temperature is maintained within a very narrow limit of ±1°C (*3*), disruption of the body's ability to regulate temperature can immediately impair physical and cognitive functions (*4*). If ambient air *TW* exceeds 35°C (typical human body skin temperature under warm conditions), metabolic heat can no longer be dissipated. Human exposure to *TW* of around 35°C for even a few hours will result in death even for the fittest of humans under shaded, well-ventilated conditions (*1*). While *TW* well below 35°C can pose dangerous conditions for most humans, 35°C can be considered an upper limit on human survivability in a natural (not air-conditioned) environment. Here, we consider maximum daily *TW* values averaged over a 6-hour window (TW_{max}), which is considered the maximum duration fit humans can survive at 35°C.

HISTORICAL DISTRIBUTION OF MAXIMUM WET-BULB TEMPERATURE

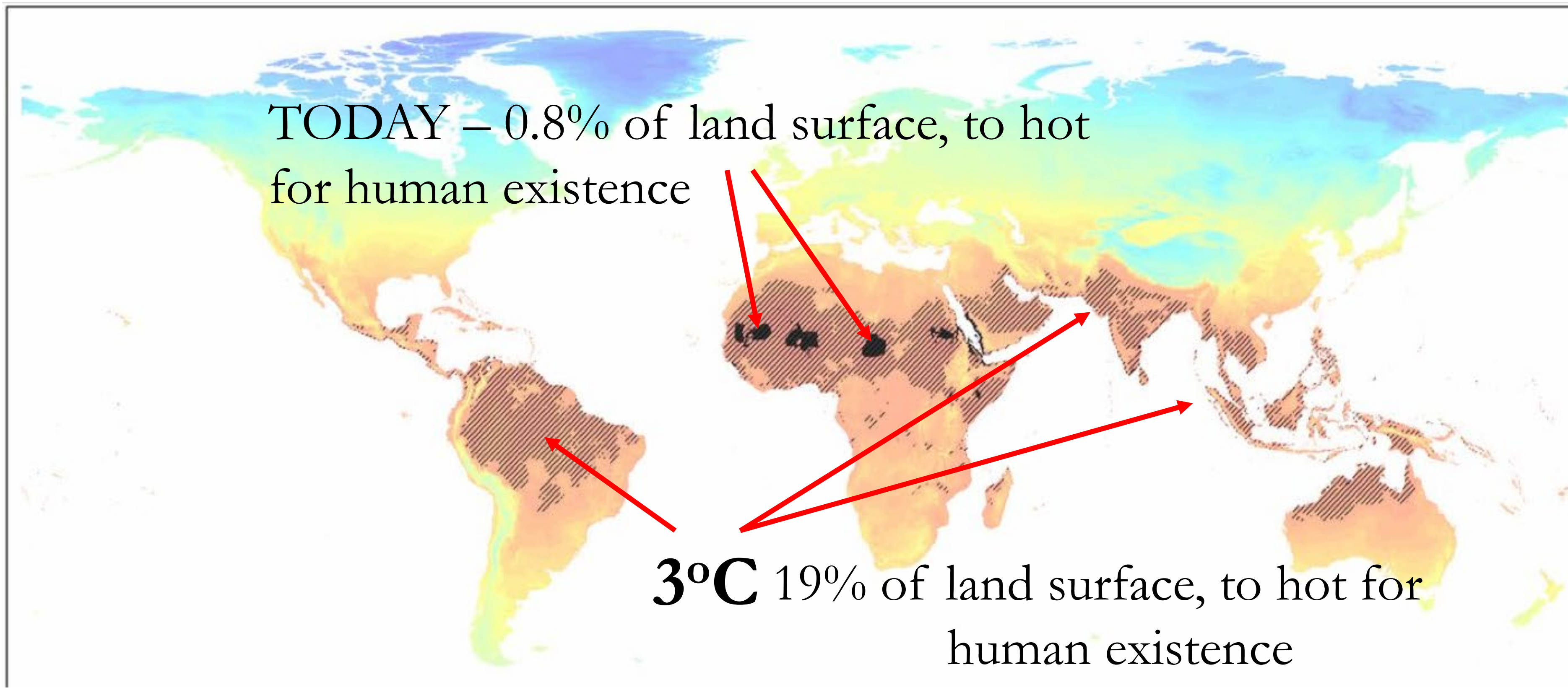
According to the global historical reanalysis for modern record (1979–2015) (*5*), the largest TW_{max} rarely exceeds 31°C in the current climate. However, three extensive regions, where values exceed 28°C, are observed: southwest Asia around the Persian/Arabian Gulf and Red Sea, South Asia in the Indus and Ganges river valleys, and eastern China (Fig. 1). To identify the precise reasons for high *TW*, individual studies need to be performed because of each region's unique geography and climate. The underlying reasons why southwest Asia stands out are discussed by Pal and Eltahir (*6*), who concluded that future TW_{max} around the Persian/Arabian Gulf region is likely to exceed the *TW* threshold for human survivability by the end of the century under a business-as-usual (BAU) scenario of atmospheric greenhouse gas (GHG) concentrations. In summer 2015, *TW* in the Bandar Mahshahr, Iran Persian/Arabian Gulf, reached nearly 35°C, suggesting that the threshold may be breached sooner than projected (*7*). In this study, we shift our attention to the region of South Asia, here defined as Pakistan, Nepal, India, Bangladesh, and Sri Lanka. The northern part of this region is the second hottest after southwest Asia but is more expansive when considering the land area affected.

Heat waves and their impacts on human health are combined consequences of high dry-bulb temperatures and humidity (that is, high *TW*) and the vulnerability of the population. Many previous studies have investigated the impacts of anthropogenic climate change on heat waves and human health (*8*, *9*). However, it is not until more recently that the combined effects of temperature and humidity have been more commonly considered. For example, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (*10*) when making projections about future heat waves only considers *T*. However, the latest IPCC report (*11*) does consider the combined effects of *T* and *Q* when considering working conditions, which are projected to worsen considerably in many regions (*12*, *13*). In addition, studies that include the combined effects at a global scale are largely based on output from climate models with resolutions on the order of 100 to 200 km (*1*, *14*). Studies that are based on higher-resolution simulations are generally focused on North America and Europe (*15*, *16*). However, the most detrimental human impacts of climate change on heat waves could potentially be those in developing nations because of the vulnerability of their populations. In much of India and Pakistan, an apparent rising trend in the frequency of deadly heat waves has been observed (*17*–*19*). For example, severe heat waves resulting in thousands of deaths to humans and livestock were reported around Odisha (eastern India) in 1998, Andhra Pradesh in 2003, and Ahmadabad and other parts of Gujarat (western India) in 2010 (*20*). In particular, the fifth deadliest heat wave in recorded history (*21*) affected large parts of India and Pakistan, claiming around

[1]Division of Environment and Sustainability, Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong. [2]Department of Civil Engineering and Environmental Science, Loyola Marymount University, Los Angeles, CA 90045, USA. [3]Ralph M. Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.
*These authors contributed equally to this work.
†Corresponding author. Email: eltahir@mit.edu

Warming on Land

1 billion displaced for every 1°C of additional global warming



Xu, C., et al. (2020) Future of the human climate niche, *PNAS*, May 2020, 201910114; DOI:10.1073/pnas.1910114117

After 200 yrs of fossil fuel expansion we are at a turning point in the global energy system

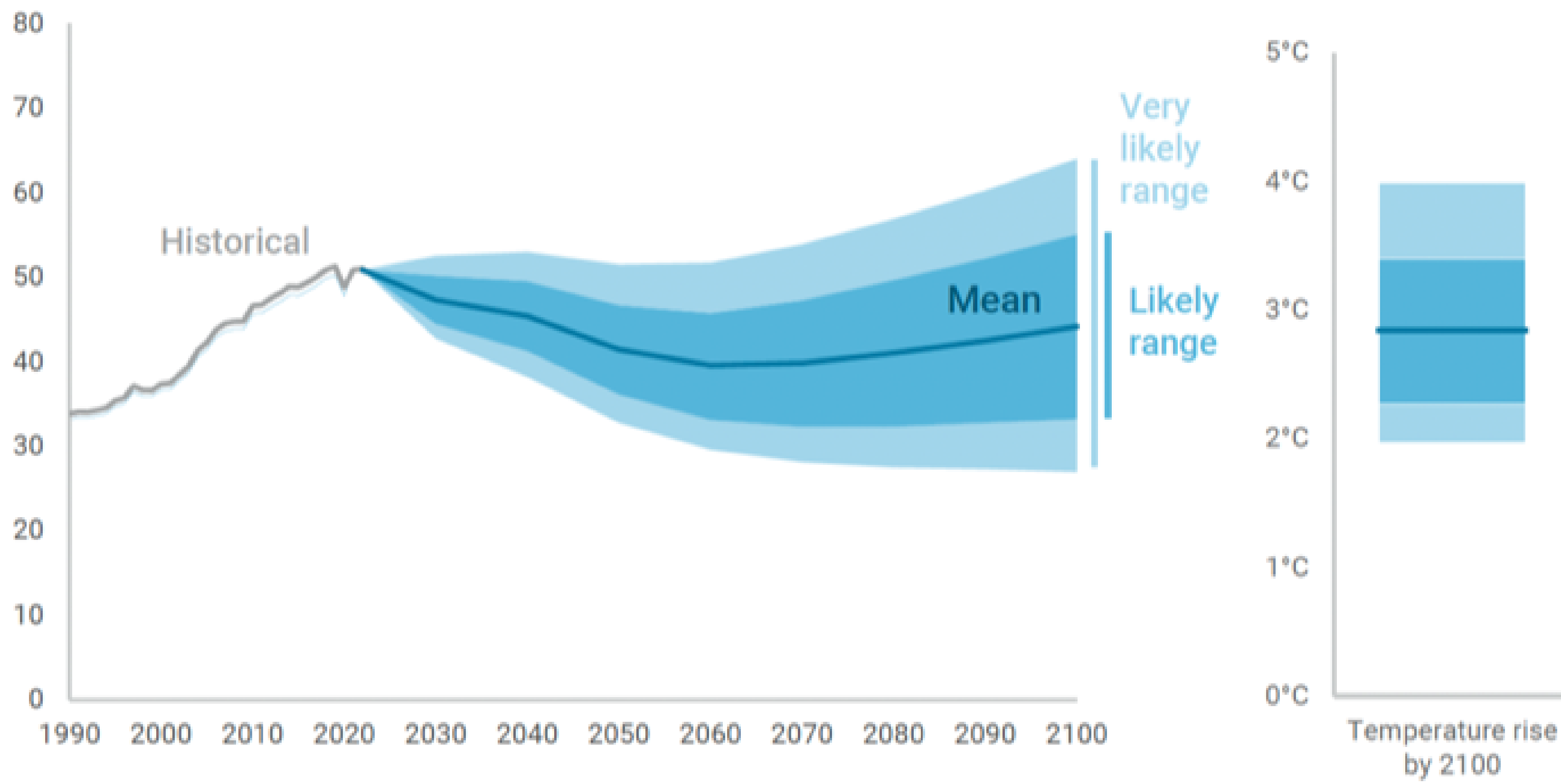
- World spent $1.8 trillion transitioning to clean power last year, more than spent producing oil & gas.
- Rooftop solar grew nearly 50% globally last year
- 2020 - 1 in 25 cars sold was electric
- 2023 - 1 in 5 cars sold was electric
- **Global energy demand growth will now "almost entirely be met by renewables" IEA**
- Economic growth no longer requires rising emissions
- **However, Ambition needs to accelerate**
  - We are headed for a long plateau of continued emissions
  - In 2022 solar and wind produced 12% of global electricity.
  - **By 2030 this must increase to 41% of global electricity** (to be on track for net-zero by 2050).

https://www.businessgreen.com/news/4061209/extraordinary-iea-heralds-energy-crisis-‘historic-point-renewables?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20221206&utm_medium=email&utm_source=Revue%20Daily

FIGURE 1

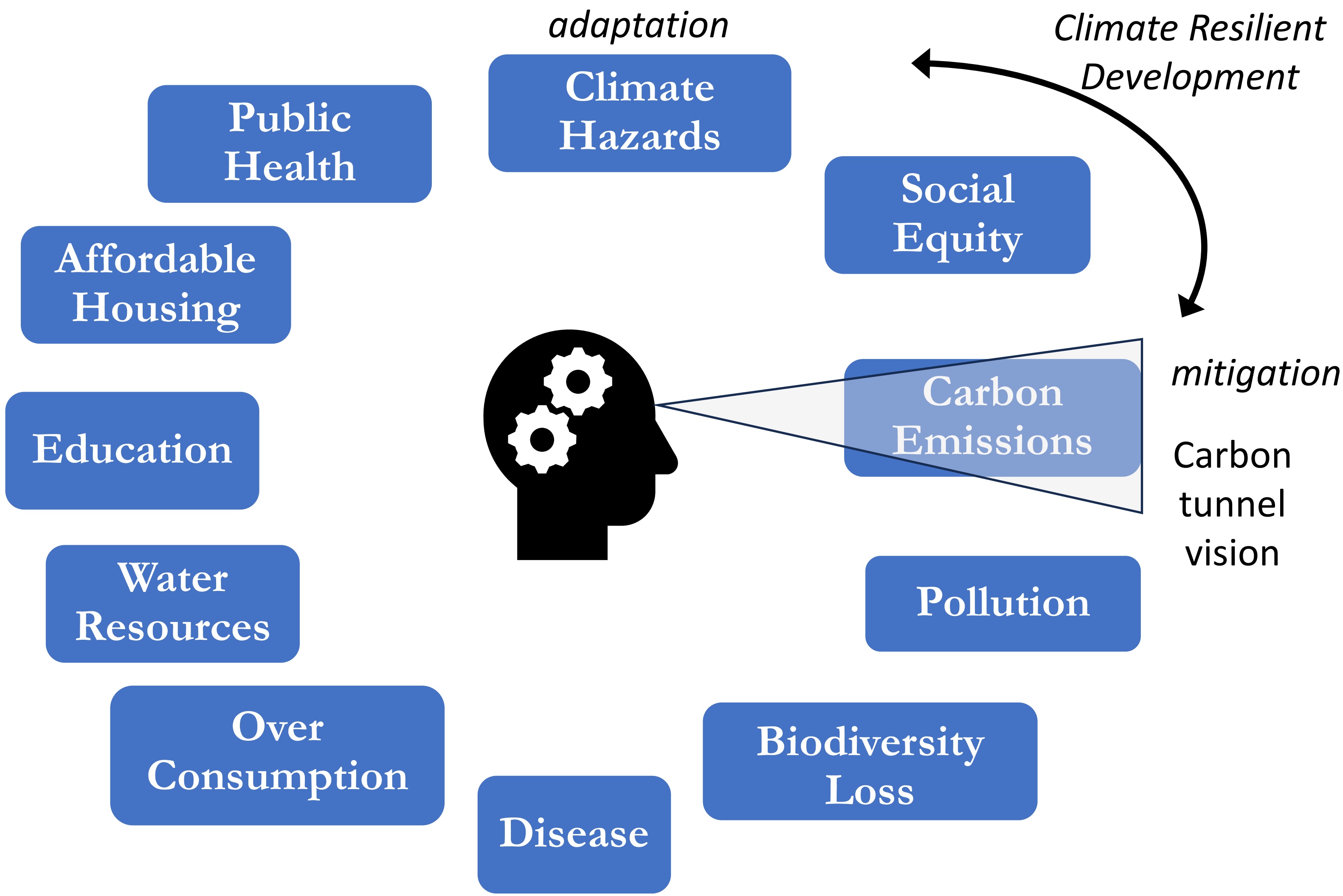
Global greenhouse gas emissions and temperature rise

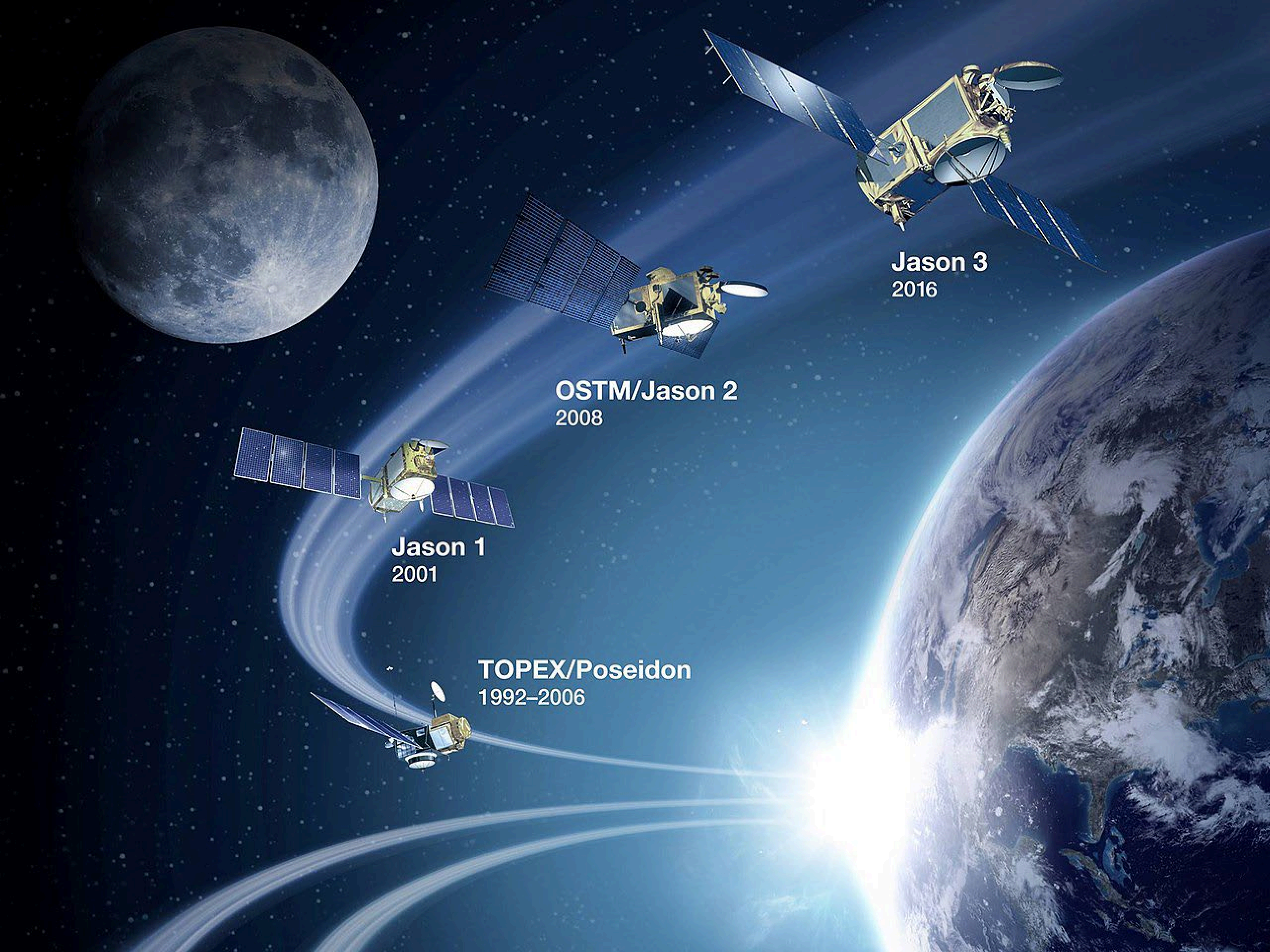
Net emissions including removals (billion metric tons of CO_2-equivalent)



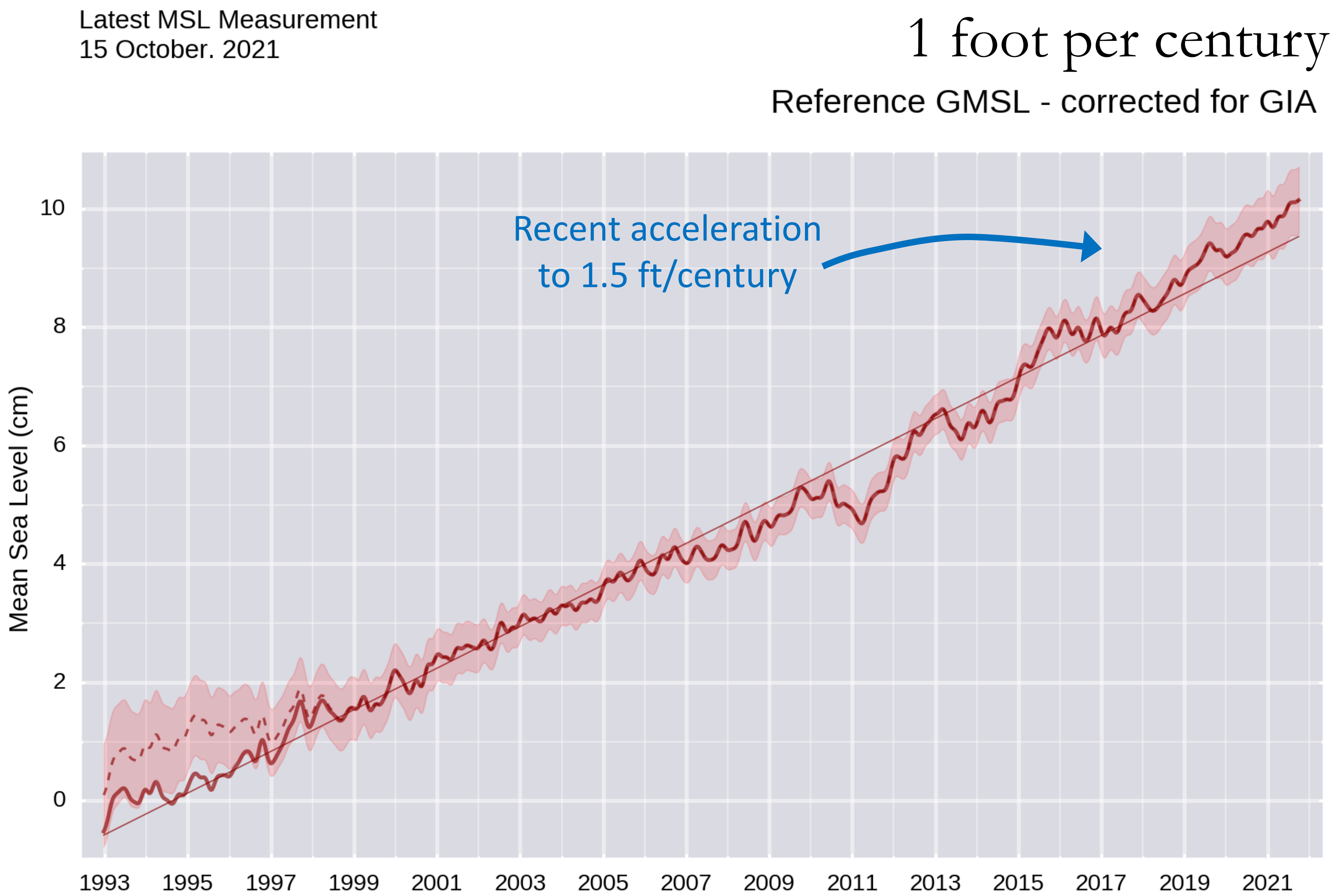
Source: Rhodium Climate Outlook, AR5 100-year GWP values. Following IPCC conventions, this report uses *very likely* to indicate a 90% probability of occurring and *likely* to indicate a 67% probability.

Sustainability Transition

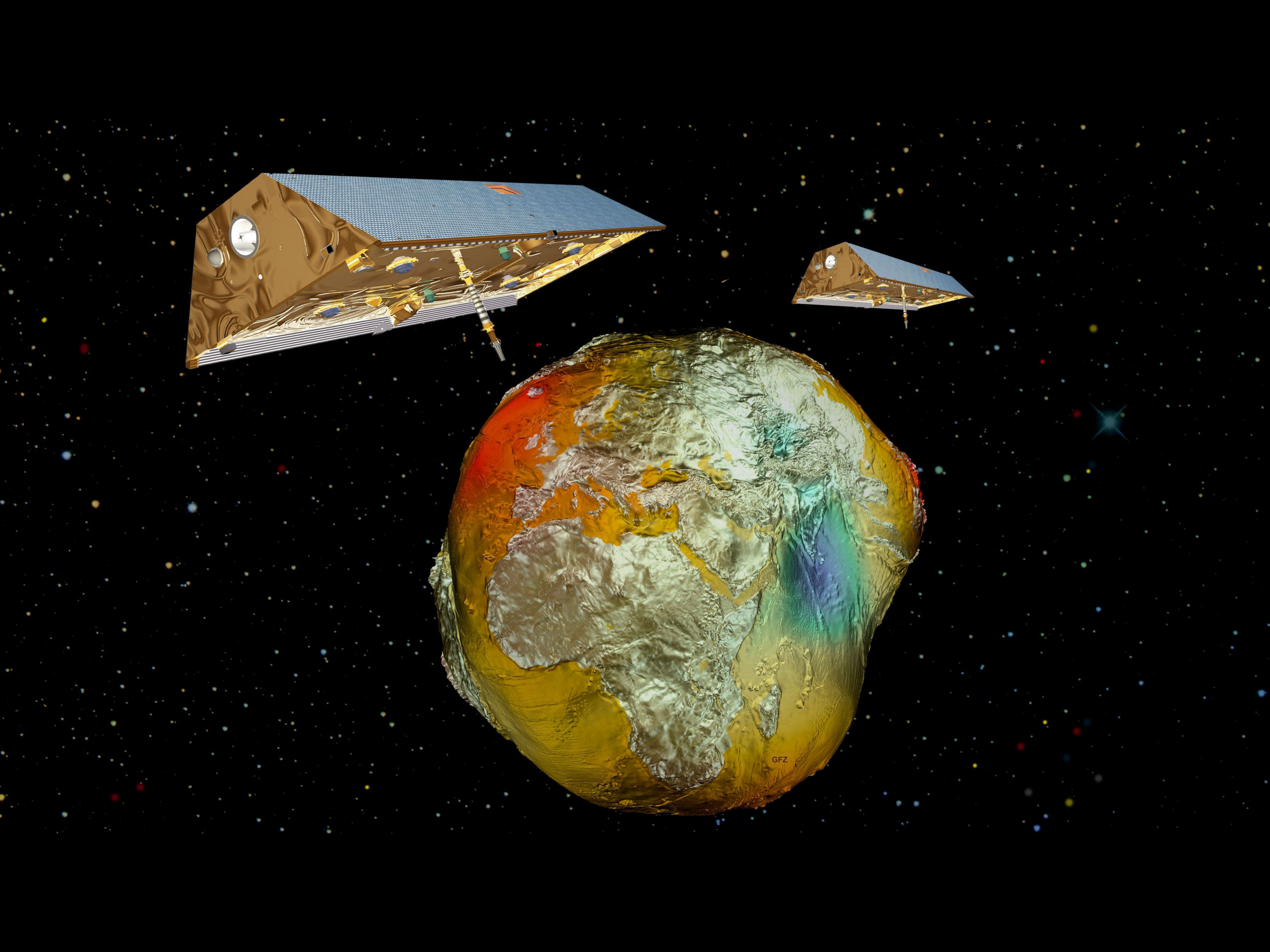


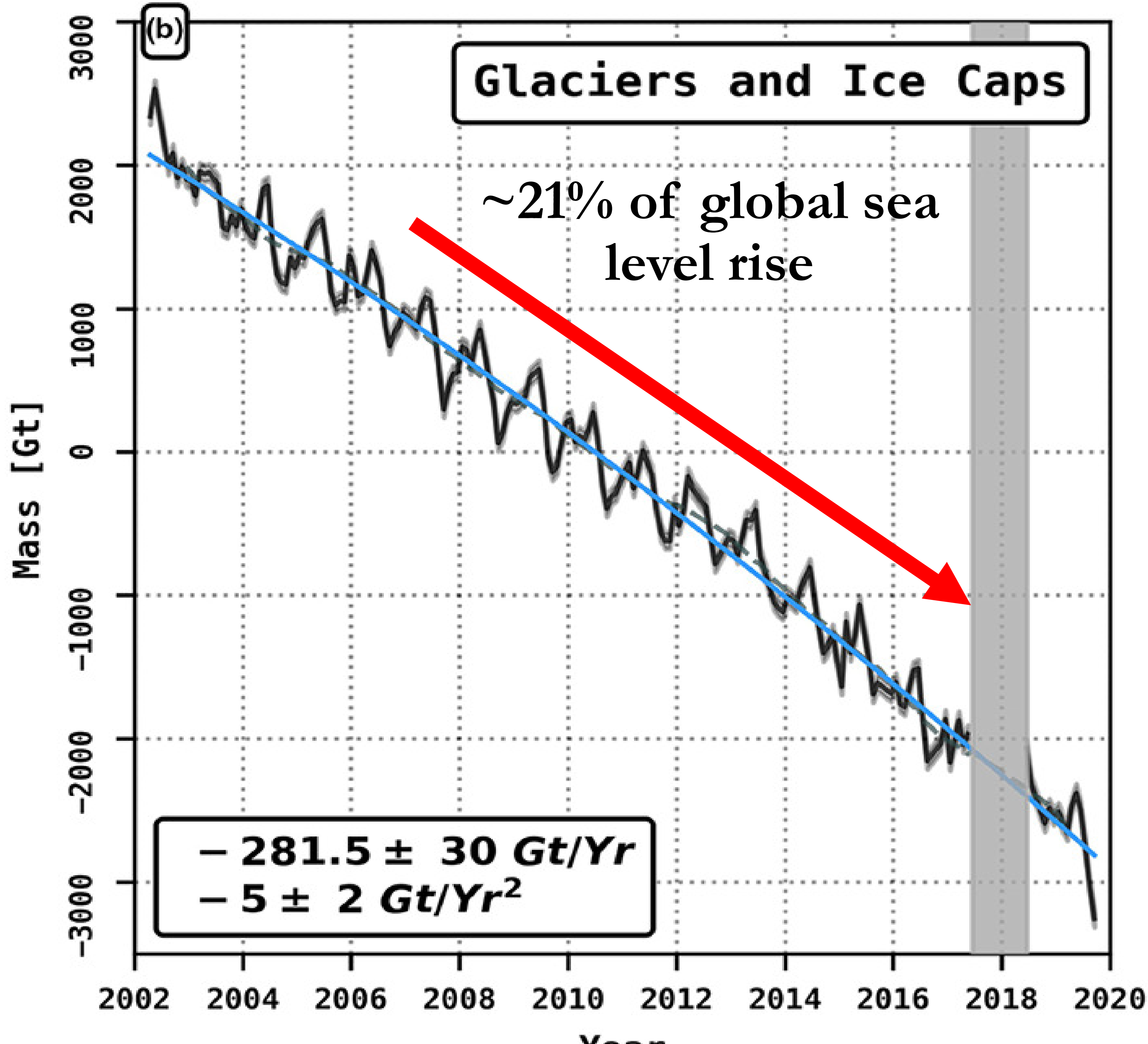

Jason 3
2016
OSTM/Jason 2
2008
Jason 1
2001
TOPEX/Poseidon
1992–2006

Global Mean Sea Level Rise



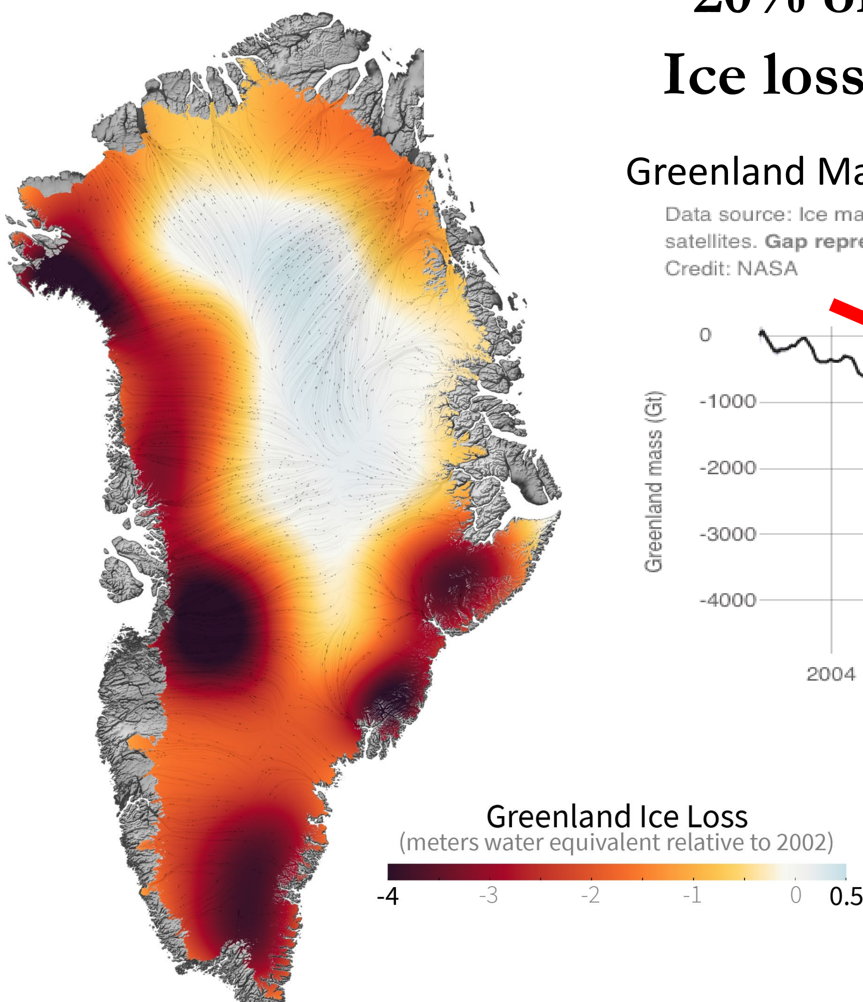
https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html


GFZ



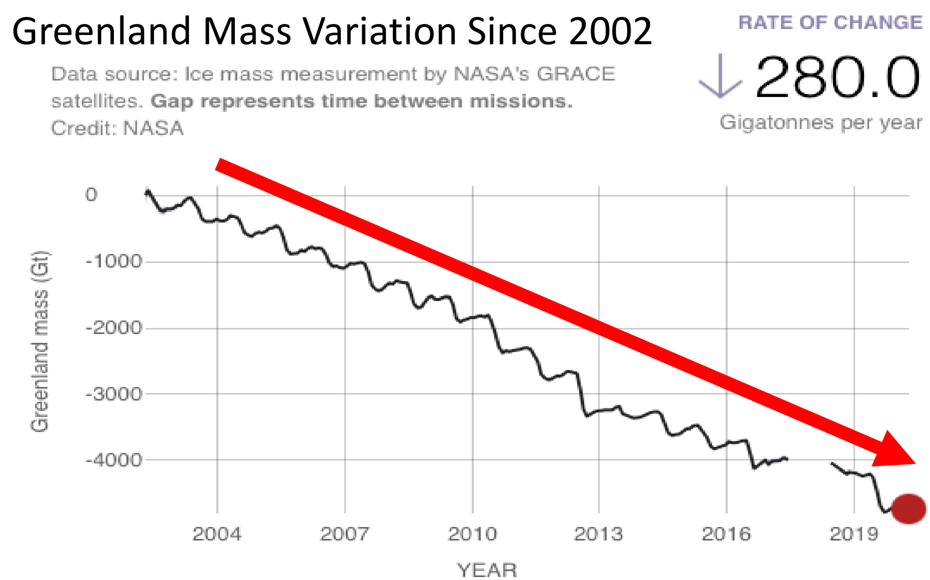
(b)
Glaciers and Ice Caps
~21% of global sea level rise
−281.5 ± 30 Gt/Yr
−5 ± 2 Gt/Yr²
Mass [Gt]
3000
2000
1000
0
−1000
−2000
−3000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year

Greenland melting has quadrupled since 2010



~20% of global sea level rise

Ice loss, billions of tonnes



Bevis, M. et al. (2019) Accelerating changes in ice mass within Greenland, and the ice sheets sensitivity to atmospheric forcing. PNAS, 116, 1934-1939. King, M.D., *et al.* (2020) Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. *Commun Earth Environ* **1**. https://doi.org/10.1038/s43247-020-0001-2

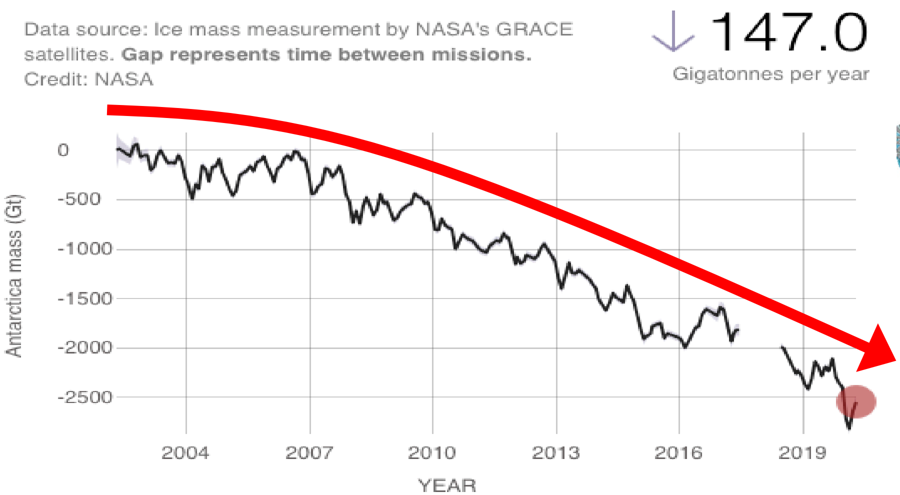
Antarctic ice melt has tripled since 2010

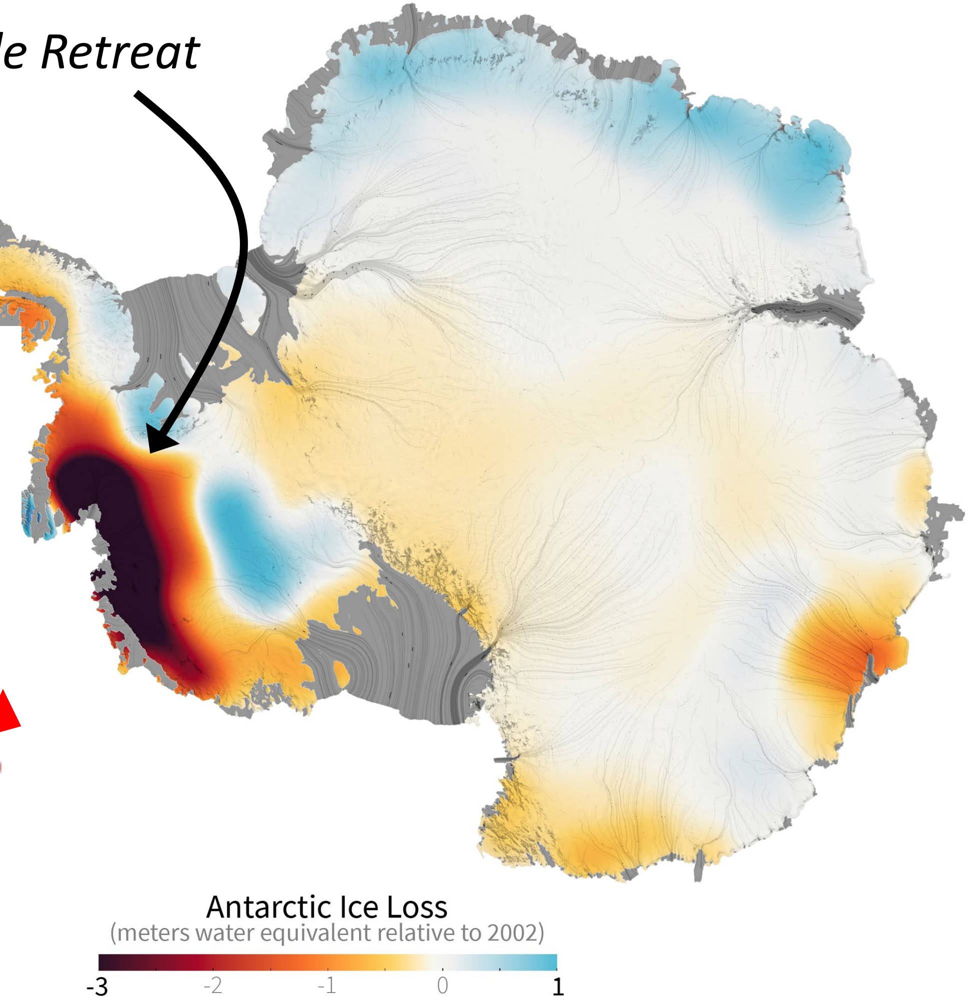
~9% of global sea level rise

West Antarctic Glaciers are in Irreversible Retreat

Ice loss, billions of tonnes

Antarctica Mass Variation Since 2002

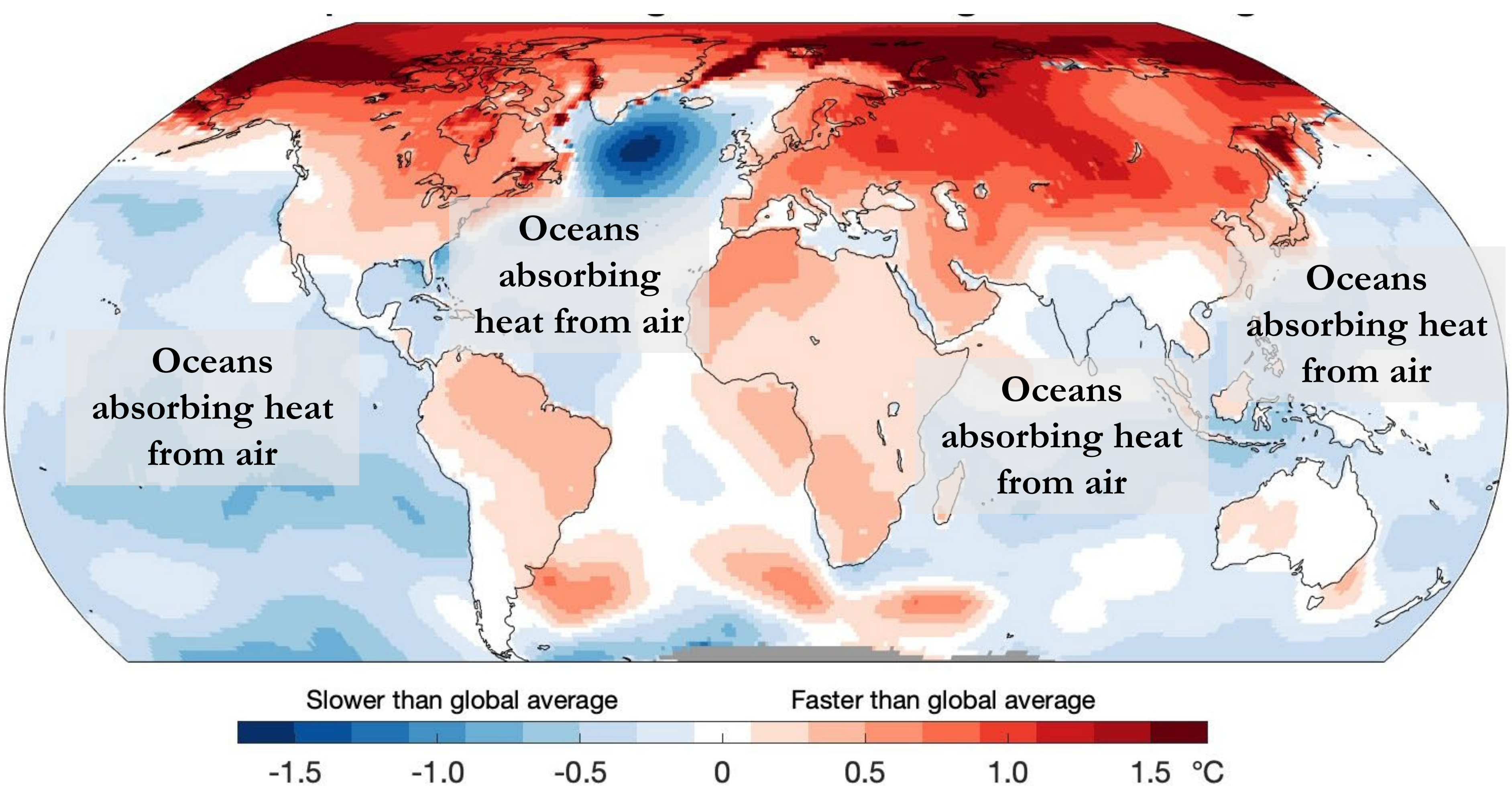




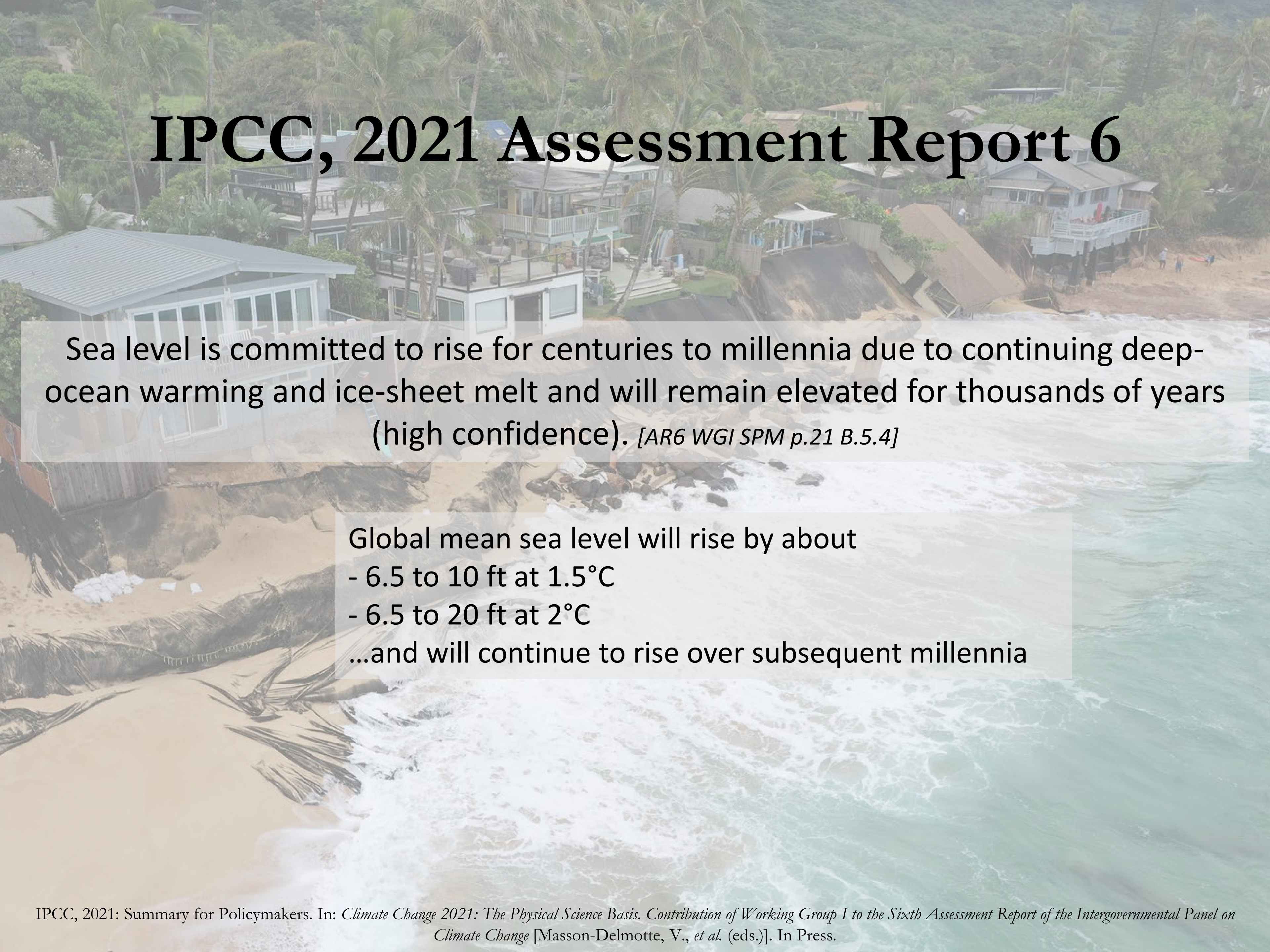
The IMBIE team (2018) Mass Balance of the Antarctic Ice Sheet, *Nature*, 558, pages219–222, https://doi.org/10.1038/s41586-018-0179-y

Temperature change relative to global average

Thermal expansion ~38% of SLR



Groundwater Depletion ~10%



IPCC, 2021 Assessment Report 6

Sea level is committed to rise for centuries to millennia due to continuing deep-ocean warming and ice-sheet melt and will remain elevated for thousands of years (high confidence). *[AR6 WGI SPM p.21 B.5.4]*

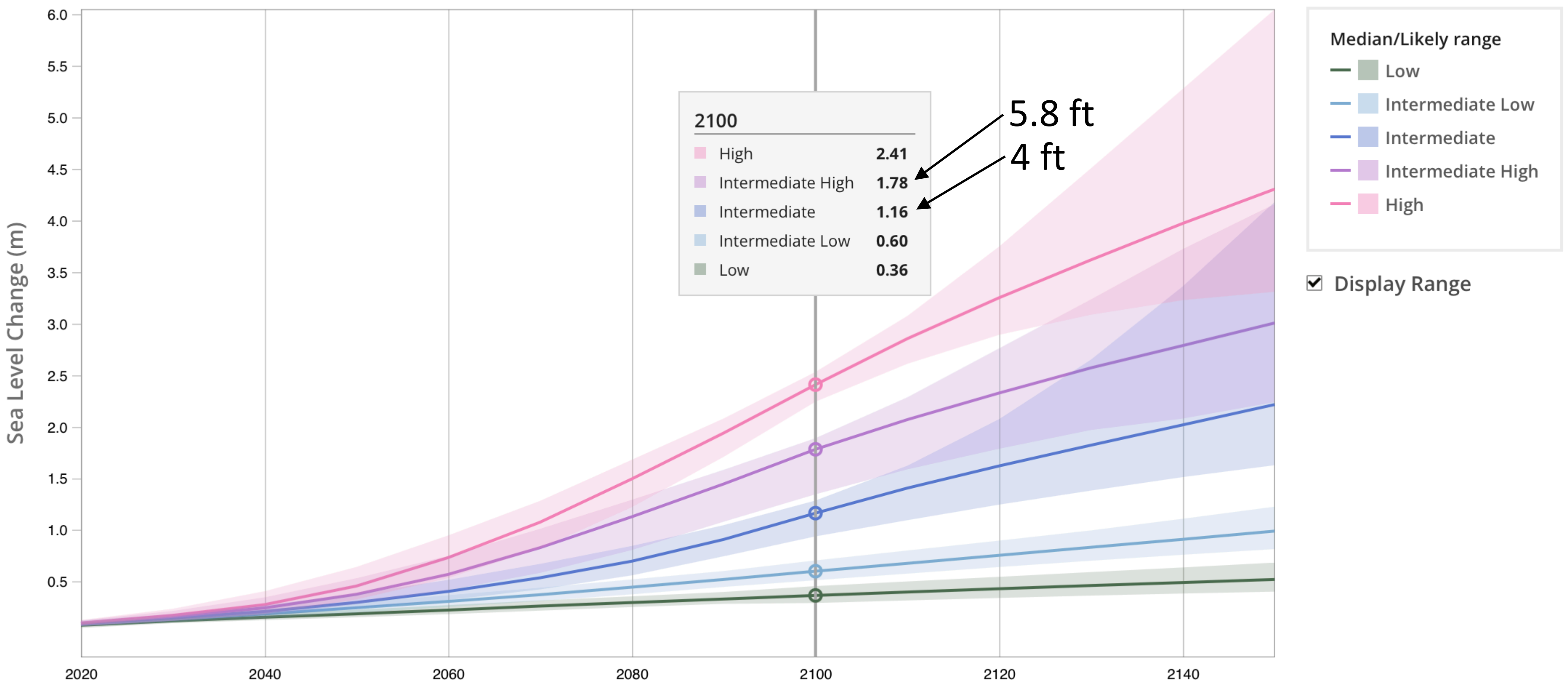
Global mean sea level will rise by about
- 6.5 to 10 ft at 1.5°C
- 6.5 to 20 ft at 2°C
…and will continue to rise over subsequent millennia

IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., *et al.* (eds.)]. In Press.

Photo, S. Habel

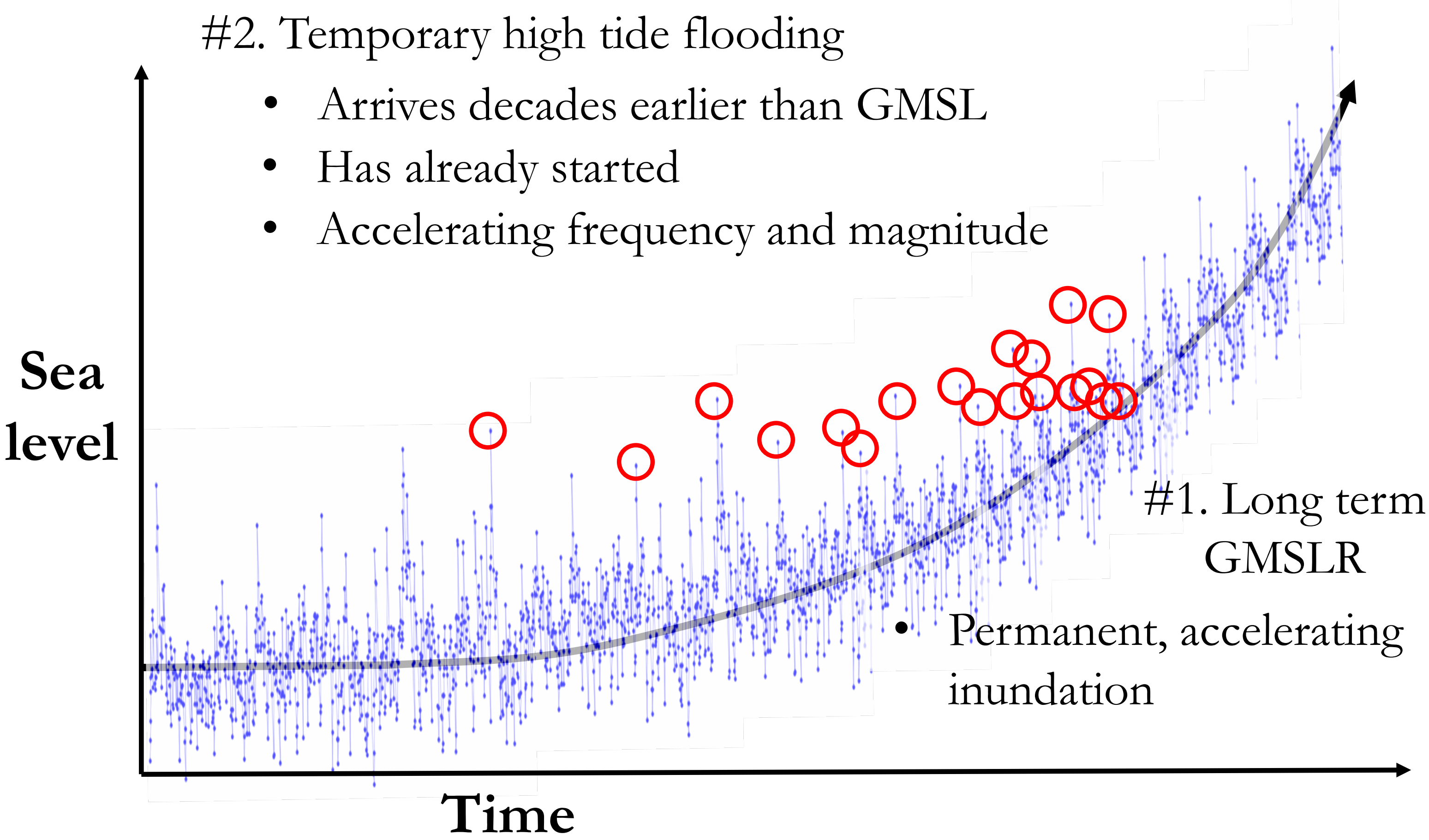

How high will sea level rise?

NOAA/NASA SLR Planning Scenarios
Honolulu, Oahu



https://sealevel.nasa.gov/task-force-scenario-tool

SLR Flooding: Nuisance and Permanent

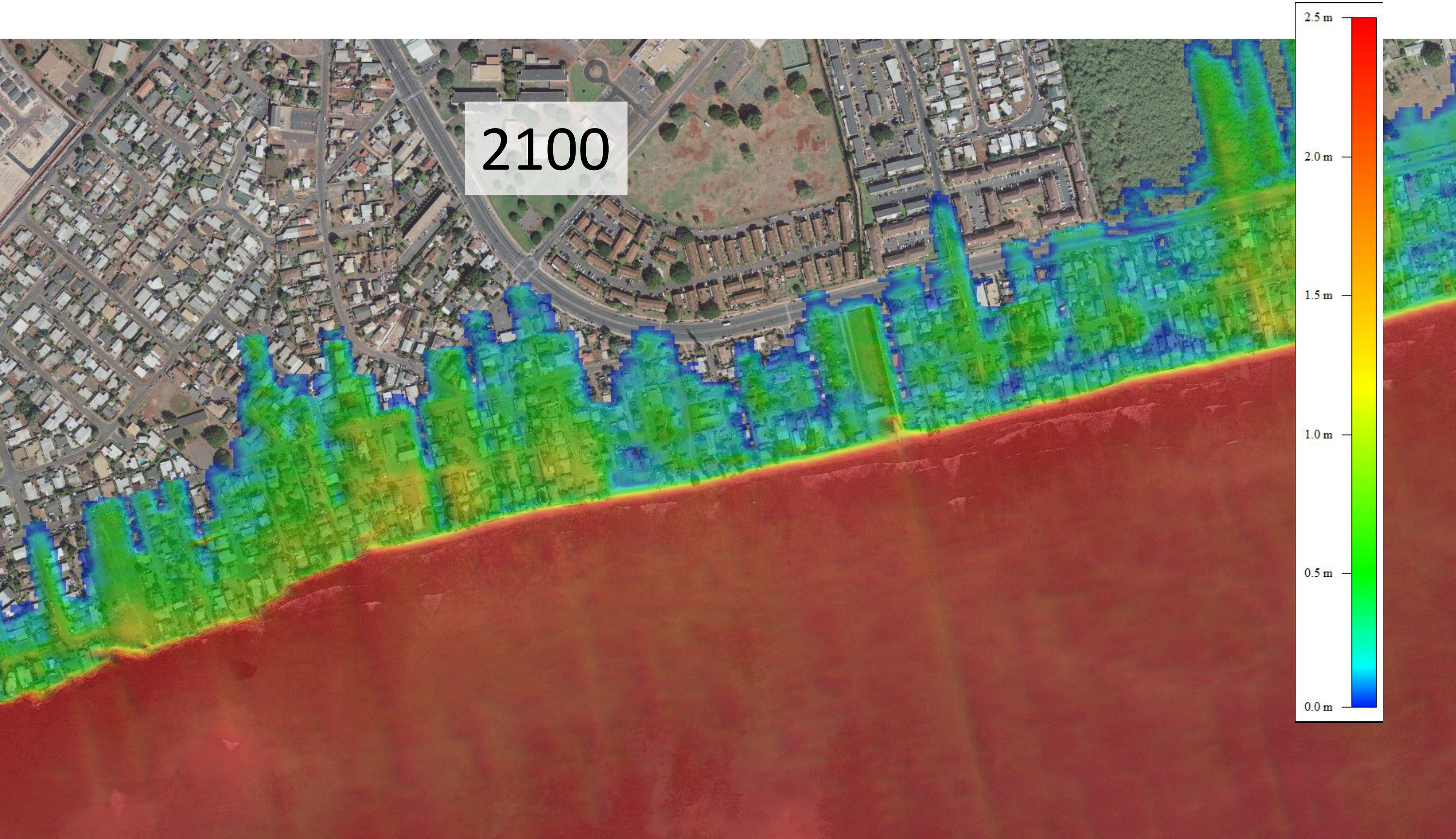


What are the impacts of SLR?

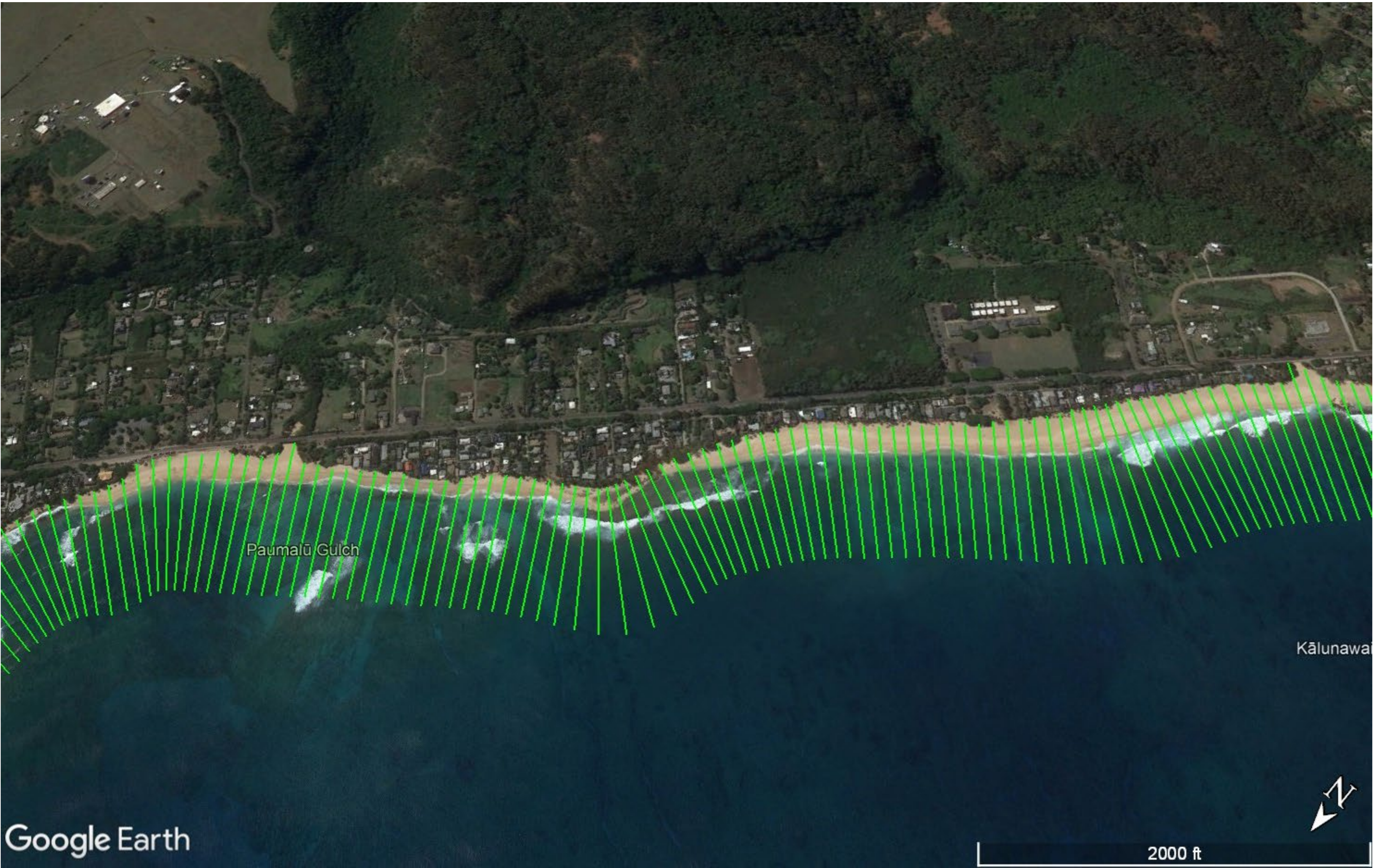
Ewa Beach – Wave Flooding, 1ft

Ewa Beach – Wave Flooding, 2-3ft

Ewa Beach – Wave Flooding, 4ft

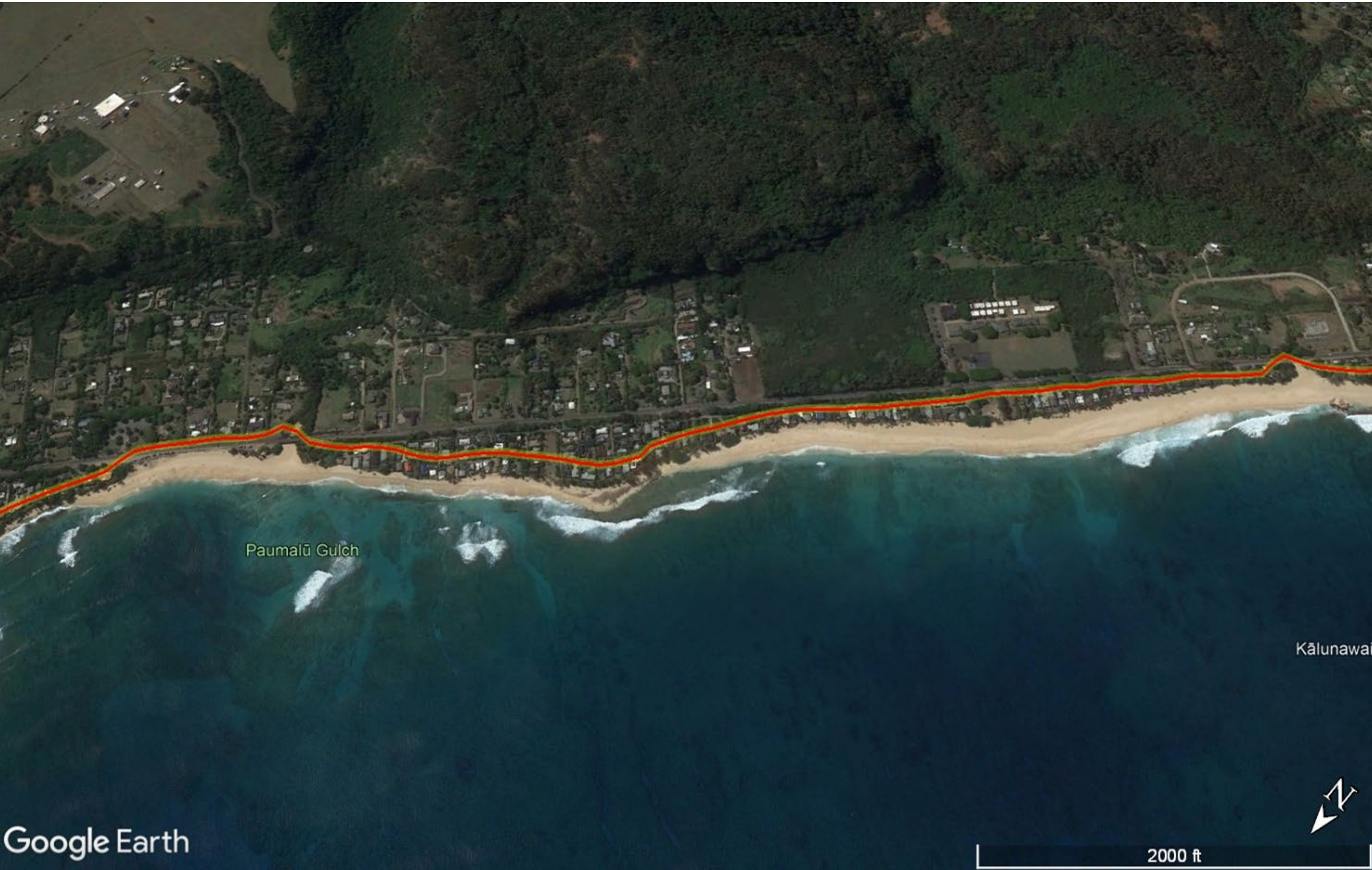


Sunset Beach – Coastal Erosion



Sunset Beach – Coastal Erosion, 1 ft

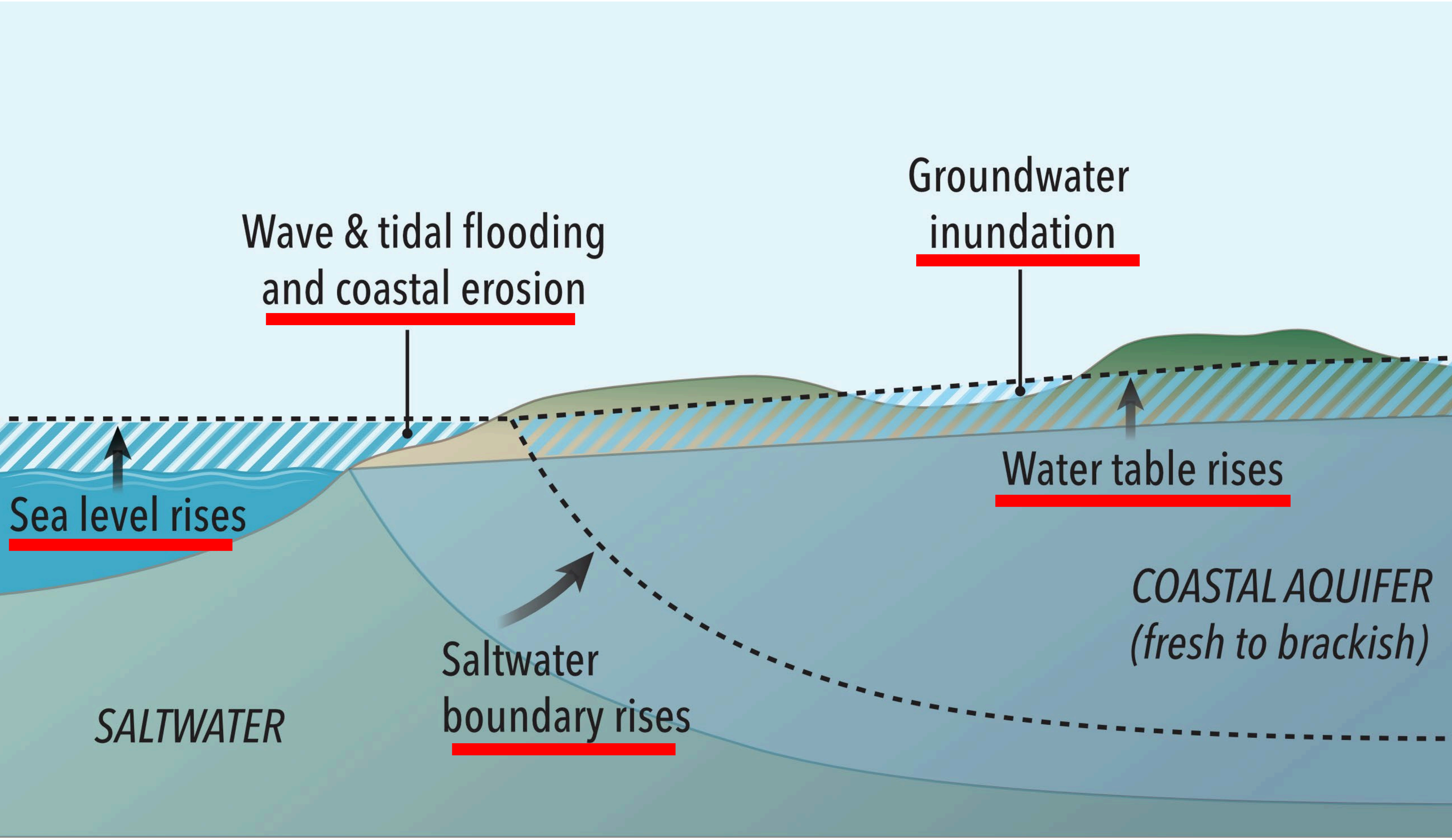
Sunset Beach – Coastal Erosion, 2 ft



Sunset Beach – Coastal Erosion, 3 ft

Sunset Beach – Coastal Erosion, 4 ft

SLR Flooding




As sea level rises, so does
the water table

SLR will bring polluted groundwater to the surface

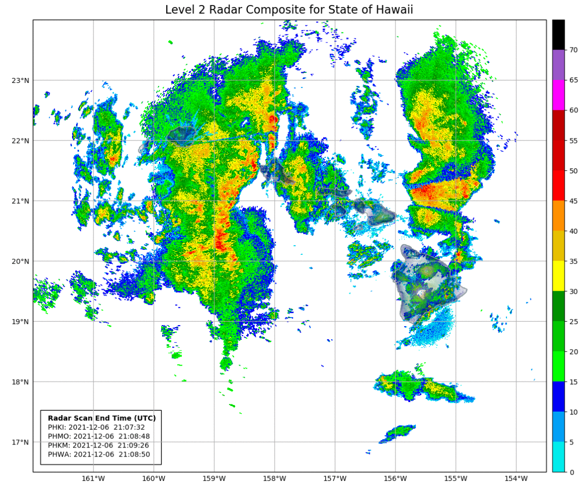
Groundwater Pollution

Storm drain backflow

Rain + High Tide = Compound Flooding

Waikiki
Dec. 5, 2021

- Sea level rise flooding today involves
  - Rain
  - Extreme tides
  - Onshore winds
  - Large waves




Thank you for your time
https://www.wbsida.org/waikiki-beach-improvements
Rendering By Jonathan Quach, Inde

https://www.soest.hawaii.edu/crc/slr-viewer/index.php?map=kp