

# POTSDAM-İNSTITUT FÜR KLIMAFOLGENFORSCHUNG



## Science and Planetary Health Check Update

ICEF - Innovation for Cool Earth Forum Tokyo, 09 October 2024

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Professor in Earth System Science, University of Potsdam





# Human Wellbeing within stable Planet

Anthropocene - Humans dominating force of change on Earth

Holocene — The only state of the Planet we know for certain can support our world

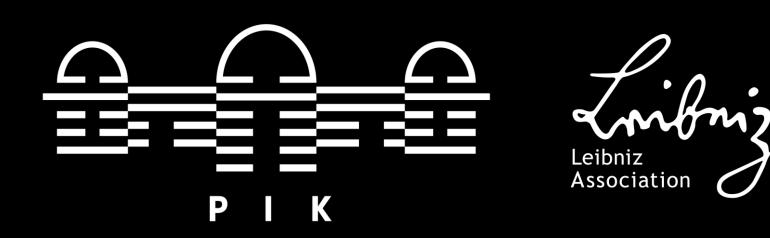
Tipping Points & Resilience — Earth as a self-regulating system



World Development within Planetary Boundaries



Transformations to prosperity and equity

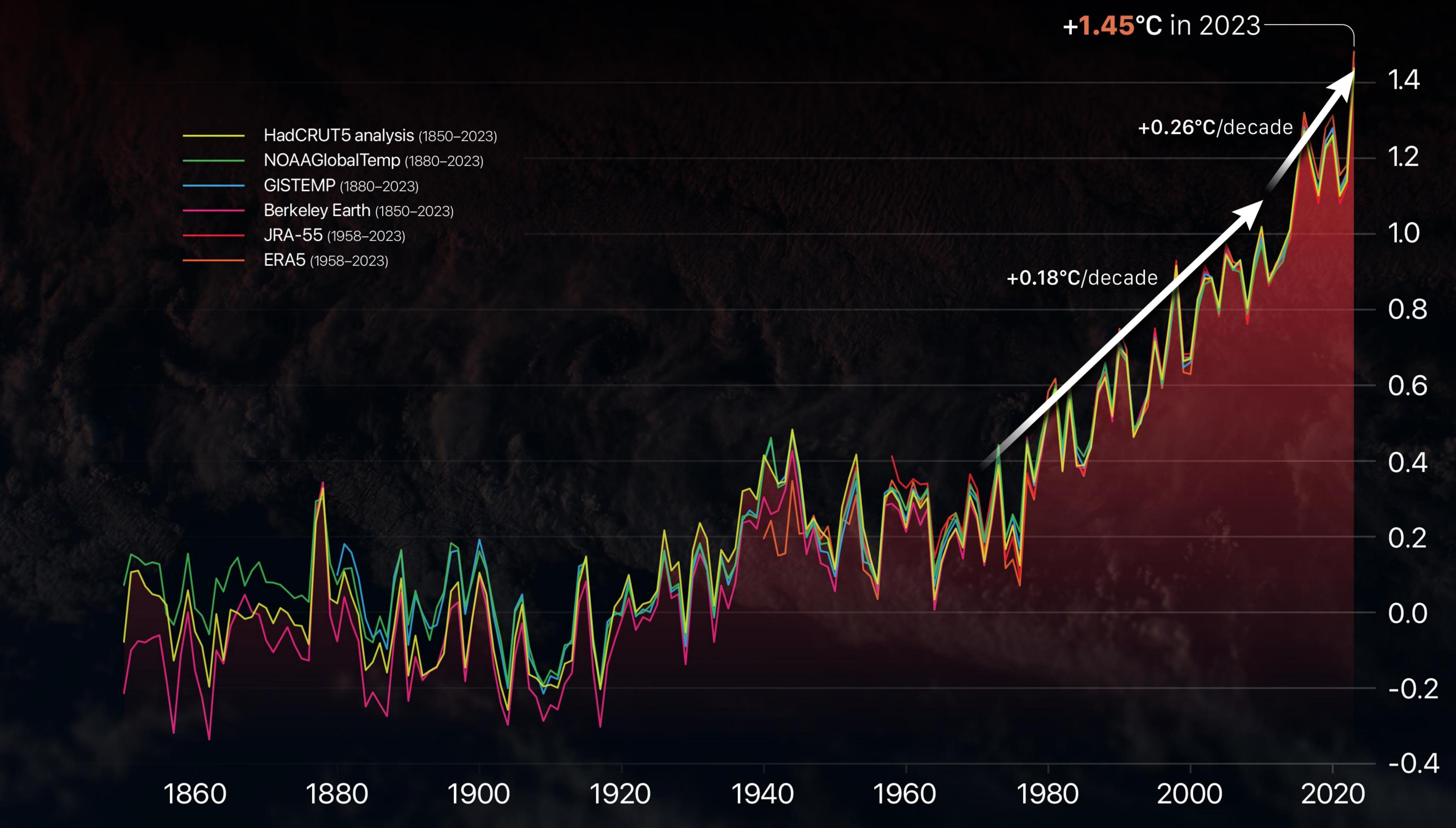


# Anthropocene

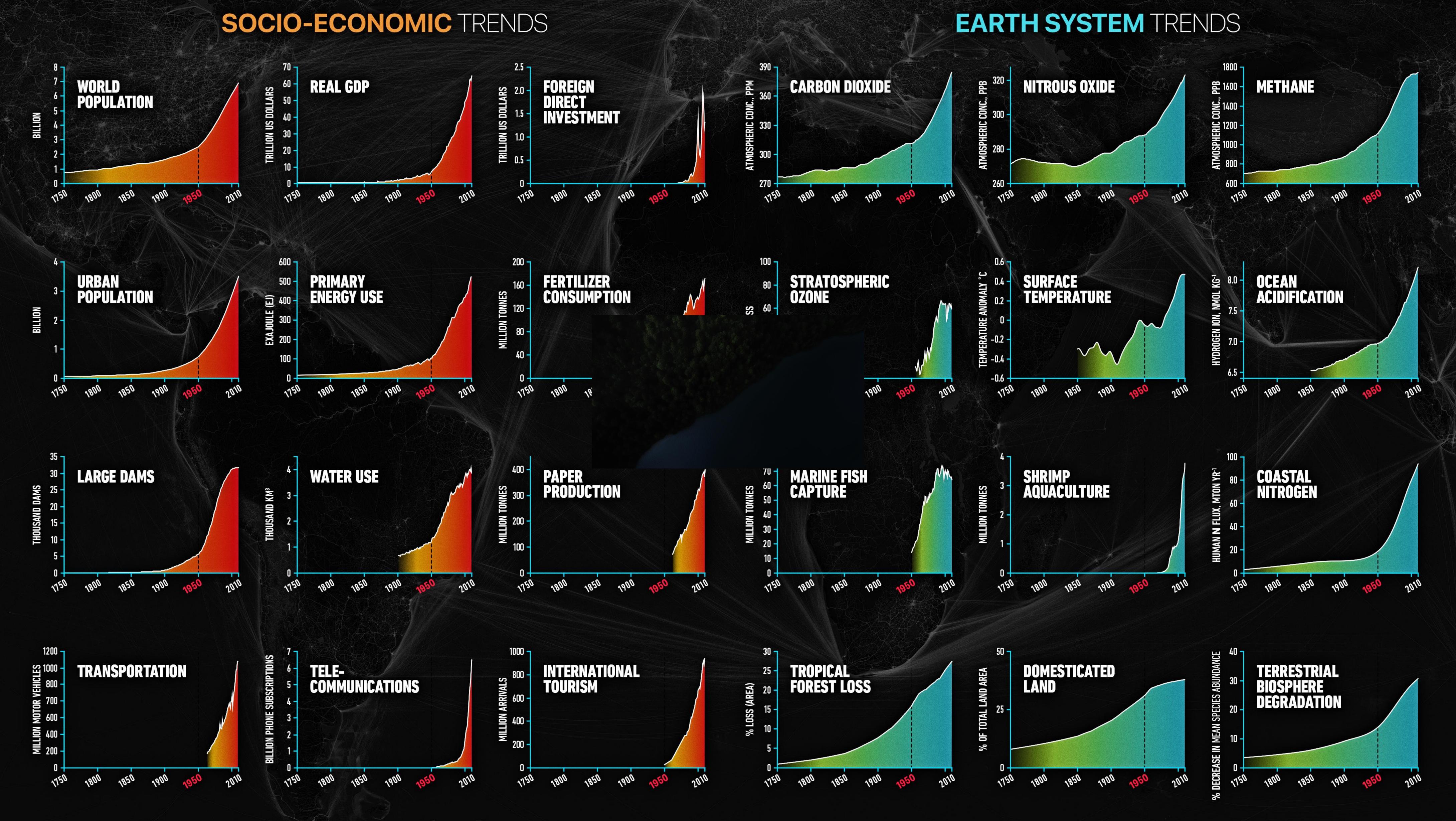


## Annual global mean temperature anomalies (°C)

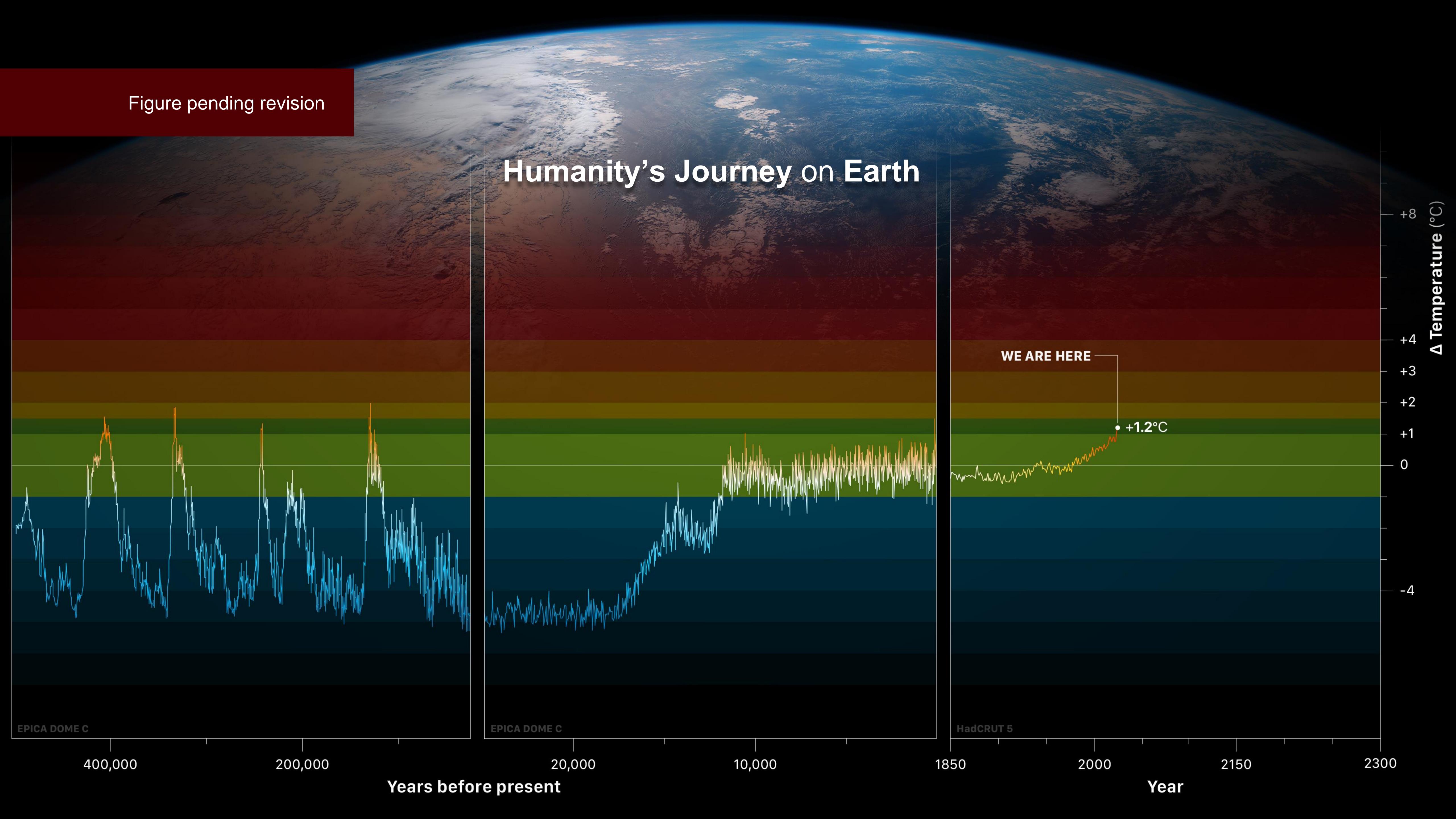
relative to 1850-1900 average

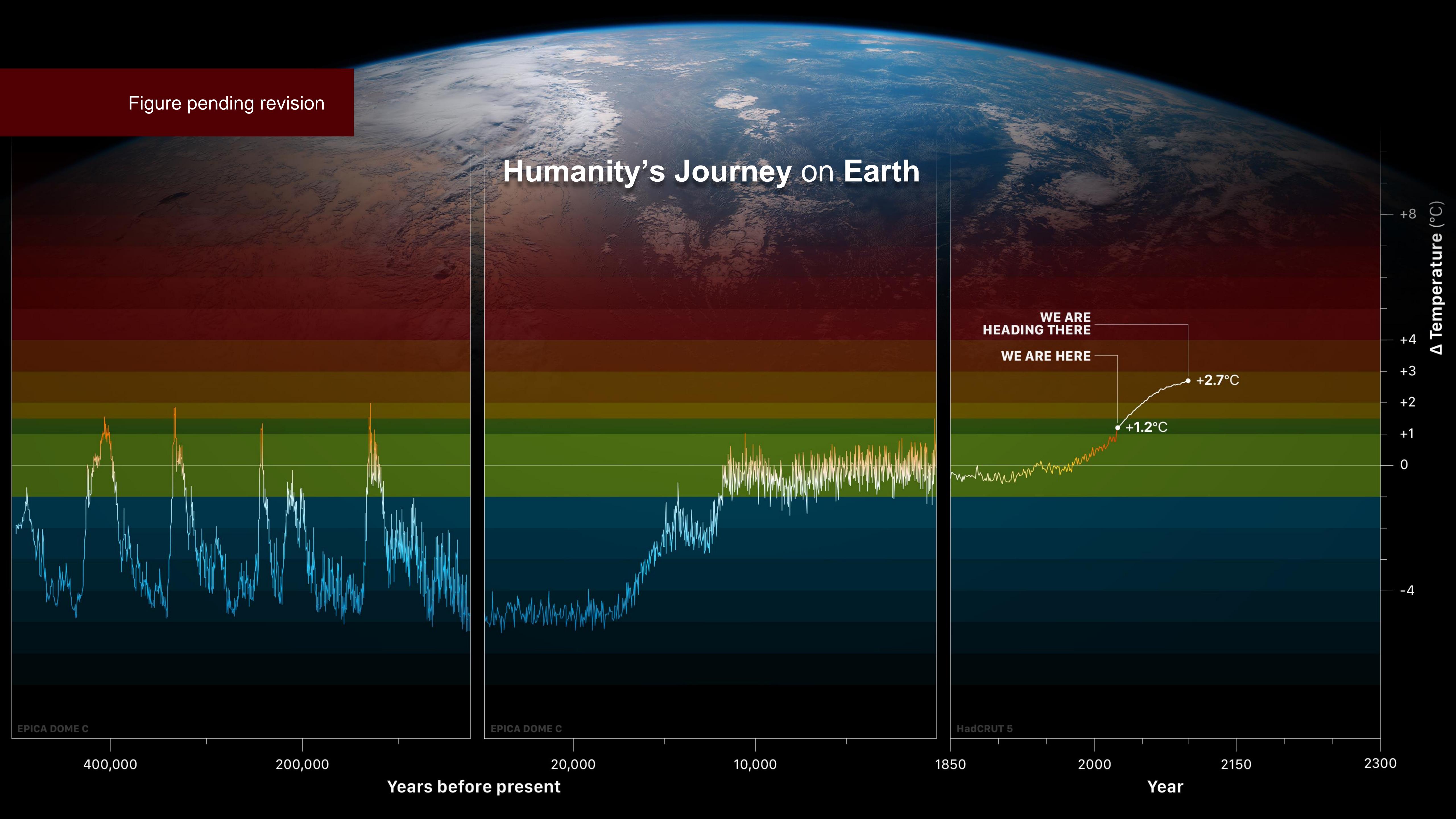


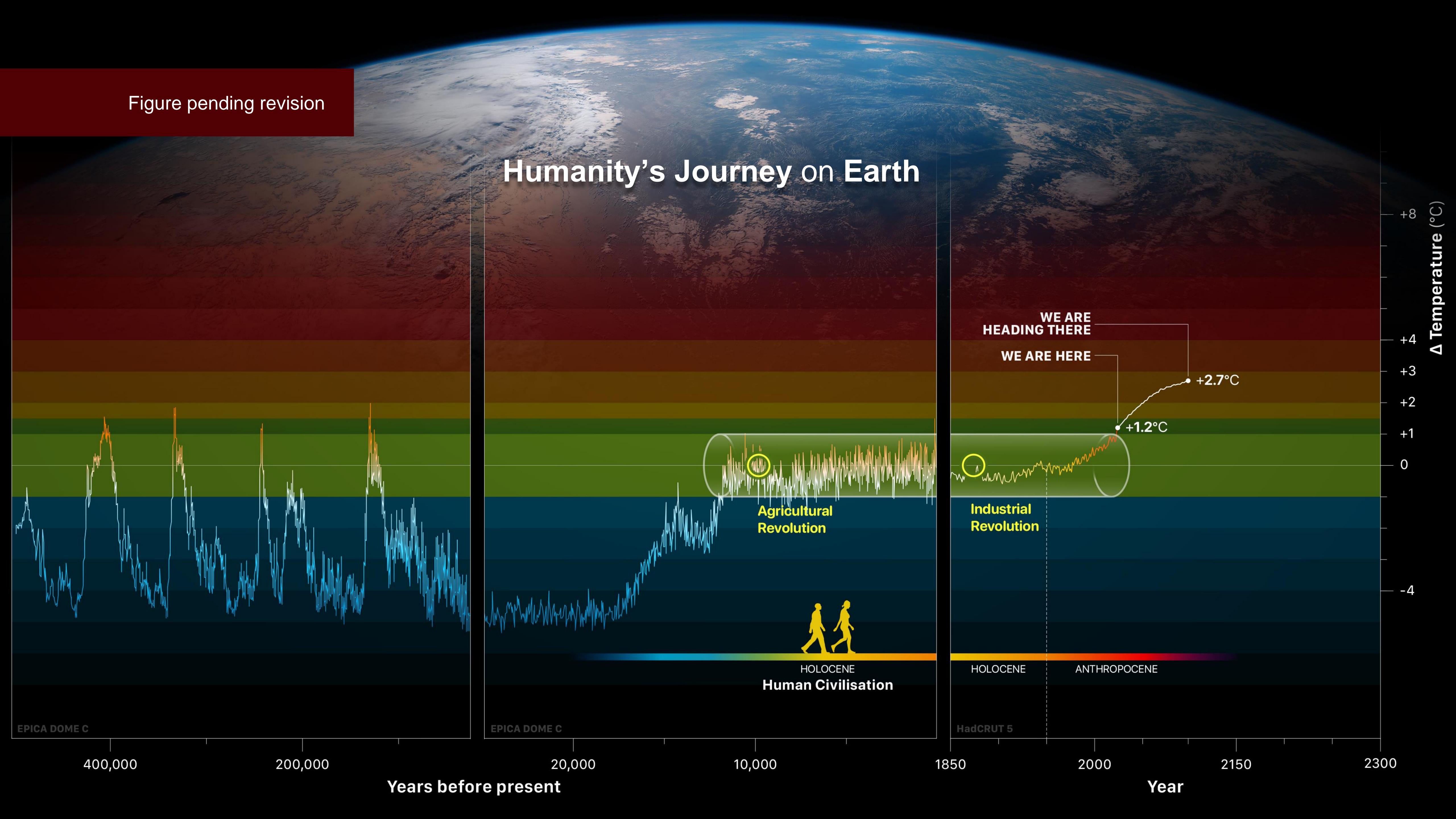
State of the Global Climate 2023. World Meteorological Organization, WMO #1347, 2024.

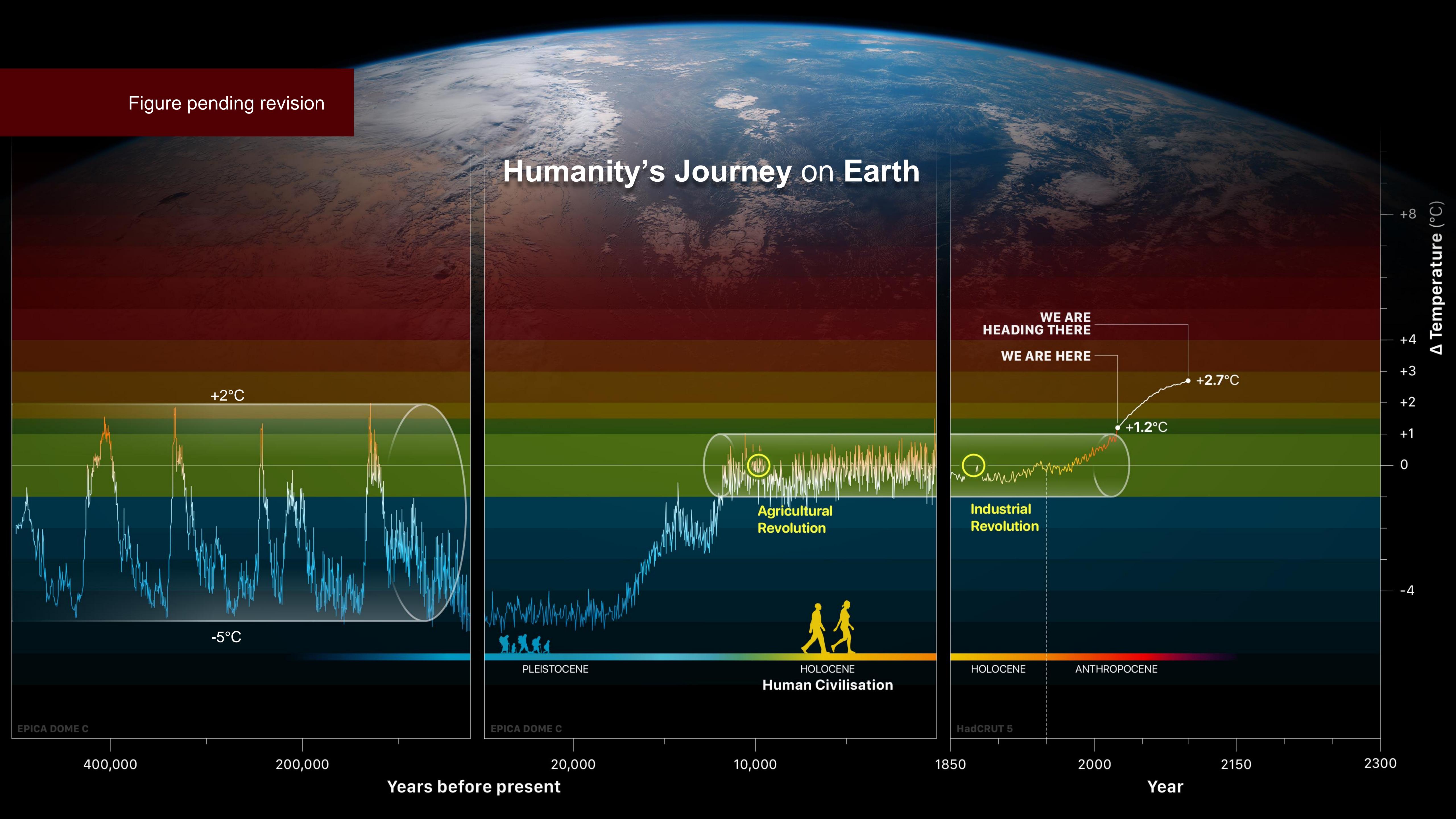


# Holocene and the Corridor of Life

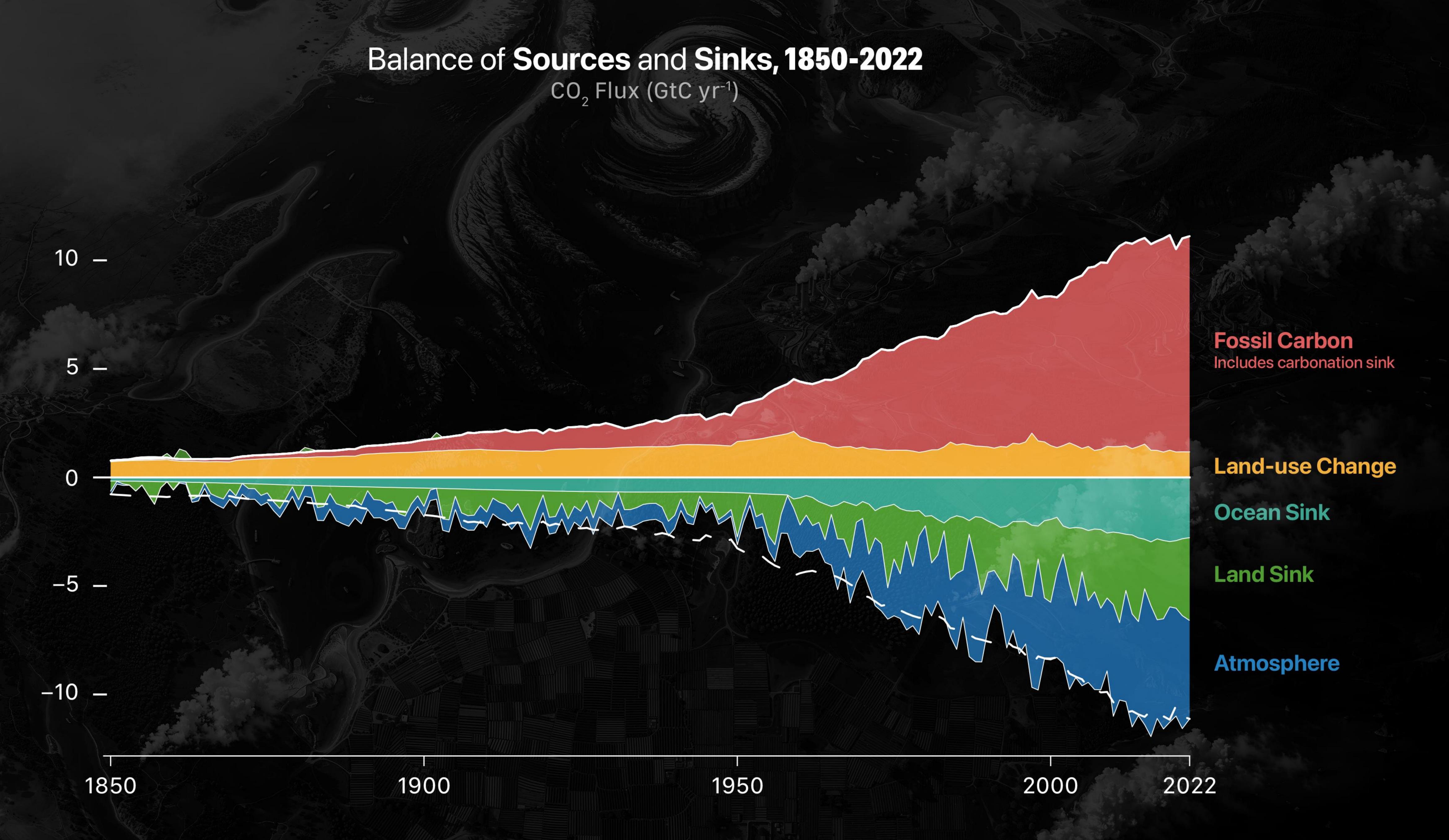








# Earth Resilience



## Losing Earth Resilience in Forest Systems

**ARTICLES |** FOCUS

nature climate change

#### Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon

Yuanwei Qin<sup>1</sup>, Xiangming Xiao<sup>1</sup>, Jean-Pierre Wigneron<sup>2</sup>, Philippe Ciais<sup>3</sup>, Martin Brandt<sup>4</sup>, Lei Fan<sup>o</sup>, Xiaojun Li², Sean Crowell<sup>o</sup>, Xiaocui Wu<sup>o</sup>, Russell Doughty<sup>o</sup>, Yao Zhang<sup>o</sup>, Fang Liu<sup>,</sup> Stephen Sitch 10 and Berrien Moore III6

Spatial-temporal dynamics of aboveground biomass (AGB) and forest area affect the carbon cycle, climate and biodiversity in the Brazilian Amazon. Here we investigate interannual changes in AGB and forest area by analysing satellite-based annual AGB and forest area datasets. We found that the gross forest area loss was larger in 2019 than in 2015, possibly due to recent loosening of forest protection policies. However, the net AGB loss was three times smaller in 2019 than in 2015. During 2010-2019, the Brazilian Amazon had a cumulative gross loss of 4.45 Pg C against a gross gain of 3.78 Pg C, resulting in a net AGB loss of 0.67 Pg C. Forest degradation (73%) contributed three times more to the gross AGB loss than deforestation (27%), given that the areal extent of degradation exceeds that of deforestation. This indicates that forest degradation has become the largest process driving carbon loss and should become a higher policy priority.

ropical forests in the Amazon account for approximately 50% and PALSAR/MODIS forest area during 2010–2019 offers a unique of the rainforests in the world<sup>1</sup> and are important for global window to assess the spatial-temporal dynamics of AGB and forest biodiversity, hydrology, climate and the carbon cycle<sup>2-6</sup>. area in the Brazilian Amazon and how these dynamics are impacted Accurate and timely data on vegetation aboveground biomass (AGB) by climate and land use. This period is of special interest, because and forest area in the region at various spatial and temporal scales the impacts on forest area and biomass from extreme climate events are needed to understand the carbon balance, which is affected and the changed policies of the new Brazilian government (in office by land use, logging and degradation, secondary forest regrowth, since January 2019), favouring the expansion of pasture<sup>25,26</sup> at the and climate<sup>7,8</sup>. In addition to in situ AGB measurements in intact expense of forest conservation, have not yet been fully quantified. forests<sup>9-11</sup>, several studies combined in situ AGB data with images Here we used the annual L-VOD AGB<sup>20</sup> and annual forest from optical, microwave and laser sensors to generate static AGB area datasets<sup>17</sup> described above to investigate the spatial-temmaps over merged periods (for example, circa 2000 (ref. 3), circa poral dynamics of forest carbon in the Brazilian Amazon dur-2007–2008 (ref. 12) and 2003–2014 (ref. 13)). Combined with forest ing 2010–2019. We investigated (1) the role of climate anomalies area change datasets from the Amazon Deforestation Monitoring in the changes in forest area and AGB (for example, the Atlantic Project (PRODES)<sup>14</sup> and the Global Forest Watch (GFW)<sup>15</sup>, these Multi-decadal Oscillation (2010), El Niño (2009–2010 and 2015– static AGB maps are used to estimate AGB dynamics from defor- 2016) and La Niña (2010–2011 and 2017)) (Extended Data Fig. 1); estation and forest degradation<sup>13,16</sup>, but forest losses from PRODES (2) whether recent changes in policies and human activities in 2019

were substantially smaller than those from GFW<sup>17-19</sup>. These dif-have a detectable effect on forest area and AGB; and (3) the relative ferences and uncertainties result from different forest definitions contributions of deforestation and forest degradation (forest fragand the use of Landsat images, which are severely impacted by frementation, edge effects, logging, forest fire and drought) to interanquent clouds and aerosols from fire, leaving very few good-quality nual variation in AGB loss in the study period. images per year<sup>17</sup>. This issue could be solved by the use of Moderate Resolution Imaging Spectroradiometer (MODIS) data. The spatial Consistency between AGB and forest area resolution of these data cannot identify small patches of forest losses The AGB and forest area data were organized into 5,656 grid cells or gains, but the daily images ensure more good-quality observa- at 0.25° spatial resolution (~25 km×25 km) (Methods). We stud-

ied the relationships between annual AGB and forest area fraction Substantial progress has been made in analysing L-band veg- (FAF) for individual grid cells. The spatial distribution of AGB etation optical depth (L-VOD) from the Soil Moisture and Ocean agrees well with that of FAF in 2019 (Fig. 1a,b). AGB and FAF are Salinity (SMOS) passive microwave images, which provide annual linearly (spatially) correlated with each other in 2019 and other maps of AGB since 2010 at 0.25° spatial resolution (Methods)<sup>20–23</sup>. years (Fig. 1c and Extended Data Fig. 2,  $R^2 \ge 0.81$ ). We also investi-Moreover, images from the Phased Array type L-band Synthetic gated the temporal consistency between AGB and FAF for all grid Aperture Radar (PALSAR) and MODIS were used to derive annual cells over the ten years. As an example, we showed two contrastmaps of evergreen forest areas at 500-m resolution for the Brazilian ing grid cells that exhibited either a large loss (Fig. 2a-c) or a large Amazon during 2000–2017 (refs. 17,24). Combining L-VOD AGB gain (Fig. 2d-f) in FAF. The temporal correlation between AGB

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SCIENCE ADVANCES | RESEARCH ARTICLE

#### NVIRONMENTAL STUDIES

The gathering firestorm in southern Amazonia

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Wildfires, exacerbated by extreme weather events and land use, threaten to change the Amazon from a net carbon sink to a net carbon source. Here, we develop and apply a coupled ecosystem-fire model to quantify how greenhouse gas-driven drying and warming would affect wildfires and associated CO<sub>2</sub> emissions in the southern Brazilian Commons Attribution Amazon. Regional climate projections suggest that Amazon fire regimes will intensify under both low- and NonCommercial high-emission scenarios. Our results indicate that projected climatic changes will double the area burned by wildfires, affecting up to 16% of the region's forests by 2050. Although these fires could emit as much as 17.0 Pg of CO<sub>2</sub> equivalent to the atmosphere, avoiding new deforestation could cut total net fire emissions in half and help prevent fires from escaping into protected areas and indigenous lands. Aggressive efforts to eliminate ignition sources and suppress wildfires will be critical to conserve southern Amazon forests.

Greenhouse gas (GHG) emissions accumulating in the atmosphere—extensive drought events. The strong climatic control over these may push Amazon forests into a new low-biomass state by altering wildfire events (11) suggests that forest flammability will increase in regional precipitation and temperature regimes. This climate-induced the near future, especially if deforestation rates increase but even forest transition has the potential to release large amounts of GHGs if they decline (5). Addressing large-scale forest degradation by to the atmosphere and accelerate global warming (1). Although CO<sub>2</sub> Amazon wildfires is therefore critical to quantifying future global fertilization of forests may partially offset this forest dieback (2), most GHG emissions. models lack representation of important negative processes such as

In Amazonia, surface forest wildfires emit GHGs to the atmoconsequently, undermine effective conservation of Amazon forests. ing methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), carbon monoxide (CO),

well-being, and biodiversity (6). nissions (8), the main GHG causing climate change. Over the species such as grasses (14). same period, emissions of CO<sub>2</sub> and other GHGs associated with Here, we used a coupled fire-ecosystem model (fig. S1) to assess wildfires (e.g., CO, CH<sub>4</sub>, NO<sub>x</sub>, and N<sub>2</sub>O) accelerated. Interactions the synergies between climate change and deforestation in determining

climate change will likely promote even more frequent, intense, and

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wildfires (3). Fire disturbance is already driving large-scale forest sphere via three main mechanisms. First, the combustion of fuels = mortality across the drier portions of the Amazon basin (4) and is (e.g., leaves, twigs, and branches) instantly transfers CO<sub>2</sub> to the likely to expand into wetter areas as climate and land use change (5). atmosphere, with most tropical wildfires contributing between 20 and Ignoring this potentially large source of GHG emissions to the 60 MgC ha<sup>-1</sup> (12-14). Second, thermal degradation of biomass atmosphere may restrict our ability to mitigate climate change and, causes the release of several types of GHGs other than CO<sub>2</sub>, includ-Better understanding of future fire regimes in Amazonia could help and nitrogen oxides ( $NO_x$ ). Last, post-fire tree mortality contributes guide efforts to increase regional capacity to prevent accidental forest CO<sub>2</sub> emissions to the atmosphere for several years or decades as fires and their negative impacts on ecosystem services, socioeconomic trees continue to die and decompose (13–15). Although forest recovery can offset CO<sub>2</sub> emissions associated with post-fire tree Deforestation in the Brazilian Amazon declined by 70% between mortality, recovery may be slowed when high-intensity fires kill 2004 and 2014 (7), avoiding the equivalent of 12% of global annual seeds and bud (resprout) banks and create niche spaces for invasive

between agricultural activities, illegal fires, and extreme weather burned area (BA) and fire-induced emissions of CO<sub>2</sub>, CO, CH<sub>4</sub>, N<sub>2</sub>O, events intensified Amazon fire regimes and their associated emissions and  $NO_x$  (hereafter referred to as  $eCO_2$ ) from the driest portions of (9, 10). During the 2000s alone, ~85,000 km² of primary forests burned the Amazon. This region represents 61% of the Brazilian Legal in Amazonia, mostly during the 2005 and 2010 droughts linked to Amazon (Fig. 1) and is a hot spot of forest fire activity (10). Our fire the warm phase of the Atlantic Multidecadal Oscillation (AMO) (9). model simulates daily fire ignition and spread as a function of climatic In 2015, the central Amazon experienced a similar spike in fire conditions, land use, fuel loads, and terrain at 500-m resolution. activity during another severe and widespread drought event, triggered Our ecosystem model also represents forest carbon (C) dynamics by anomalous warming of both the tropical Pacific (El Niño) and the and drought-induced changes in fuel loads and drying—a process tropical North Atlantic (9). Superimposed upon these episodic droughts, that is absent in most ecosystem models (fig. S1). We used this coupled model to test the hypothesis that future forest fires will be highest

where (i) forest edges are exposed to ignition sources due to deforestpartment of Earth System, University of California, Irvine, CA 92697, USA. ation and fragmentation and (ii) climate becomes drier and hotter beoods Hole Research Center, 149 Woods Hole Rd., Falmouth, MA 02540, USA. stituto de Pesquisa Ambiental da Amazônia (IPAM), SHIN, CA-5, Brasilia, DF 7500, Brazil. <sup>4</sup>Centro de Sensoriamento Remoto, Instituto de Geociências, <mark>Univ</mark>ersidade could decrease where high deforestation reduces forest connectivity and deral de Minas Gerais (UFMG), Av. Antônio Carlos 6627, CEP 31270-901, Belo associated fuel continuity, despite the presence of flammable edges. We orizonte, MG, Brazil. 5NASA Goddard Space Flight Center, Greenbelt, MD 20771, also expected low BA where dense primary forests create a moist Agriculture Global Practice, World Bank Group, 1818 H. St., NW, Washington, understory microclimate (16). The latter includes the interior of protected areas and indigenous reserves, referred to here as protected

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Mapping the irrecoverable carbon in Earth's ecosystems

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Avoiding catastrophic climate change requires rapid decarbonization and improved ecosystem stewardship at a planetary scale. The carbon released through the burning of fossil fuels would take millennia to regenerate on Earth. Though the timeframe of carbon recovery for ecosystems such as peatlands, mangroves and old-growth forests is shorter (centuries), this timeframe still exceeds the time we have remaining to avoid the worst impacts of global warming. There are some natural places that we cannot afford to lose due to their irreplaceable carbon reserves. Here we map 'irrecoverable carbon' globally to identify ecosystem carbon that remains within human purview to manage and, if lost, could not be recovered by mid-century, by when we need to reach net-zero emissions to avoid the worst climate impacts. Since 2010, agriculture, logging and wildfire have caused emissions of at least 4.0 Gt of irrecoverable carbon. The world's remaining 139.1  $\pm$  443.6 Gt of irrecoverable carbon faces risks from land-use conversion and climate change. These risks can be reduced through proactive protection and adaptive management. Currently, 23.0% of irrecoverable carbon is within protected areas and 33.6% is managed by Indigenous peoples and local communities. Half of Earth's irrecoverable carbon is concentrated on just 3.3% of its land, highlighting opportunities for targeted efforts to increase global climate security.

he concept of irrecoverable carbon is intended to discrimiconversion or climate change. We also map areas where irrecoverable nate among the billions of tonnes of carbon stored in the biosphere on the basis of three criteria relevant for conservation Indigenous peoples and local communities' (IPLC) lands and thus efforts. We assess ecosystem carbon stocks according to: (1) how potentially more secure. This spatial perspective on irrecoverable they can be influenced by direct and local human action ('manage- carbon and its conservation status can inform upcoming efforts ability'), (2) the magnitude of carbon lost upon disturbance ('vul- to manage the biosphere, such as the Convention on Biological nerability') and (3) the recoverability of carbon stocks following loss Diversity's (CBD) Post-2020 Global Biodiversity Framework as ('recoverability'). Applying the three criteria across all terrestrial, well as upcoming revisions of nationally determined contribucoastal and freshwater ecosystems reveals that some places contain tions (NDCs) to the Paris Agreement to keep global warming well irrecoverable carbon, or manageable carbon stocks that, if lost, repbelow 2 °C. The findings are also important for civil society groups resent a permanent debit from the remaining carbon budget<sup>2</sup>, or advocating for increased access to climate finance, for multilateral the amount of carbon humans can emit while still keeping global donors and foundations as a spatial input to targeting conservation warming within safe levels (1.5–2°C above pre-industrial levels). Investments and for companies sourcing forest-risk commodities Effective strategies to reduce the risk of catastrophic climate change or engaging in carbon markets.

emissions and restore degraded ecosystems. can only be addressed with spatially explicit data. Specifically, 1, manageability, we created a 'total manageable carbon' map from we identify areas with recent losses of irrecoverable carbon as a comprehensive suite of carbon datasets across terrestrial, coastal well as those that face near- or medium-term risks from land-use and freshwater ecosystems globally, considering both biomass car-

will need to locate large irrecoverable carbon reserves that are at risk due to anthropogenic action and prioritize their protection and Mapping three key dimensions of ecosystem carbon stocks sustainable management, alongside efforts to phase out fossil fuel Our irrecoverable carbon map (Fig. 1) identified irrecoverable carbon reserves that are manageable, are vulnerable to disturbance and The concept of irrecoverable carbon in ecosystems was intro-could not be recovered by 2050 if lost today. While irrecoverability duced in a 2020 study<sup>2</sup> which synthesized ecosystem-level data to can be considered over any timeframe, we selected 30 years as the estimate the magnitude of irrecoverable carbon across major eco- most policy-relevant scenario to align with the Paris Agreement systems. Here, we map irrecoverable carbon globally and at high goal to reach net-zero emissions by mid-century. All major global resolution (300 m), using remotely sensed or modelled products climate models that simulate Paris-aligned emissions reductions that were created or substantially improved on within the last over the next several decades take for granted that nature's vast caryear<sup>4-6</sup>. The resulting spatial product is relevant for both global and bon stocks will remain stored rather than emitted and that these national planning and helps answer important questions which natural areas will continue to sequester carbon<sup>8</sup>. To assess criterion

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in Forests and Global Change

#### Forests and Decarbonization – Roles of Natural and Planted Forests

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Marcello Vitale, Sapienza University of Rome, Ital

> This article was submitted to Frontiers in Forests and Global

and Decarbonization - Roles

bonnie.waring@gmail.com - Afforestation is likely to mitigate emissions most effectively when trees are planted in

The severe consequences of human disruptions to the global carbon cycle have prompted intense interest in strategies to reduce atmospheric CO<sub>2</sub> concentrations. Because growing forests capture CO2 in their biomass and soils, large-scale tree planting efforts have been advertised as a viable way to counteract anthropogenic Edited by: emissions as part of net-zero emission strategies. Here, we assess the potential impact of reforestation and afforestation on the global climate system, and identify ecological, (KIT), Germany economic, and societal implications of such efforts.

Natural forests store more carbon than plantation forests, due to complex stand structures and accumulation of carbon belowground and in the forest floor. These features take centuries to emerge. Mature natural forests provide significant litional benefits and must be conserved, whilst regeneration of secondary natural forests is promoted.

Policy-makers must avoid generating "perverse incentives" that can compromise or even destroy existing carbon sinks in forests, savannas, grasslands and Forests and the Atmosphere, peatlands. Newly planted forests can create "carbon debts" that take significant time to be repaid.

Received: 14 February 2020 formerly forested, high-productivity sites, commonly found in tropical or sub-tropical Accepted: 17 April 2020 ecosystems. Planting species mixtures frequently increases productivity, reduces disturbance impacts, and enhances biodiversity relative to monocultures. - Total carbon capture associated with afforestation and reforestation can be enhanced Prentice IC, Adams M, Smith P and by substituting long-lived harvested wood products for steel, cement, and aluminur and by using harvest residues as bioenergy to replace fossil fuels.

of Natural and Planted Forests. Front. For. Glob. Change 3:58. Keywords: greenhouse gas emisisons, sequestration, CO<sub>2</sub> drawdown, forest management, native forest, doi: 10.3389/ffgc.2020.00058 biodiveristy

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Boreal Forests in the Face of Climate Change

Sustainable Management 3 as tarriable marray emen

COMMUNICATIONS

Alessandro Cescatti

ttps://doi.org/10.1038/s41467-021-21399-7 Emergent vulnerability to climate-driven disturbances in European forests

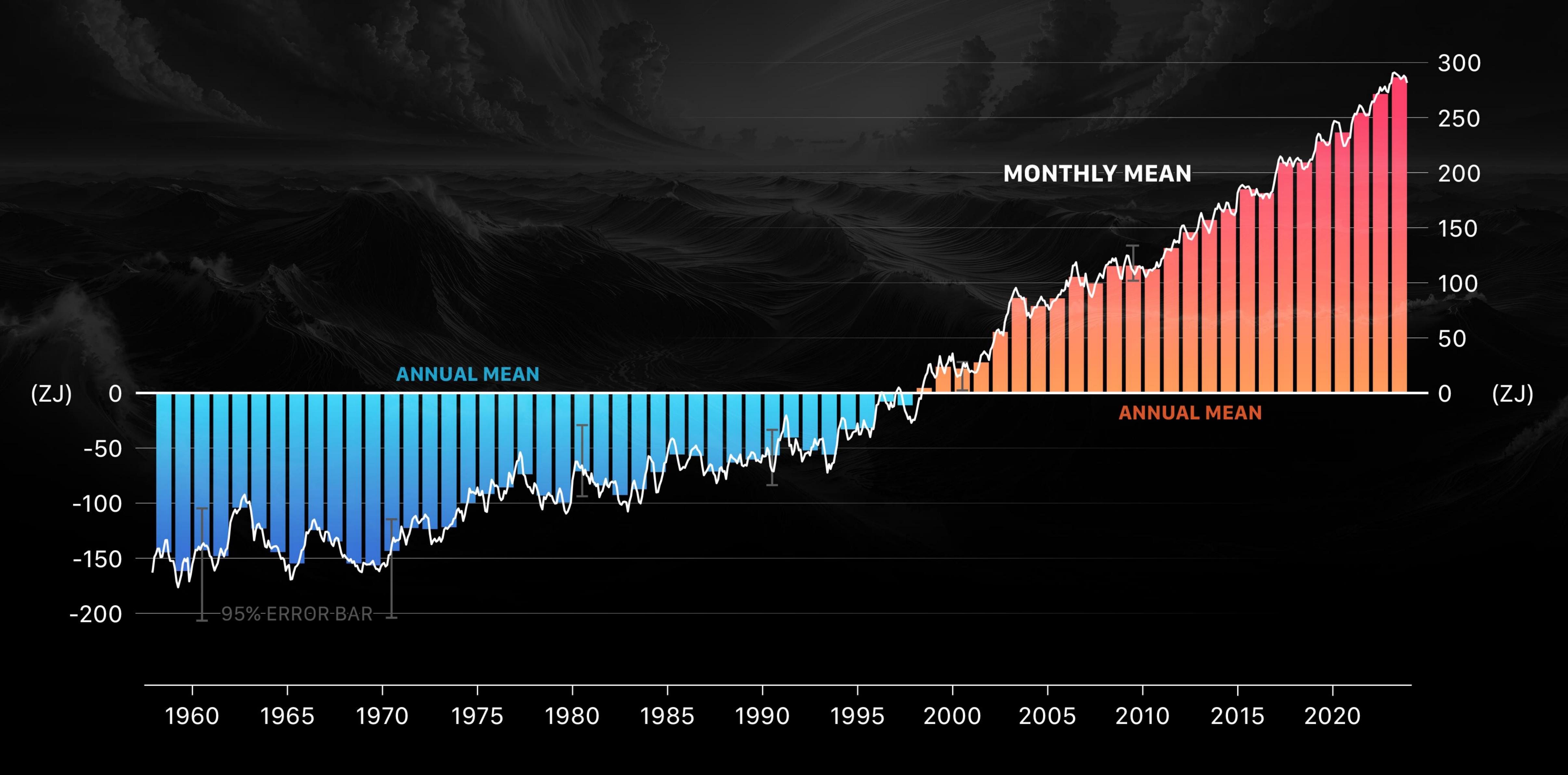
Henrik Hartmann ( <sup>2</sup>, Pieter S. A. Beck <sup>1</sup>, Gustau Camps-Valls ( <sup>3</sup>, Gherado Chirici ( <sup>4</sup>, Achille Mauri <sup>5</sup> &

Forest disturbance regimes are expected to intensify as Earth's climate changes. Quantifying forest vulnerability to disturbances and understanding the underlying mechanisms is crucial to develop mitigation and adaptation strategies. However, observational evidence is largely missing at regional to continental scales. Here, we quantify the vulnerability of European forests to fires, windthrows and insect outbreaks during the period 1979-2018 by integrating machine learning with disturbance data and satellite products. We show that about 33.4 billion tonnes of forest biomass could be seriously affected by these disturbances, with higher relative losses when exposed to windthrows (40%) and fires (34%) compared to insect outbreaks (26%). The spatial pattern in vulnerability is strongly controlled by the interplay between forest characteristics and background climate. Hotspot regions for vulnerability are located at the borders of the climate envelope, in both southern and northern Europe. There is a clear trend in overall forest vulnerability that is driven by a warming-induced reduction in plant defence mechanisms to insect outbreaks, especially at high latitudes.

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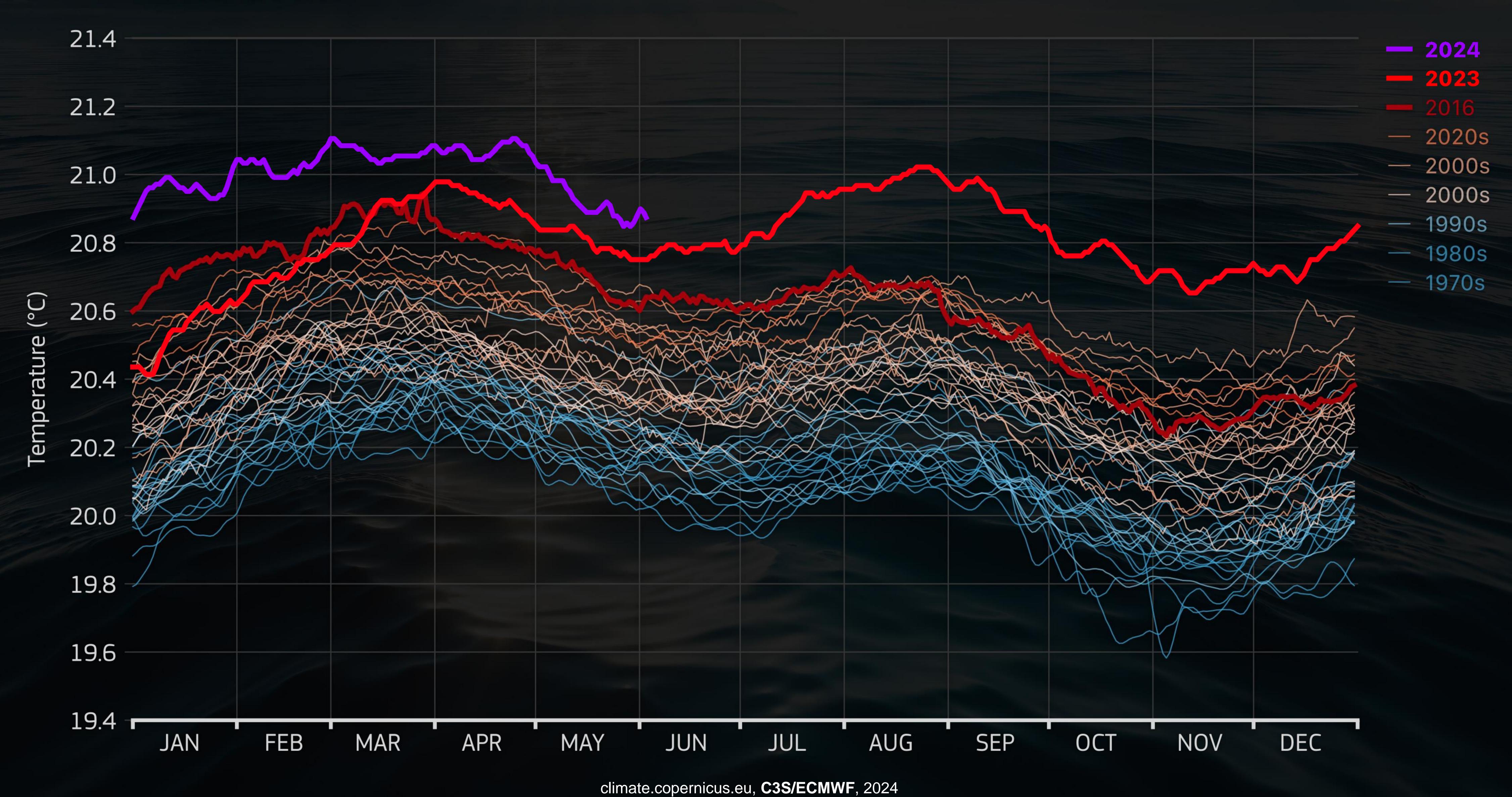
## Global Ocean Heat Content Anomaly in the upper 2,000 meters, 1958-2023

1 Zetta Joule (ZJ) =  $10^{21}$  Joules · 1981-2010 Baseline

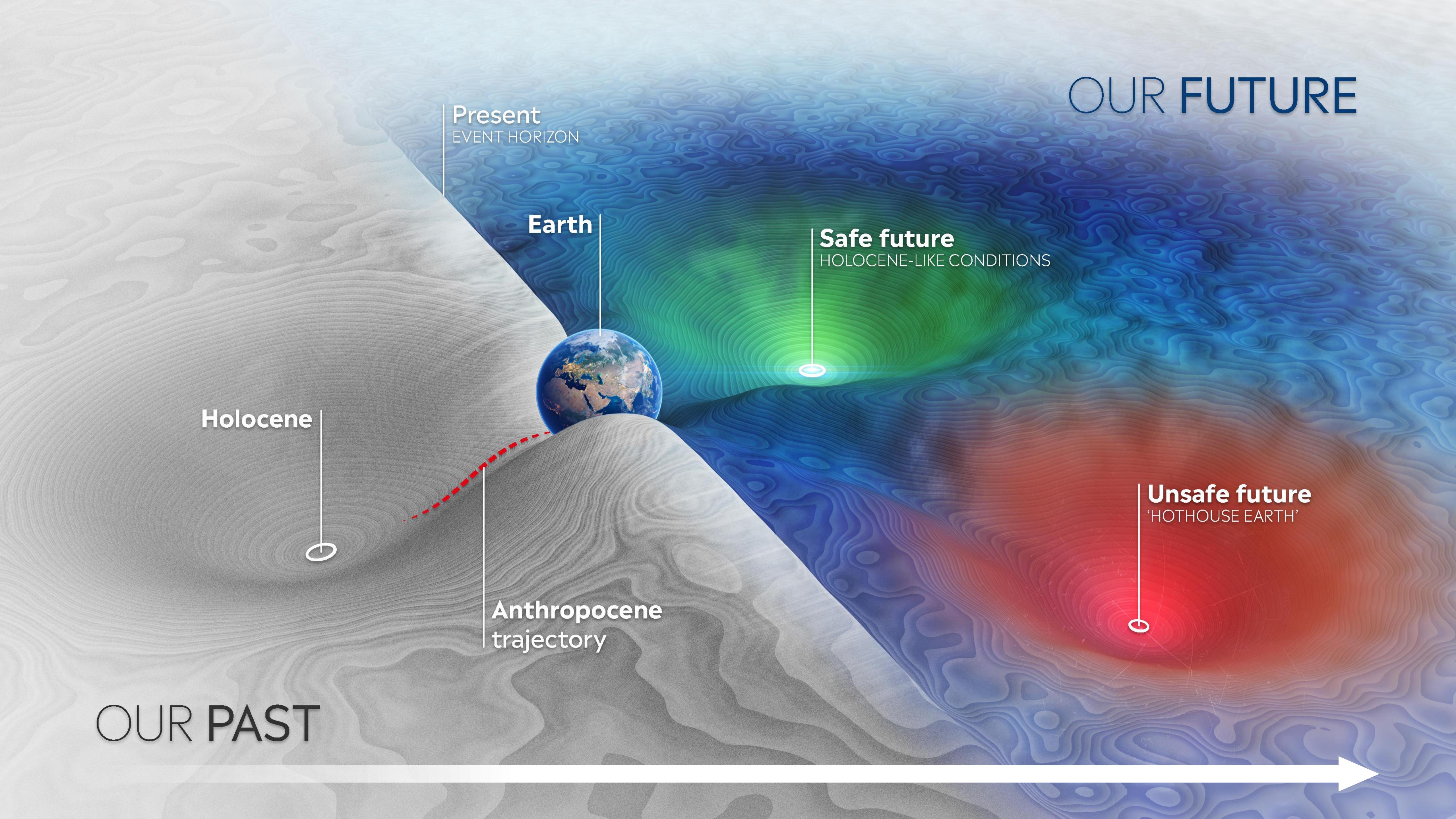


## Daily Sea Surface Temperature · 60°S-60°N

Data: **ERA5 1979-2024** 



# Tipping Points

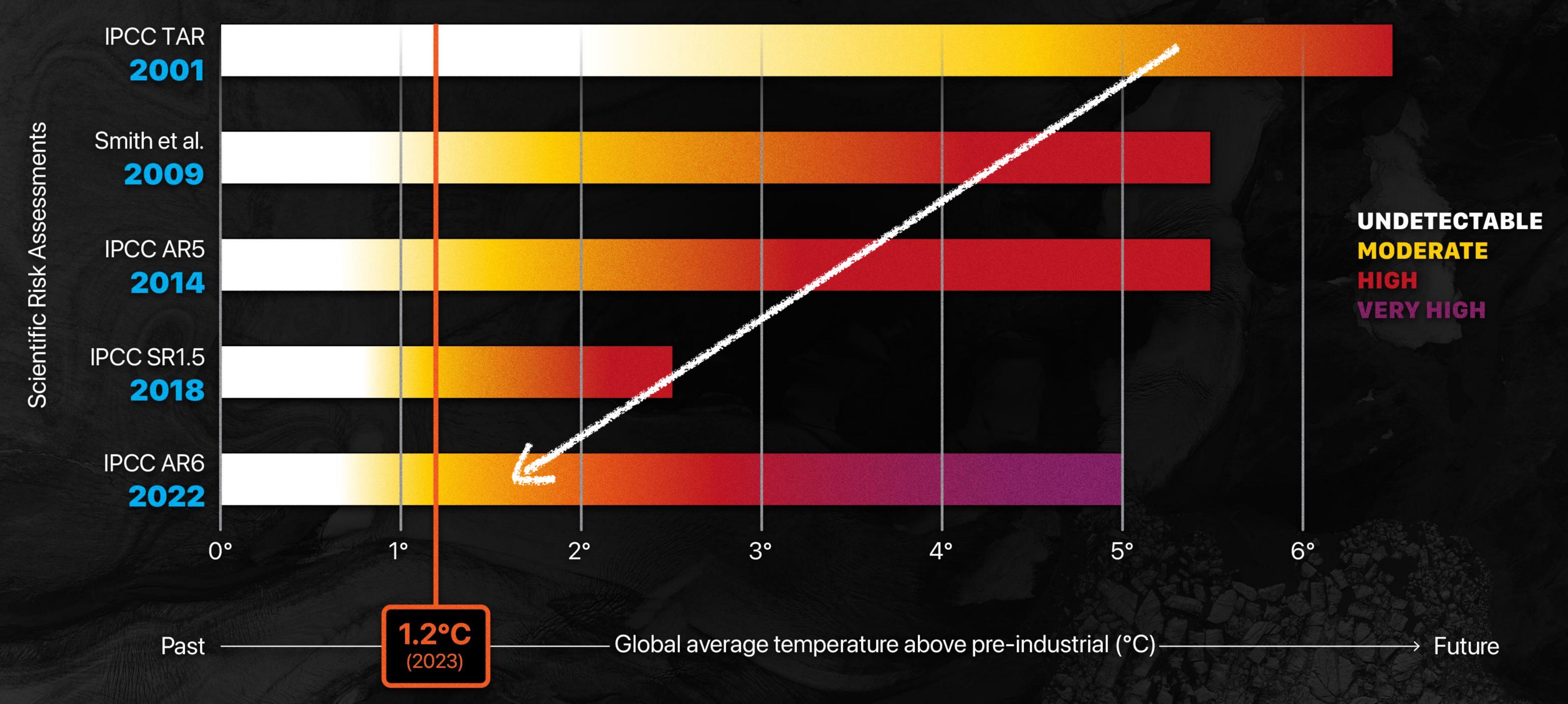


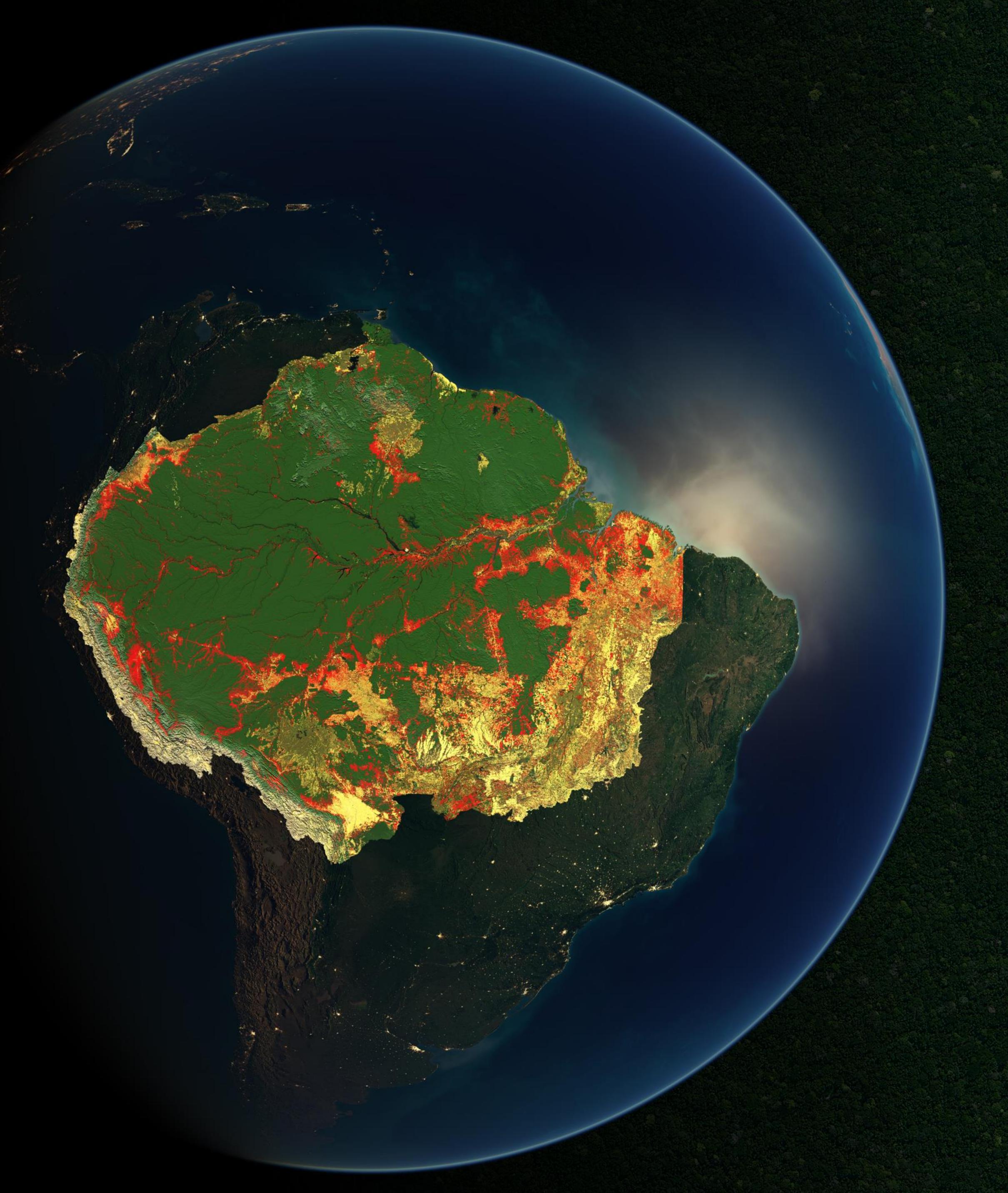


## The risk of climate tipping points is rising rapidly as the world heats up Estimated range of global heating needed to pass tipping point temperature 1.2°C Current level of warming 1.5-2.0°C Paris agreement targets °C 0 6 Greenland ice sheet collapse West Antarctic ice sheet collapse CURRENTLY Tropical coral reef die-off IN DANGER ZONE Northern permafrost abrupt thaw Labrador Sea current collapse Barents Sea ice loss Mountain glaciers loss DANGER ZONE Atlantic current collapse WITHIN THE PARIS AGREEMENT RANGE Northern forests dieback · South Northern forests expansion · North West African monsoon shift East Antarctic glacier collapse Amazon rainforest dieback Northern permafrost collapse Arctic winter sea ice collapse East Antarctic ice sheet collapse RANGE CENTRAL ESTIMATE MAX MIN Source: Armstrong McKay et al, Science, 2022.

## Large scale singular events (tipping elements)

## Level of additional risk due to climate change





# Risk of Amazon Tipping Point Closer than we thought?

CLIMATE RISK

3-500

CLIMATE & ECOLOGICAL RISKS

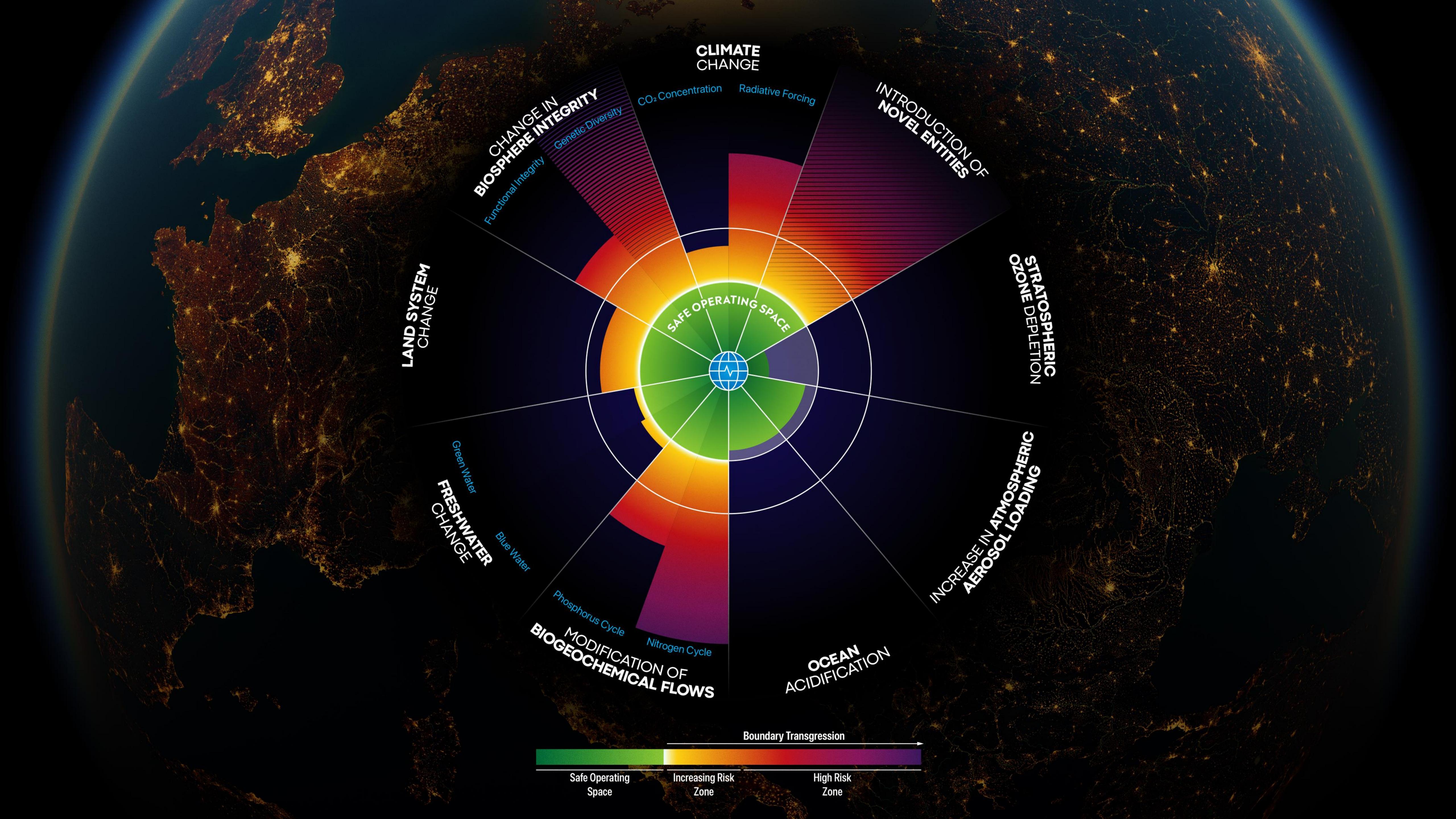
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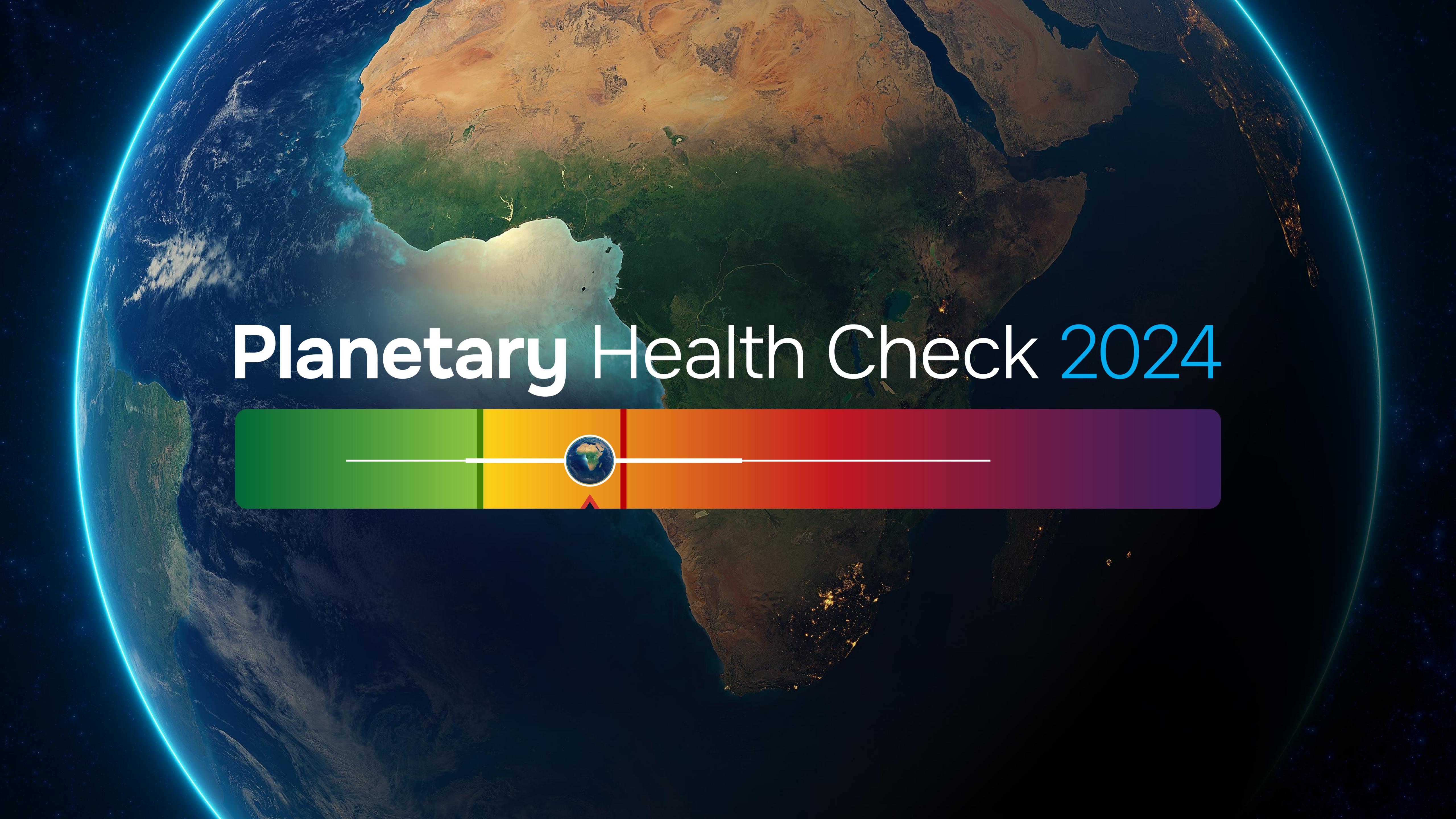
deforestation

TODAY

1200 + 17%

# Path to a Safe Landing for Humanity on Earth







Genetic Diversity



#### Planetary Boundary Process Staratospheric Ozone Depletion Increase in Atmospheric Aerosol Loading Ocean Acidification Freshwater Change O>>> Green Water Freshwater Change 0>>> Blue Water Land System Change Climate Change CO2 Concentration \*Climate Change **O**>>> Radiative Forcing Modification of Biogeochemical Flows O >>> Phosphorus Cycle \*Modification of Biogeochemical Flows O>>> Nitrogen Cycle **Introduction of Novel Entities** Change in Biosphere Integrity **Q**>>> Functional Integrity \*Change in Biosphere Integrity

