

Climate Change: Science, Causes, Impacts, Vulnerability

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Key Questions

Science

- What is climate change and how do we know it is happening?

Causes

- What is causing it?

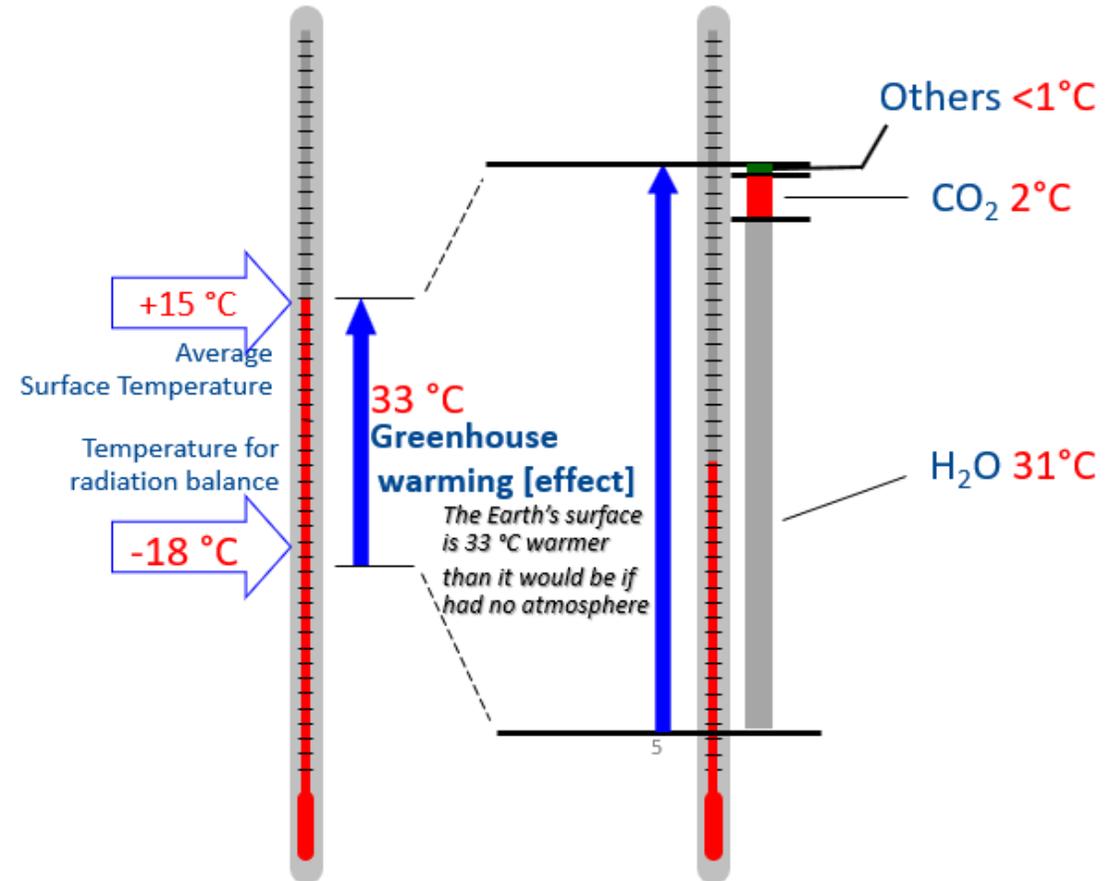
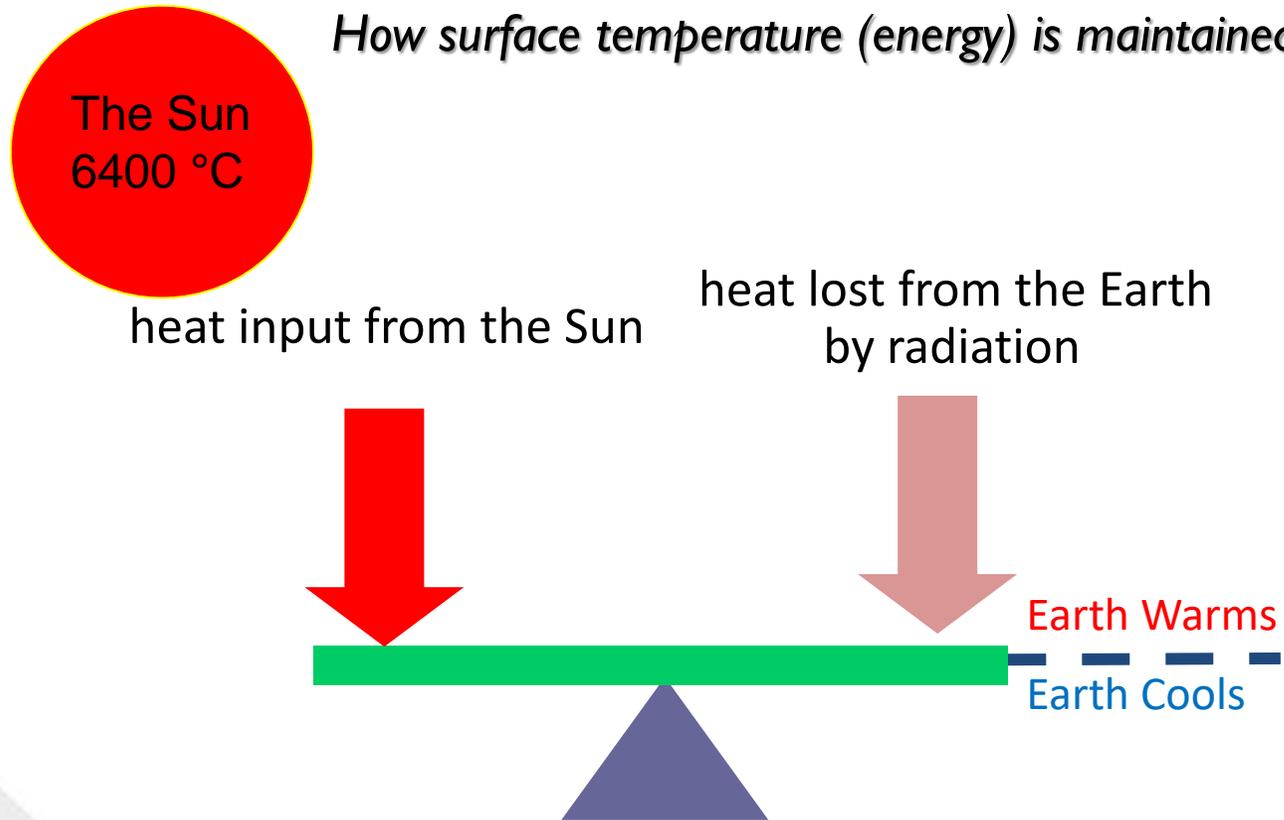
Impacts and vulnerability

- Why does climate change matter to us? What are the associated risks?

What is climate change and how do we know it is happening?

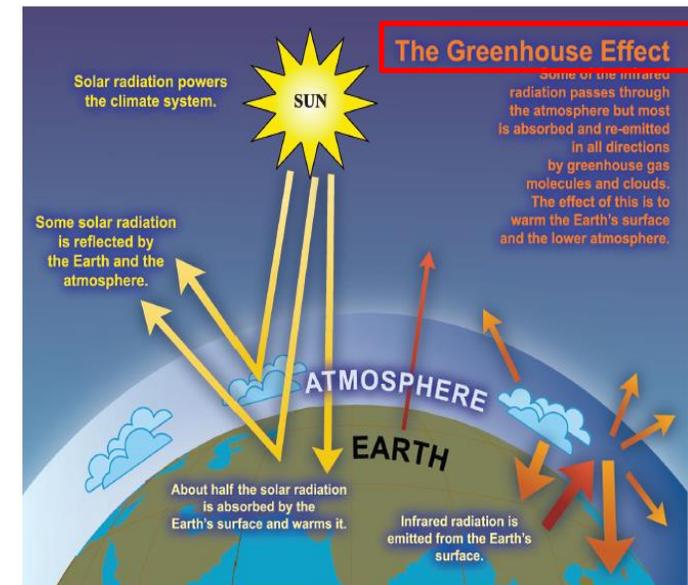
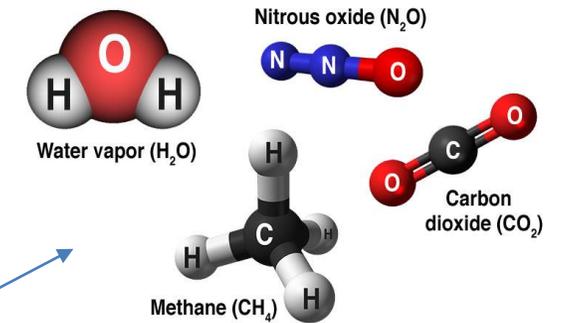
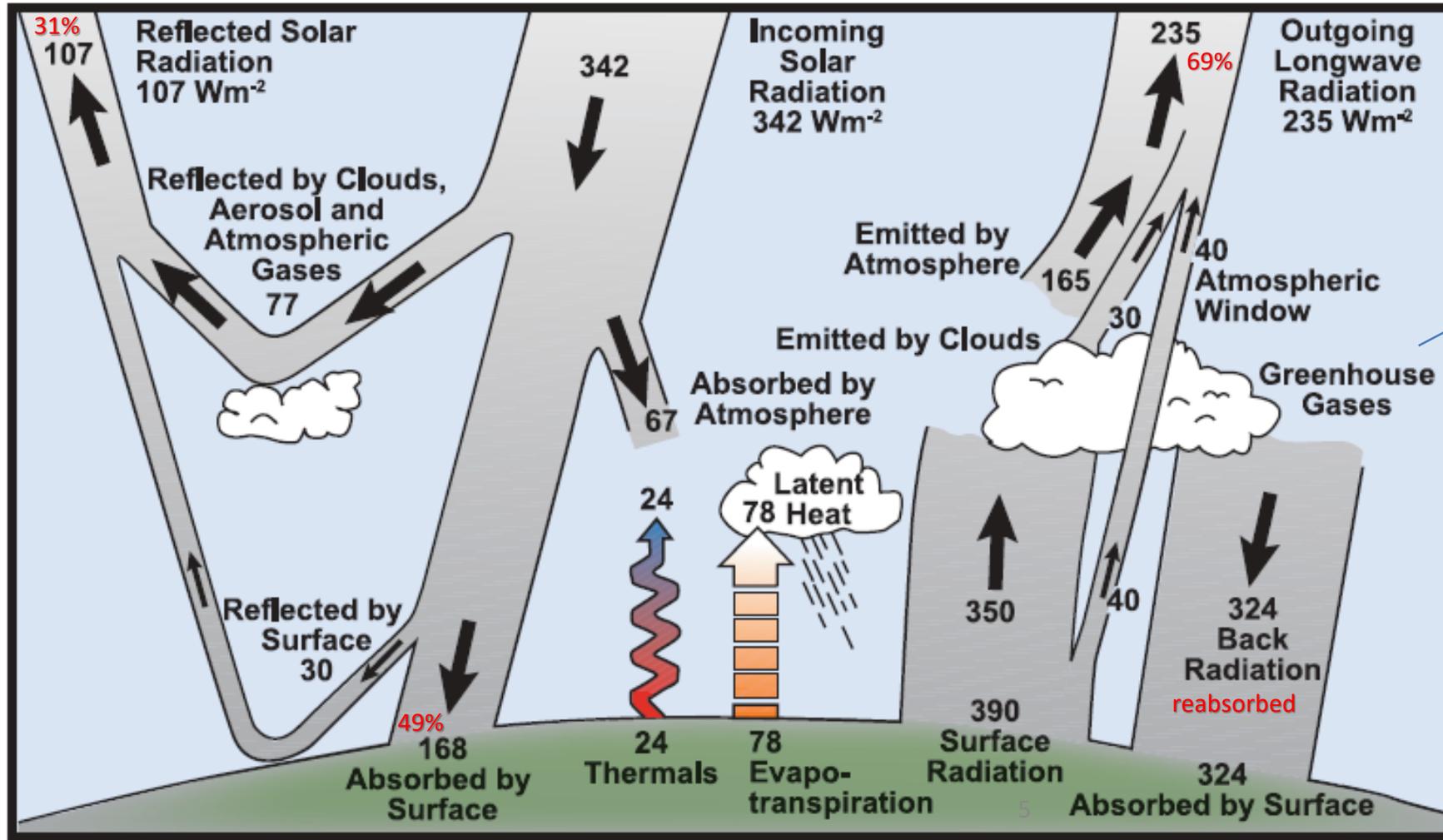
Radiation Energy Balance

How surface temperature (energy) is maintained?



- Average temperature of the Earth is determined by the balance between incoming solar radiation and outgoing 'heat' radiation. *Difference between incoming and the outgoing radiation energy in a given climate is **Net irradiance**.*
- When there is balance, the Earth's average temperature will be stable

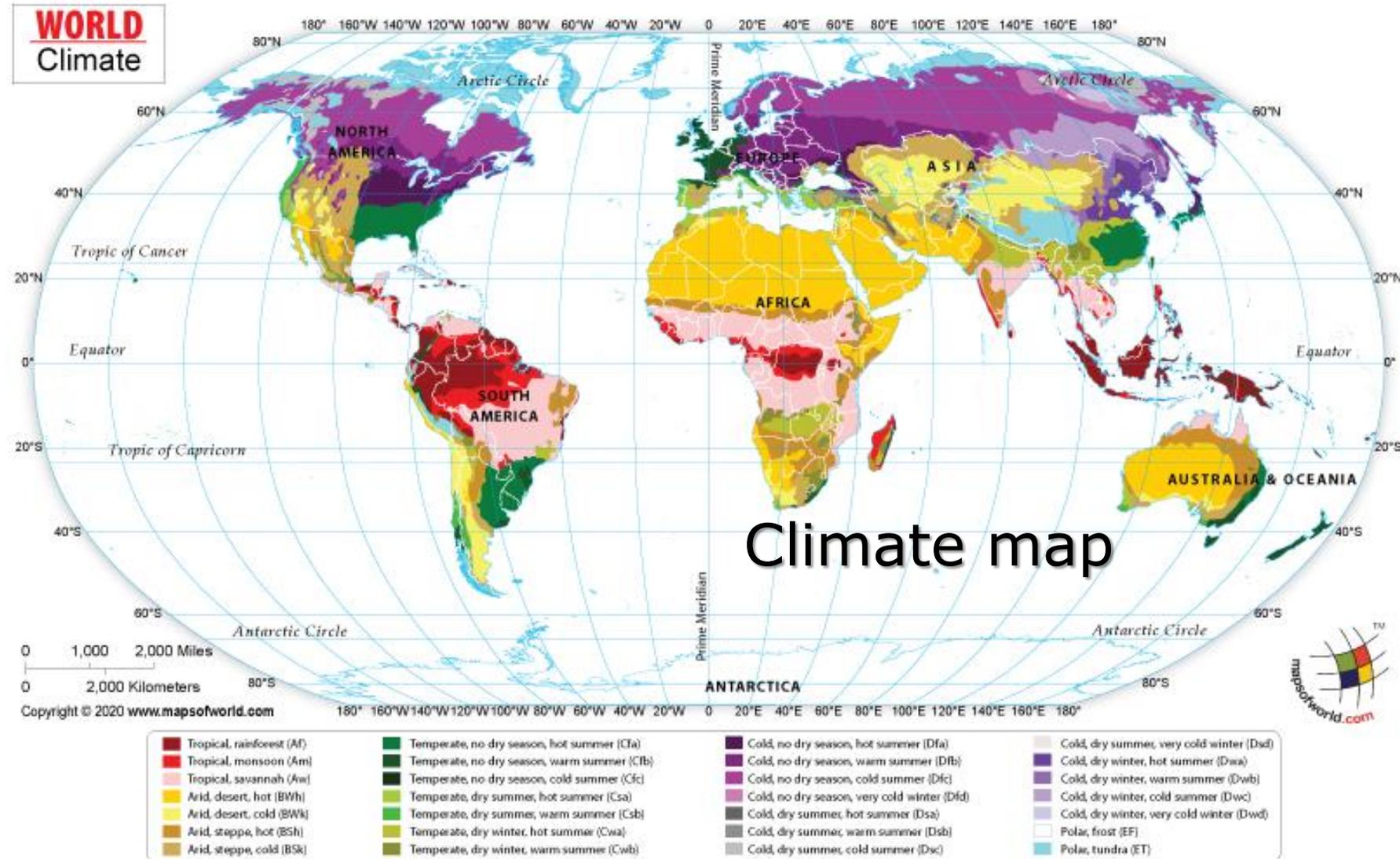
Radiance balance: *Incoming and Outgoing radiation*



FAQ 1.1, Figure 1. Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

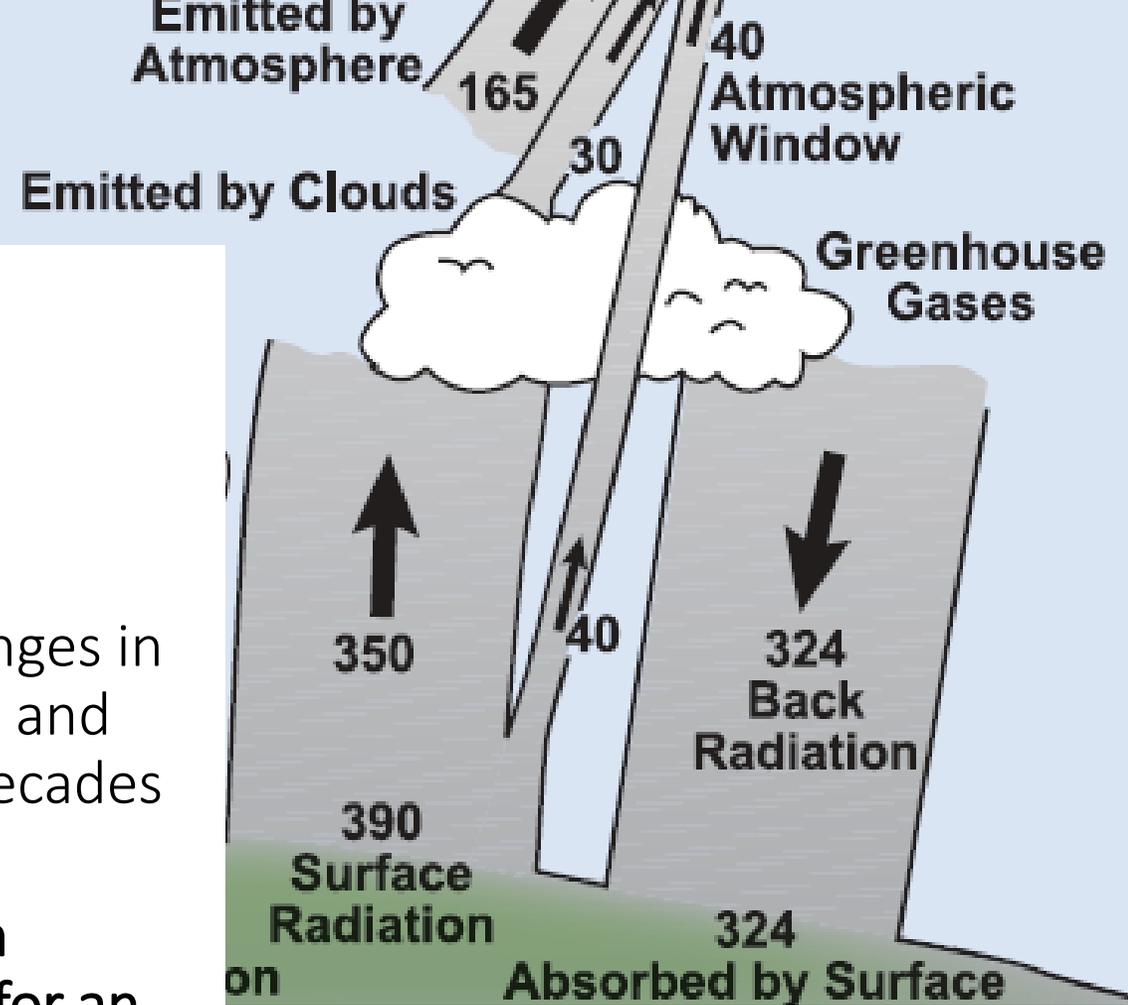
Climate

– the “average weather”, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities (of surface variables – *temperature, precipitation, wind*) over a period of time, classically 30 years, as defined by the WMO [IPCC]



Climate Change

- a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
- a change in composition of global atmosphere in addition to natural climate variability, persisting for an extended period – decades or longer, attributed directly/indirectly to human activities [UNFCCC, Article 1]



Climate Change timeline

1898: Swedish scientist Svante Arrhenius warns carbon dioxide from coal and oil burning could warm the planet

1987: Montreal protocol, an environmental treaty (for CFCs)

1988: NASA scientist James Hansen tells U.S. Congress global warming "is already happening now"

Exceptional drought hits the USA

Creation of the IPCC [Inter-governmental Panel on Climate Change]

1992: UNFCCC aims at stabilising atmospheric concentrations of GHG

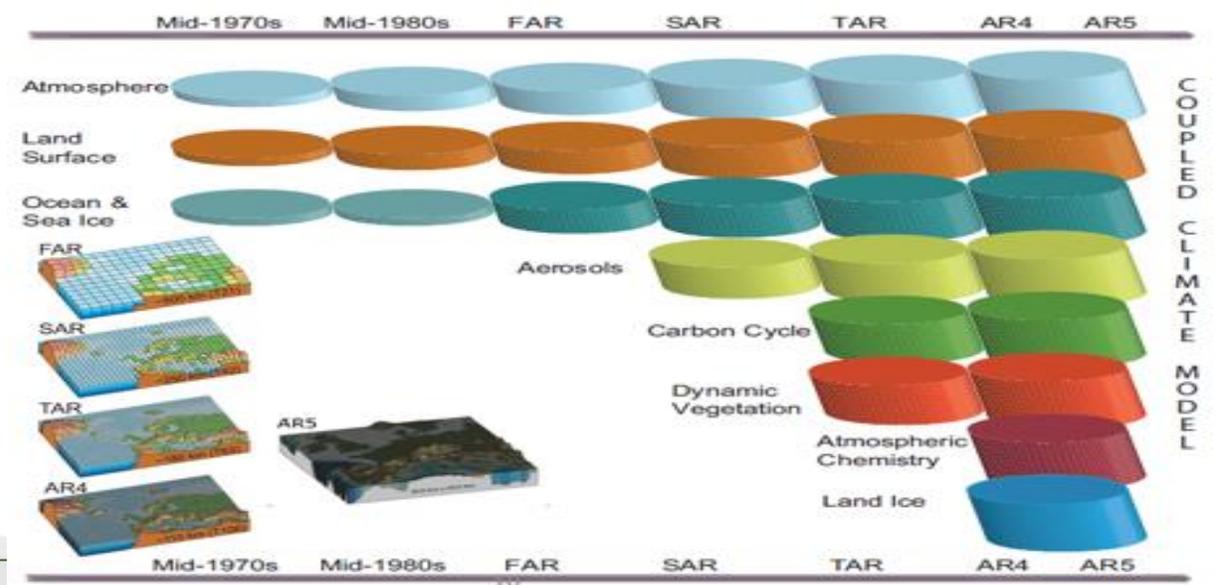
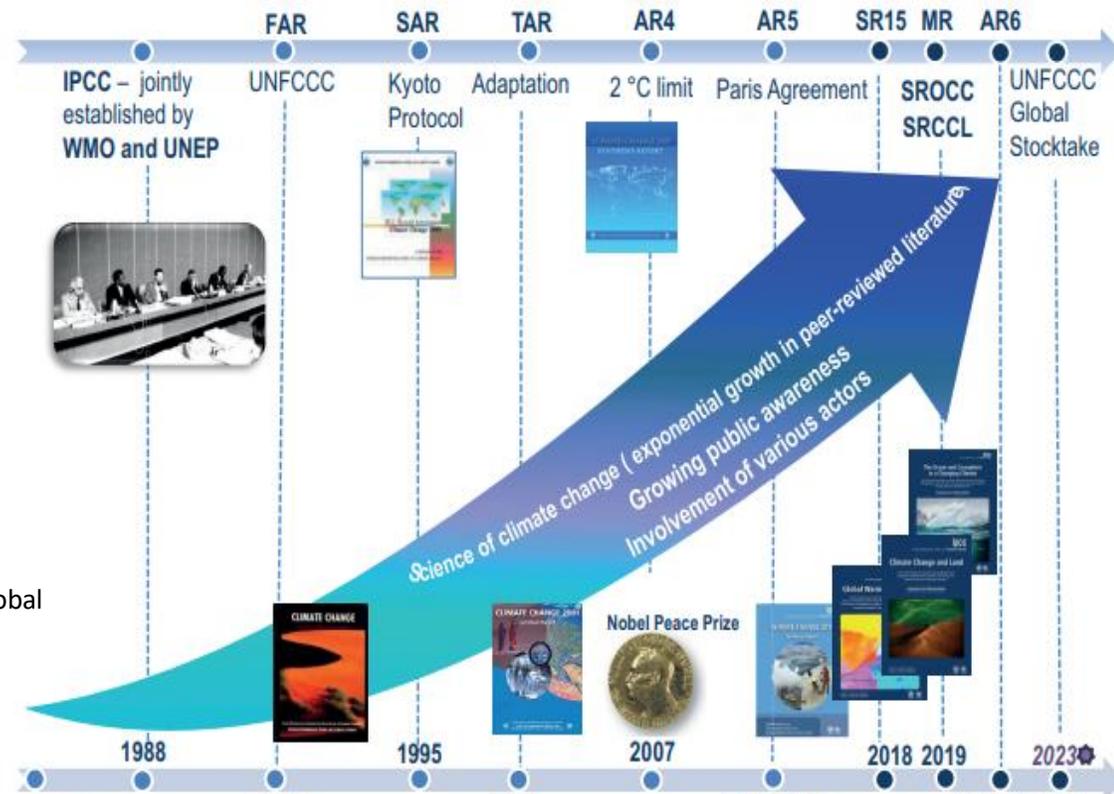
1997: Kyoto Protocol mandating emission cuts by industrial nations (took effect in 2005-2020)

2016: Paris Agreement

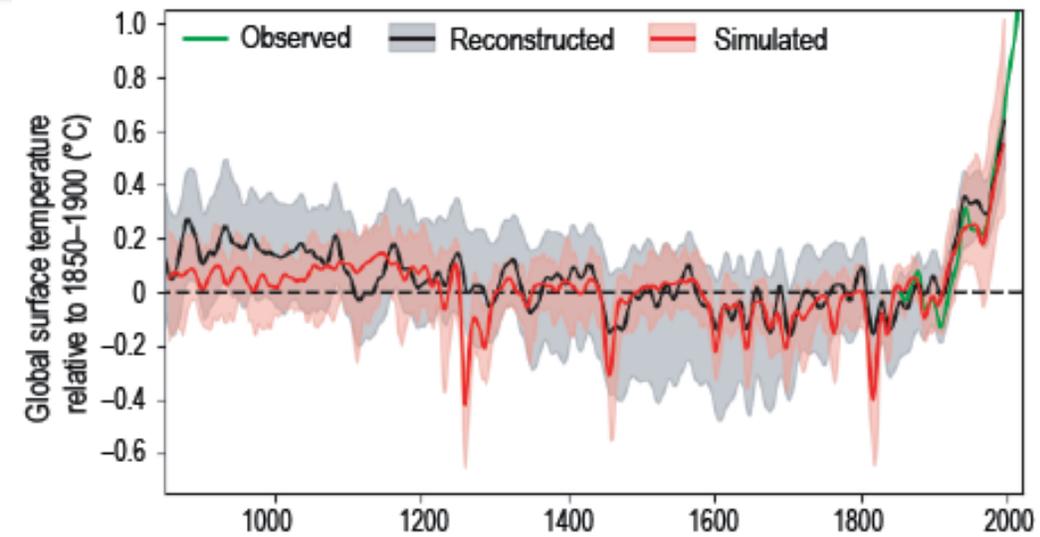
Warmest years (NOAA, 1880-2022): top 10 warmest years since 2013 so far

Increasing understanding of complexity of climate system

Special Reports (SR): Methodology Report - Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (MR), Global Warming of 1.5°C (SR15); Climate Change and Land (SRCCL), Ocean and Cryosphere in a Changing Climate (SROCC)

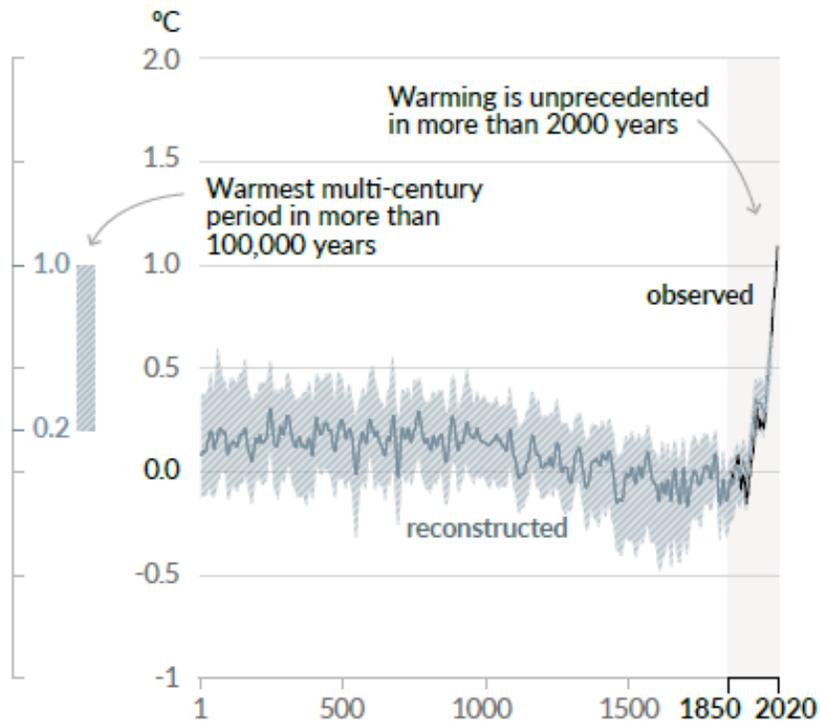


Human influence warmed climate at a rate that is unprecedented in at least the last 2000 years

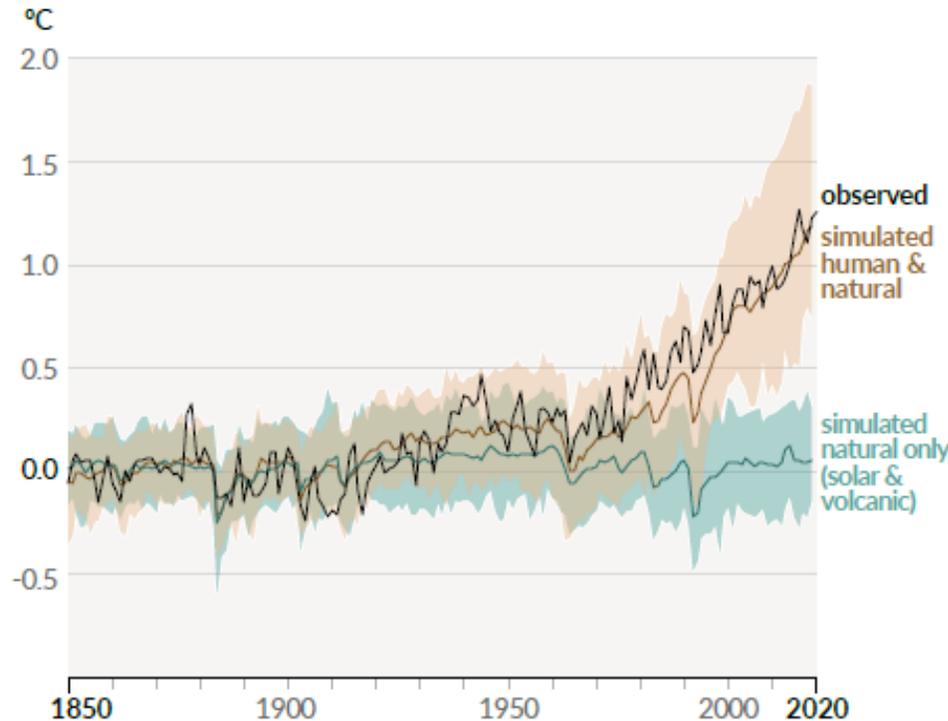


Changes in global surface temperature relative to 1850-1900

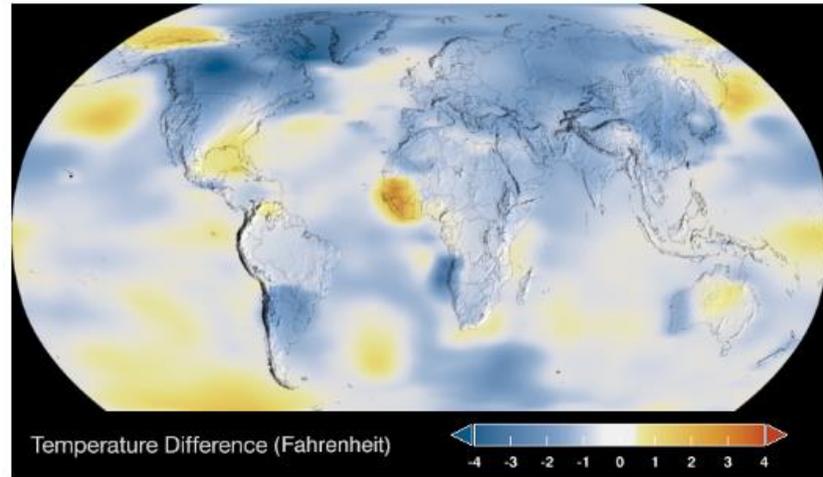
a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)



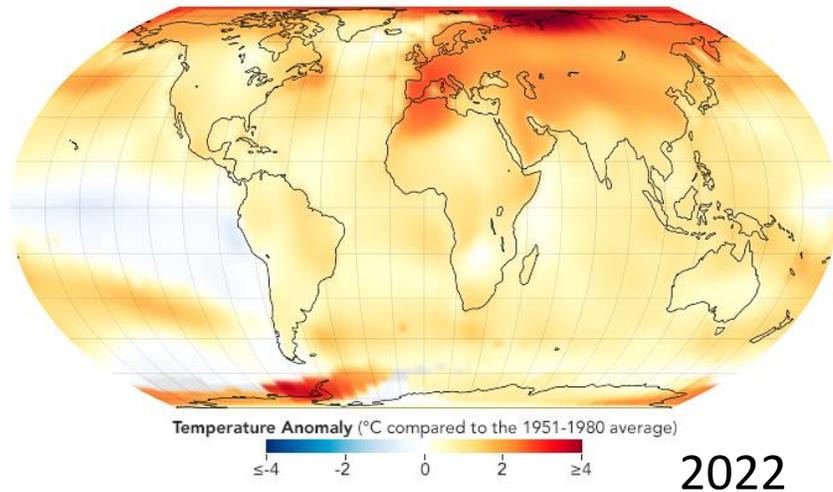
b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)



Global Temperature Trend [1880-2022]

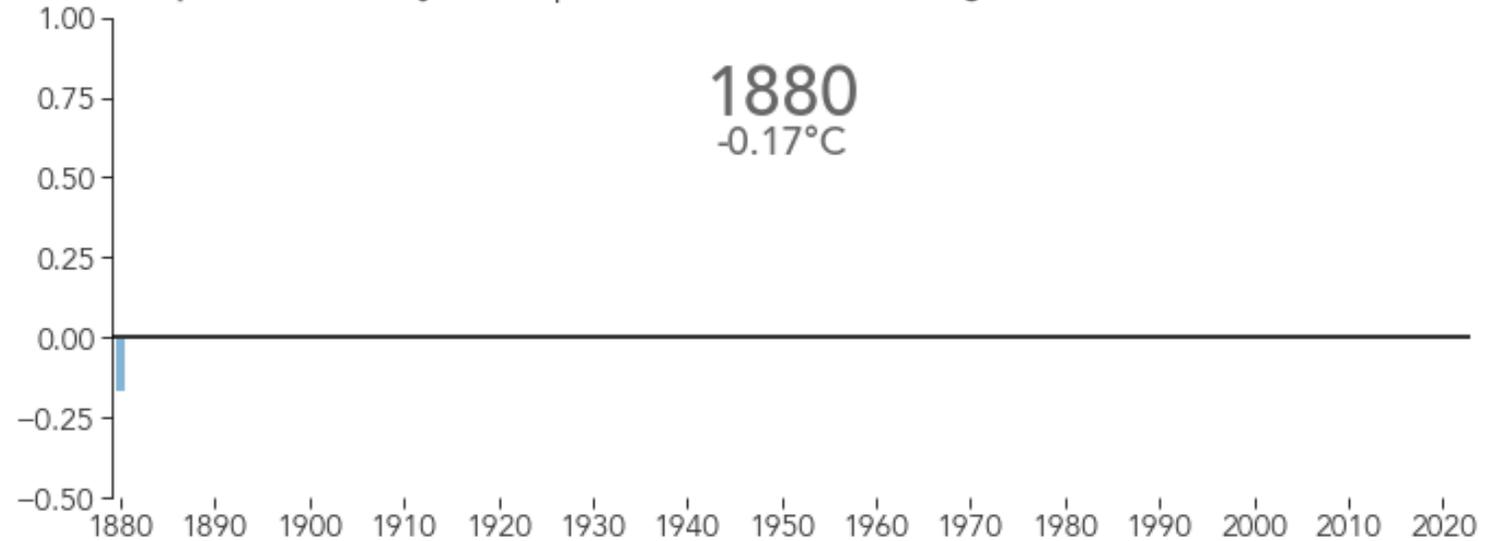


▶ 1884 ○



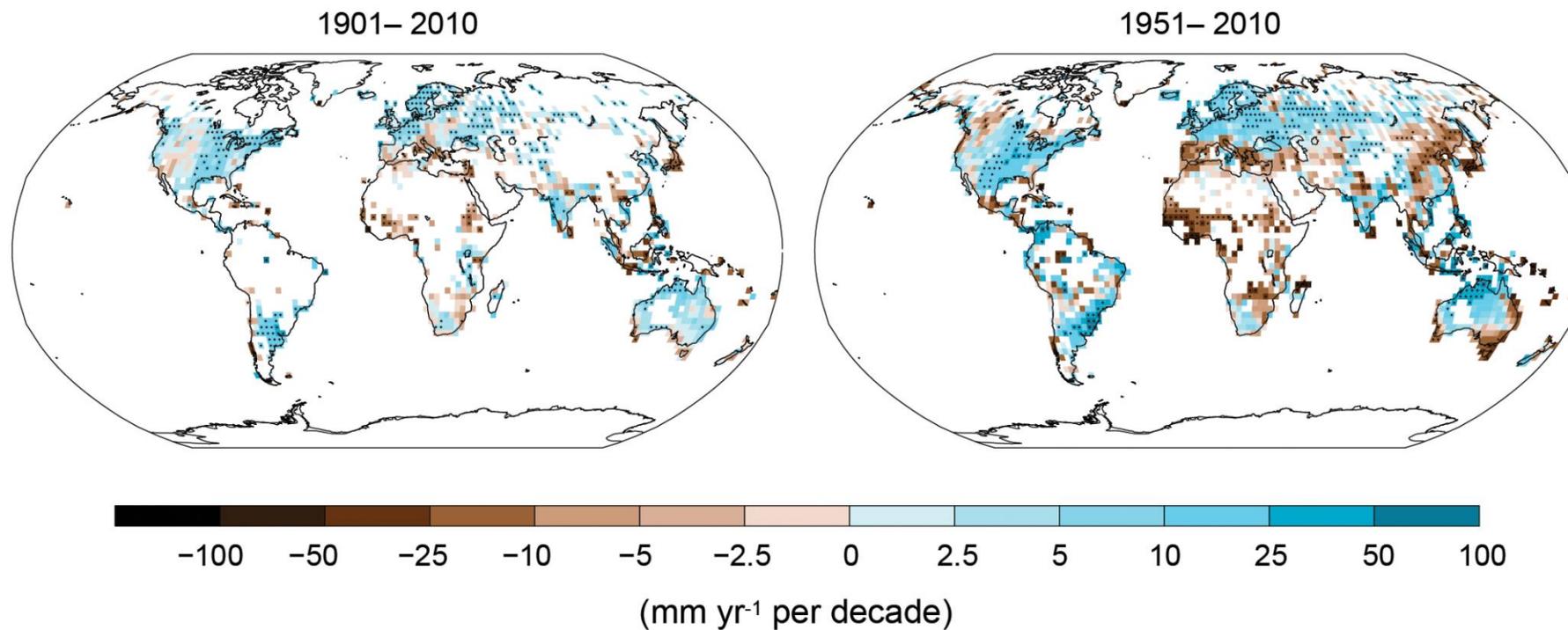
Last 9 Years Warmest on Record

Global Temperature Anomaly (°C compared to the 1951-1980 average)



<https://earthobservatory.nasa.gov/images/150828/2022-tied-for-fifth-warmest-year-on-record>

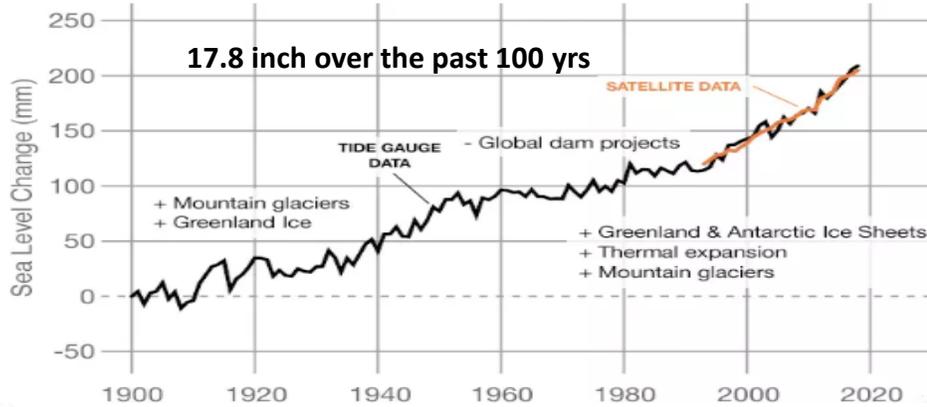
Observed change in Annual Precipitation over land



Sea level rise

SOURCE DATA: 1900-2018

Data source: Frederikse et al. (2020)
 Credit: NASA's Goddard Space Flight Center/PO.DAAC

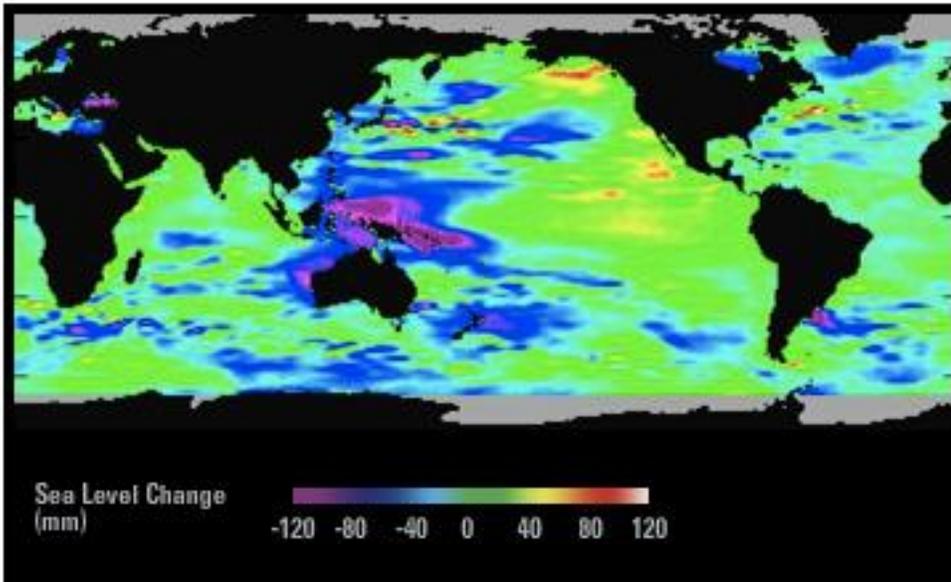
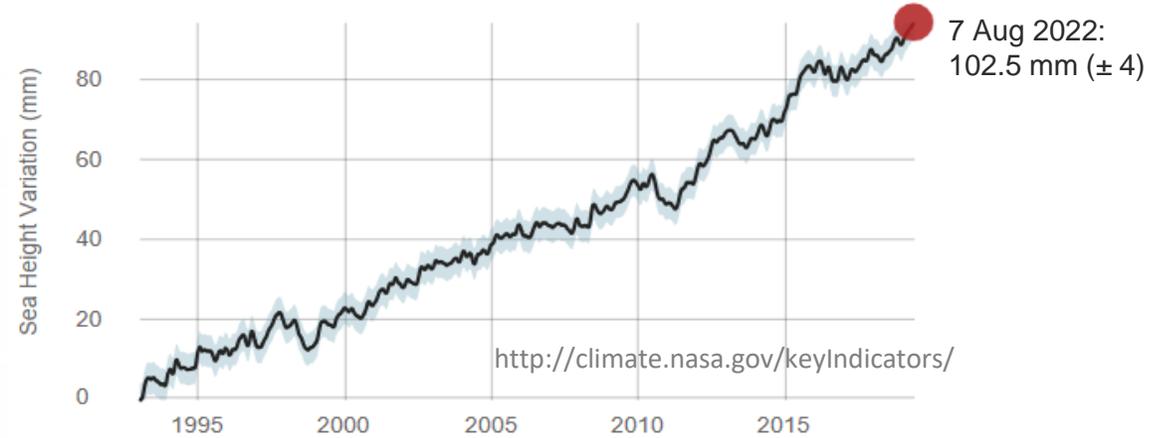


SATELLITE DATA: 1993-PRESENT

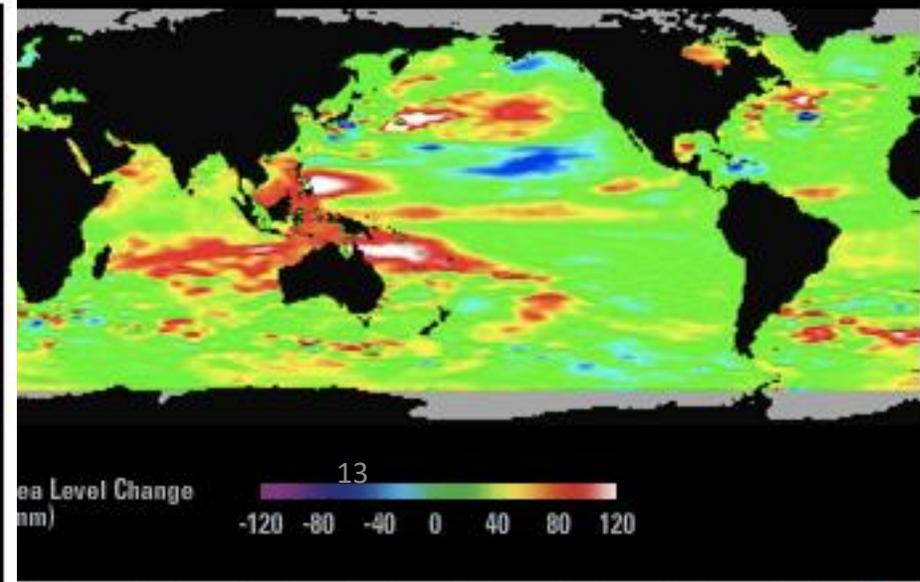
Data source: Satellite sea level observations.
 Credit: NASA Goddard Space Flight Center

RISE SINCE 1993

↑ **102.5**
 millimeters

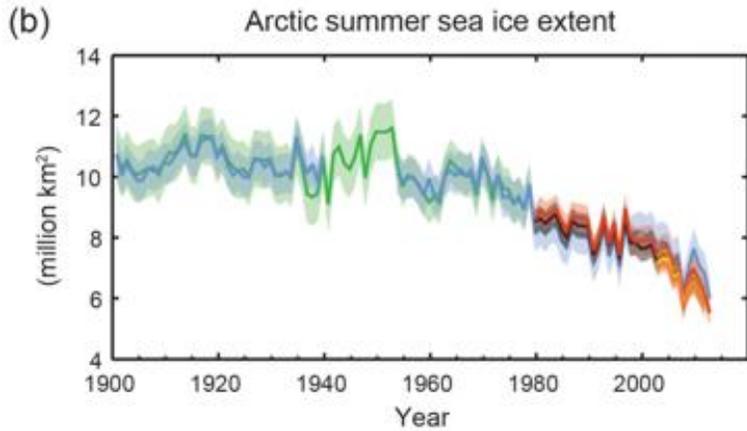


1994 1996 1998 2000 2002 2004 2006 2008



1994 1996 1998 2000 2002 2004 2006 2008

Arctic Sea Ice



TIME SERIES: 1979-2019

Data source: Satellite observations.
Credit: [NASA Scientific Visualization Studio](#)

1979



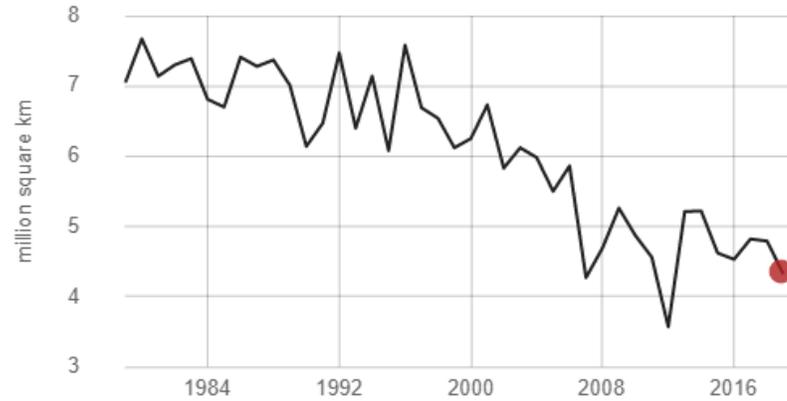
▶ 1979 ○ 2019

AVERAGE SEPTEMBER EXTENT

Data source: Satellite observations. Credit: [NSIDC/NASA](#)

RATE OF CHANGE

↓ 12.85
percent per decade



TIME SERIES: 1979-2019

Data source: Satellite observations.
Credit: [NASA Scientific Visualization Studio](#)

2019



▶ 1979 ○ 2019

Summer Arctic sea ice extent is shrinking by 12.6% per decade as a result of global warming.



ARIZONA

Antarctica and Greenland Ice sheets

ANTARCTICA MASS VARIATION SINCE 2002

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

RATE OF CHANGE

↓ **151.0**
billion metric tons per
year since 2002



GREENLAND MASS VARIATION SINCE 2002

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

RATE OF CHANGE

↓ **273.0**
billion metric tons per
year since 2002



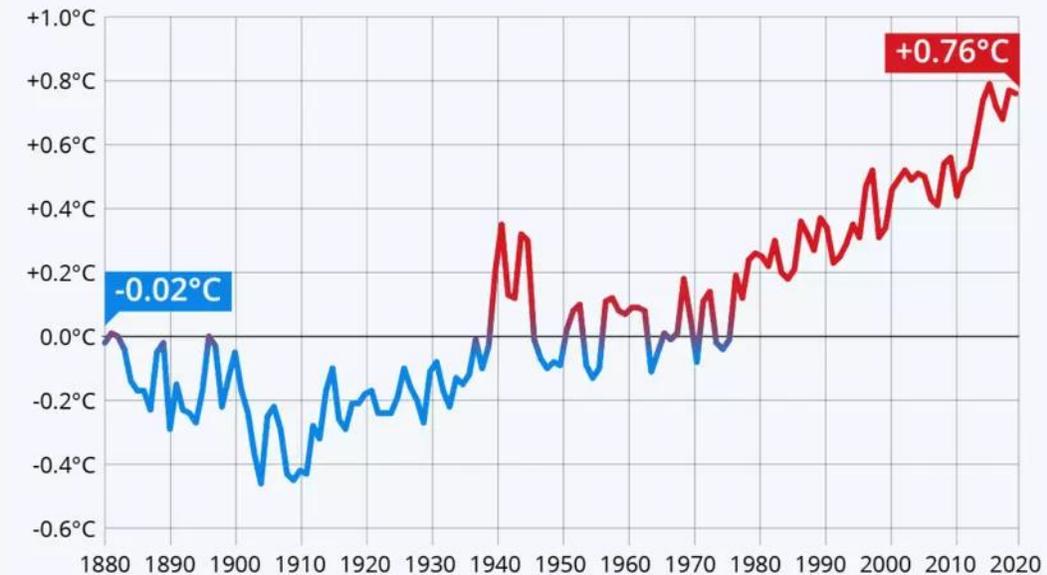
Antarctica is losing ice mass (melting) at an average rate of about **150 billion tons per year**
Greenland is losing about **280 billion tons per year**, adding to sea level rise.

Ocean warming

- Ocean warming by 0.302° F of top 700 m ocean since 1969
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010.

The Oceans Are Getting Warmer

Annual divergence of global ocean temperature from 20th century average (1880-2020)



Ocean surface temperatures

Source: NOAA National Centers for Environmental Information (NCEI)

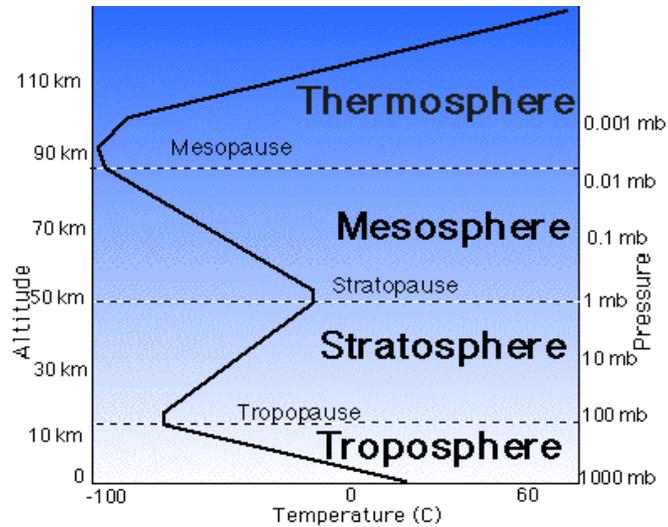


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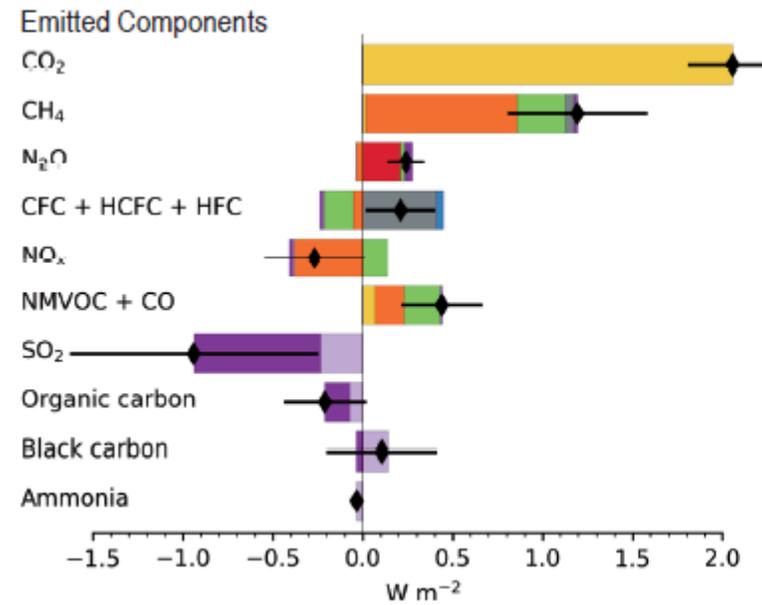
What is causing it?

Radiative forcing due to anthropogenic cause

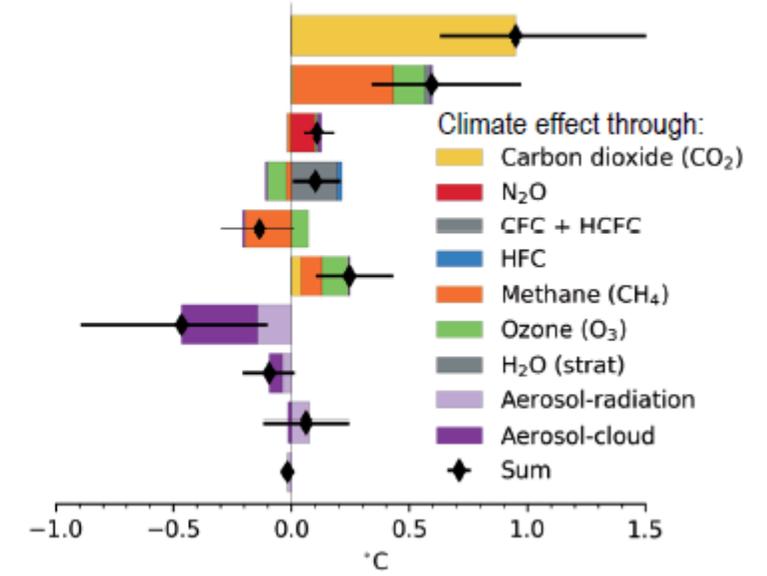
Radiative Forcing is change in net irradiance at the atmospheric boundary between the troposphere and the stratosphere (the tropopause)



Effective radiative forcing 1750 to 2019



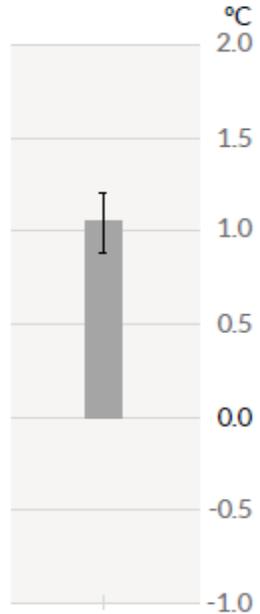
Change in global surface temperature 1750 to 2019



Observed warming is driven by emissions from human activities, with GHGs warming partly masked by aerosol cooling

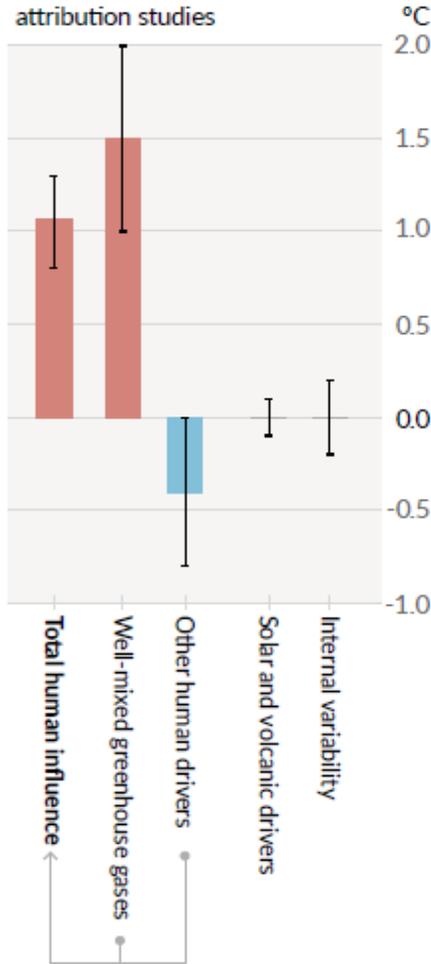
Observed warming

a) Observed warming 2010-2019 relative to 1850-1900

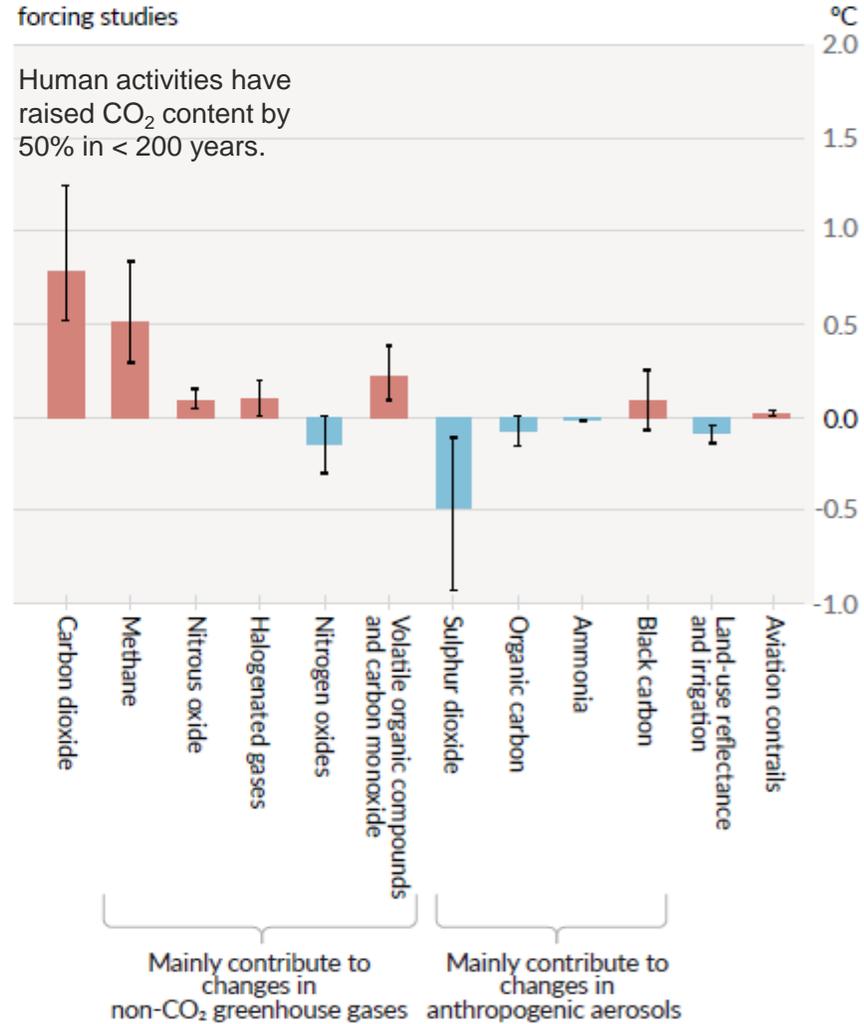


Contributions to warming based on two complementary approaches

b) Aggregated contributions to 2010-2019 warming relative to 1850-1900, assessed from attribution studies



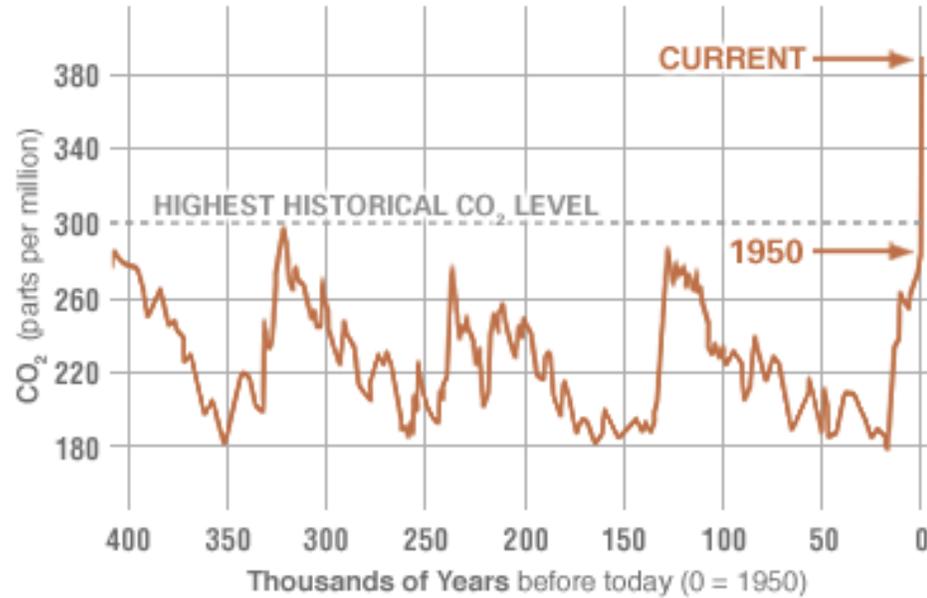
c) Contributions to 2010-2019 warming relative to 1850-1900, assessed from radiative forcing studies



PROXY (INDIRECT) MEASUREMENTS

Data source: Reconstruction from ice cores.

Credit: [NOAA](#)

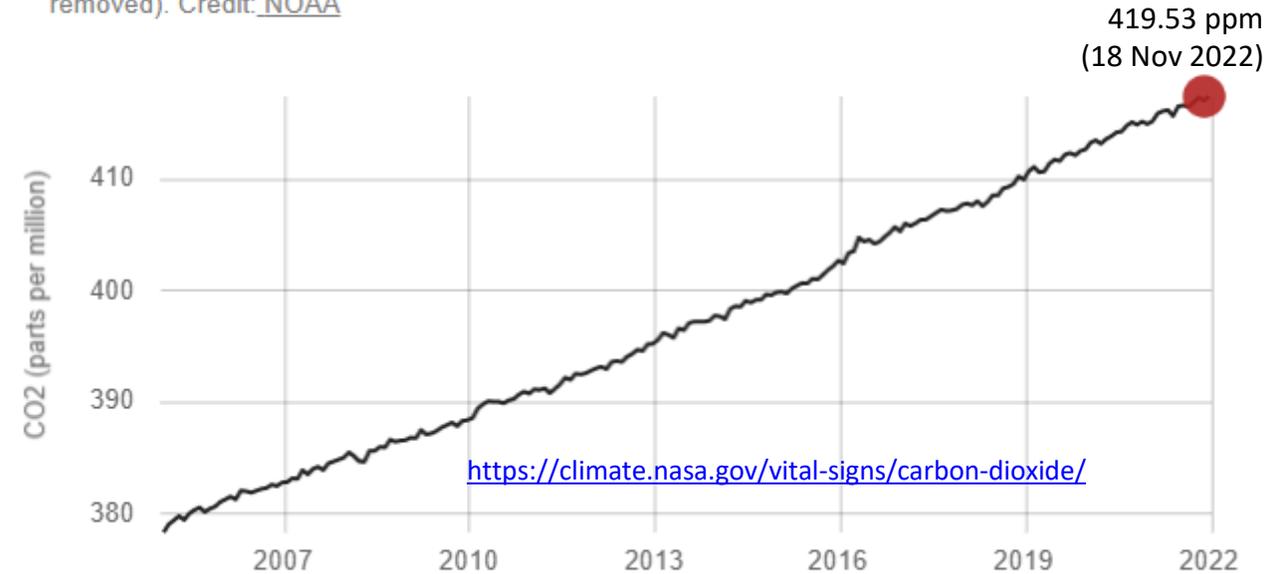


TIME SERIES: 2002-2016

Data source: Atmospheric Infrared Sounder (AIRS).
Credit: [NASA](#)

DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (average seasonal cycle removed). Credit: [NOAA](#)



SEPTEMBER

2002

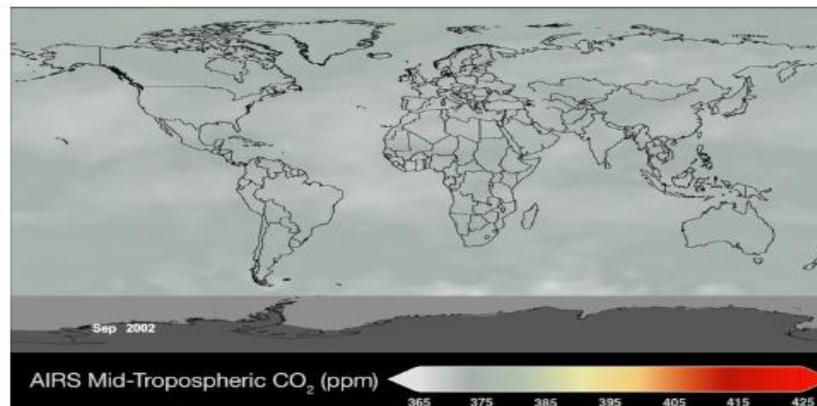
TIME SERIES: 2002-2016

Data source: Atmospheric Infrared Sounder (AIRS).
Credit: [NASA](#)

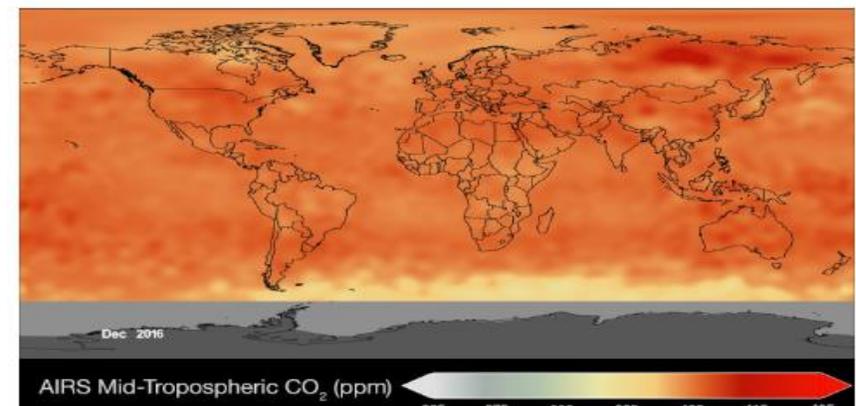
DECEMBER

2016

Carbon dioxide concentration

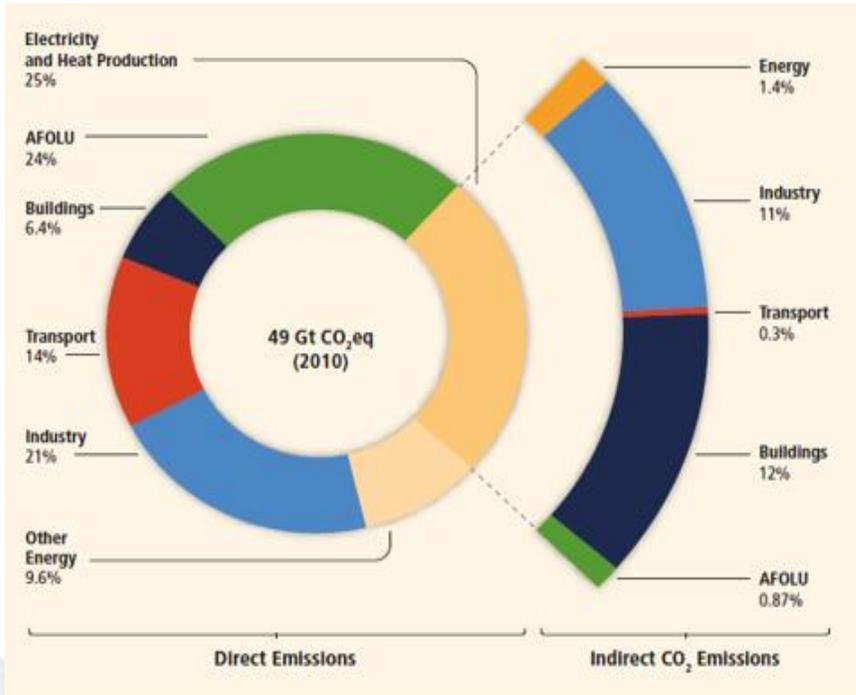


▶ 2002 ○ ————— 2016

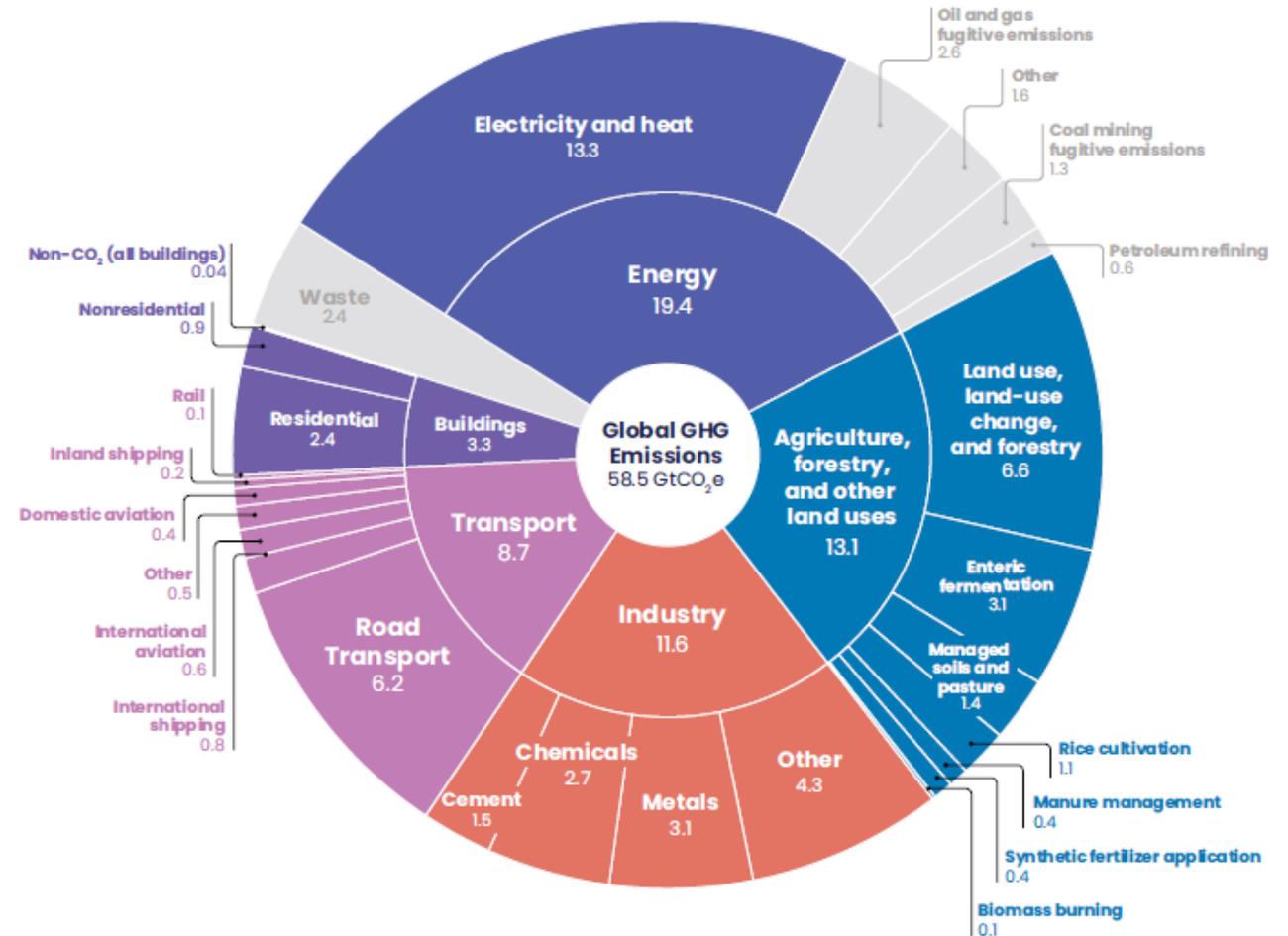


▶ 2002 ————— ○ 2016

Global GHG emissions by sectors in 2019



~20% increase



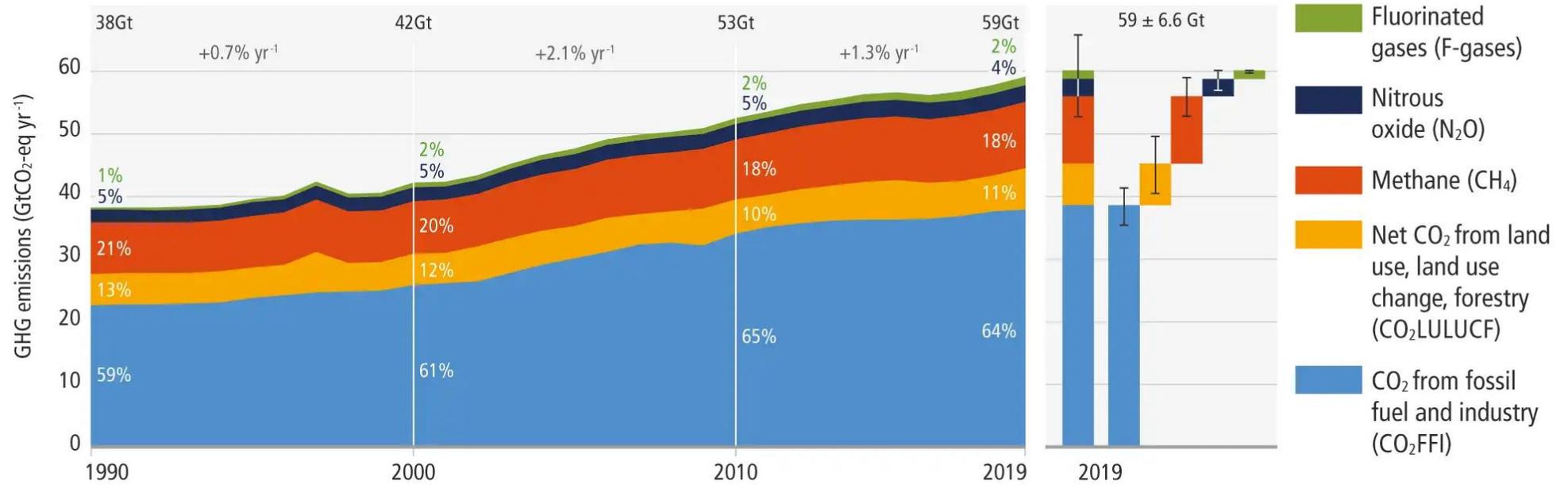
Notes: CO₂ = carbon dioxide; GHG = greenhouse gas; GtCO₂e = gigatonnes of carbon dioxide equivalent.
Source: Minx et al. (2022), described in Minx et al. (2021) and used in IPCC (2022b).

Boehm, S., L. Jeffery, K. Levin, J. Hecke, C. Schumer, C. Fyson, A. Majid, J. Jaeger, A. Nilsson, S. Naimoli, J. Thwaites, E. Cassidy, K. Lebling, M. Sims, R. Waite, R. Wilson, S. Castellanos, N. Singh, A. Lee, and A. Geiges. 2022. *State of Climate Action 2022*. <https://doi.org/10.46830/wrirpt.22.00028>.

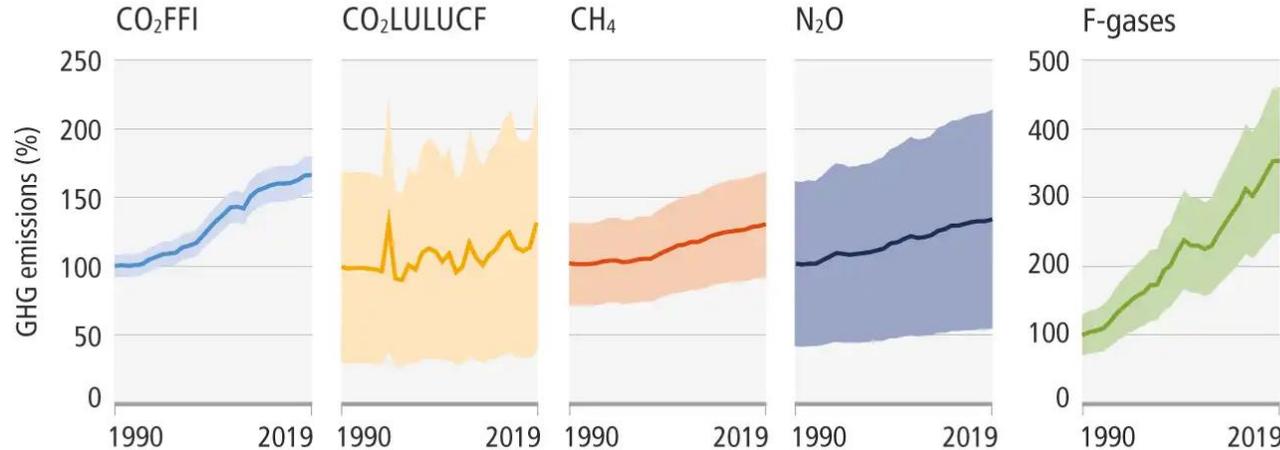
Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.

Global net anthropogenic GHG emissions (GtCO₂-eq yr⁻¹) 1990–2019

a. Global net anthropogenic GHG emissions 1990–2019 ⁽⁵⁾



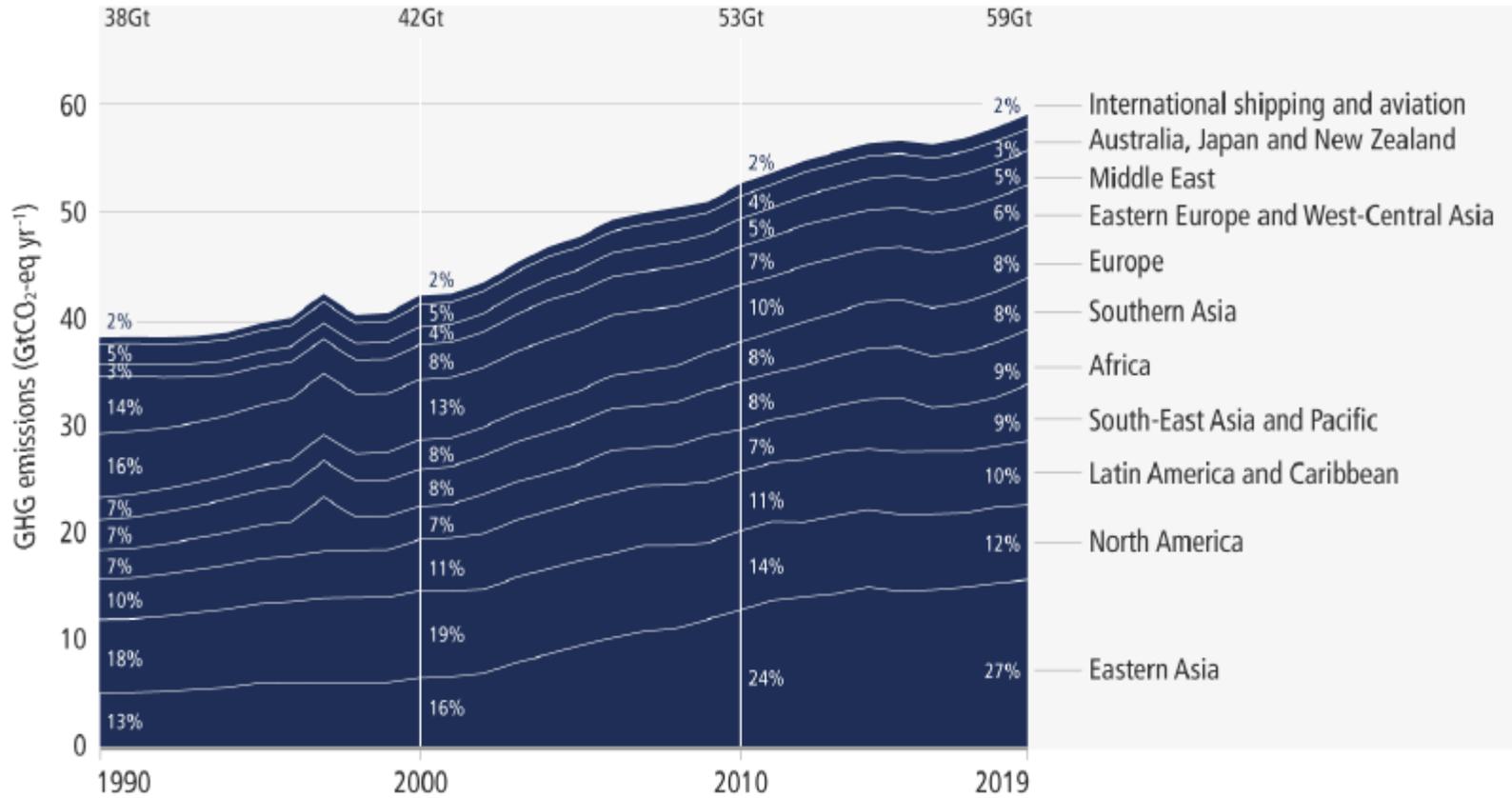
b. Global anthropogenic GHG emissions and uncertainties by gas – relative to 1990

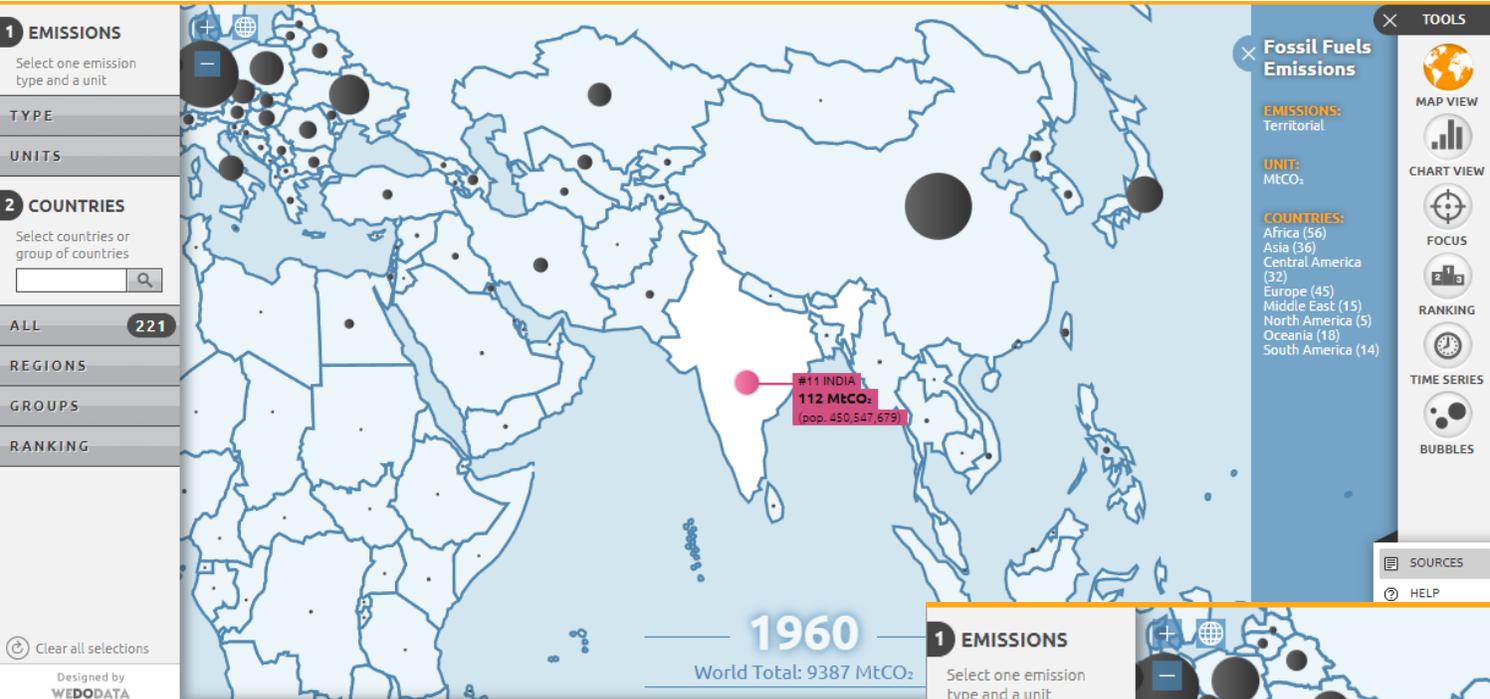


	2019 emissions (GtCO ₂ -eq)	1990–2019 increase (GtCO ₂ -eq)	Emissions in 2019, relative to 1990 (%)
CO ₂ FFI	38 ± 3	15	167
CO ₂ LULUCF	6.6 ± 4.6	1.6	133
CH ₄	11 ± 3.2	2.4	129
N ₂ O	2.7 ± 1.6	0.65	133
F-gases	1.4 ± 0.41	0.97	354
Total	59 ± 6.6	21	154

The solid line indicates central estimate of emissions trends. The shaded area indicates the uncertainty range.

Global net anthropogenic GHG emissions by region (1990-2019)





Countrywise CO₂ emission

<http://www.globalcarbonatlas.org/en/CO2-emissions>

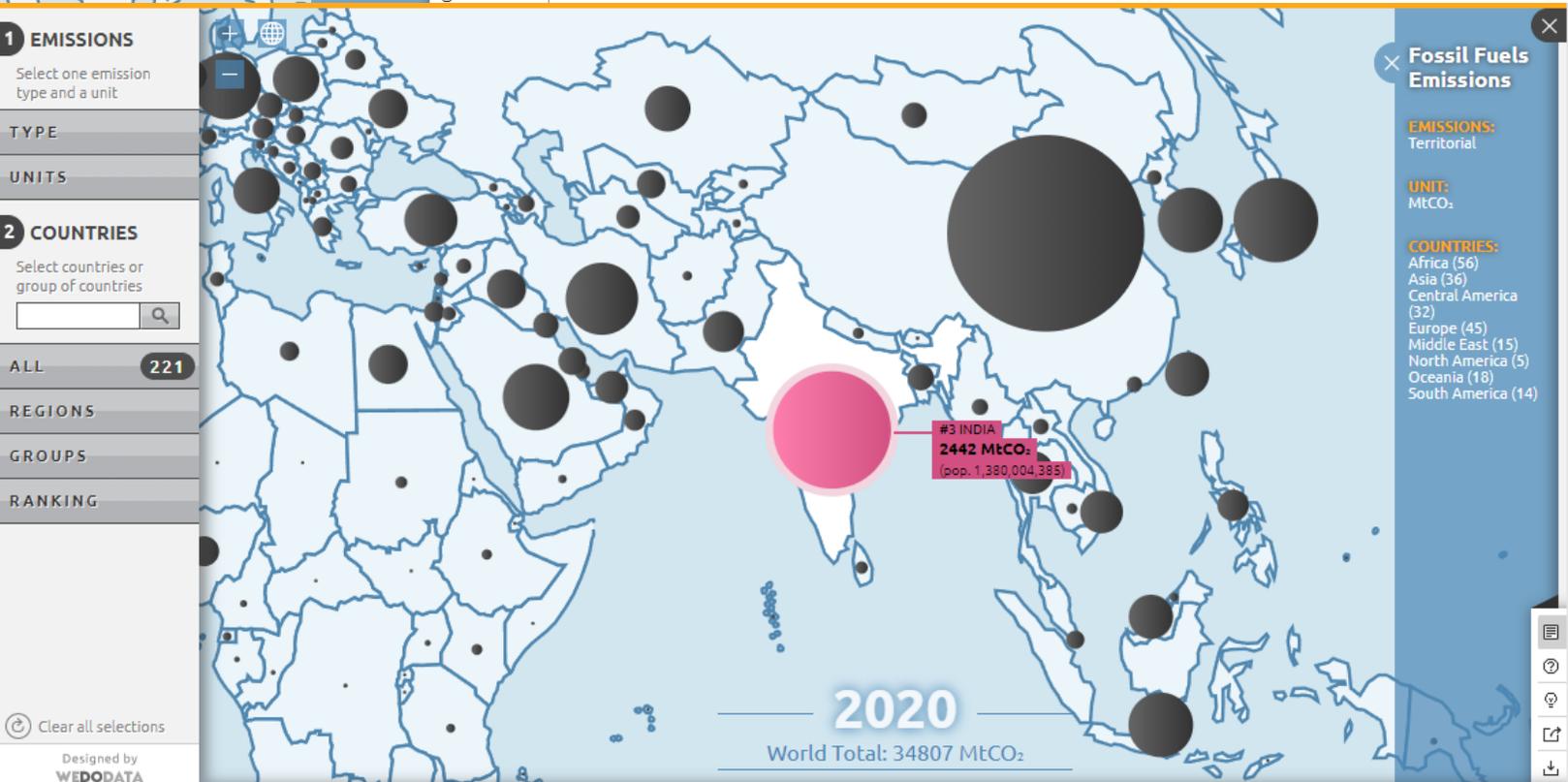


Country	Metric tons / capita
Qatar	32.42
Kuwait	21.82
UAE	20.80
Bahrain	19.59
Brunei Darussalam	18.64
Palau	18.19
Canada	15.50
Australia	15.48
Luxembourg	15.33
Saudi Arabia	15.27
USA	15.24

Per capita CO₂ emission (2018)

Country	Metric tons / capita
Afghanistan	0.20
Bangladesh	0.51
Bhutan	1.83
China	7.35
India	1.8
Nepal	0.43
Sri Lanka	1.00

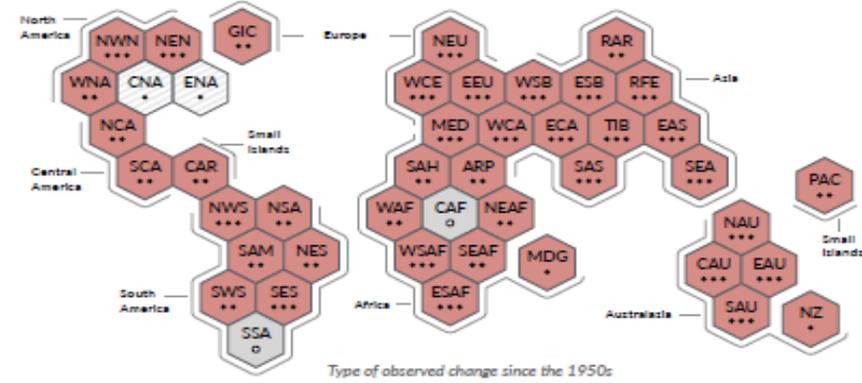
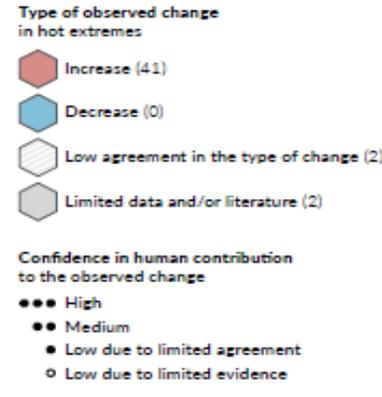
<https://data.worldbank.org/indicator/EN.ATM.CO2E.PC>



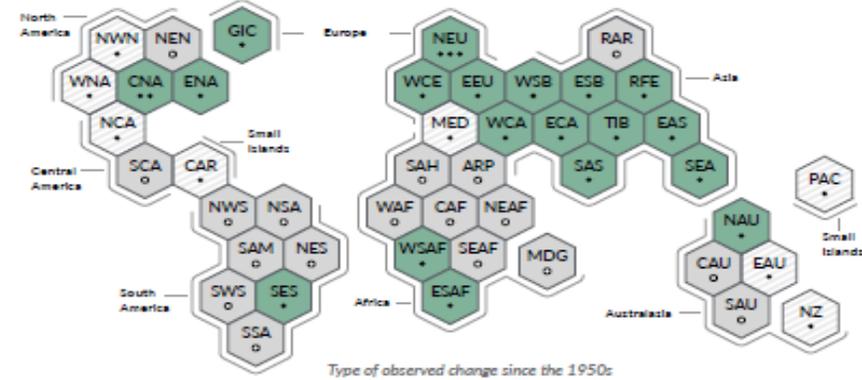
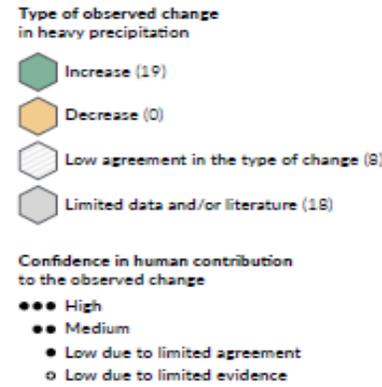
Why does climate change matter to us?

Climate change is already affecting every inhabited region with many observed changes in weather and climate extremes

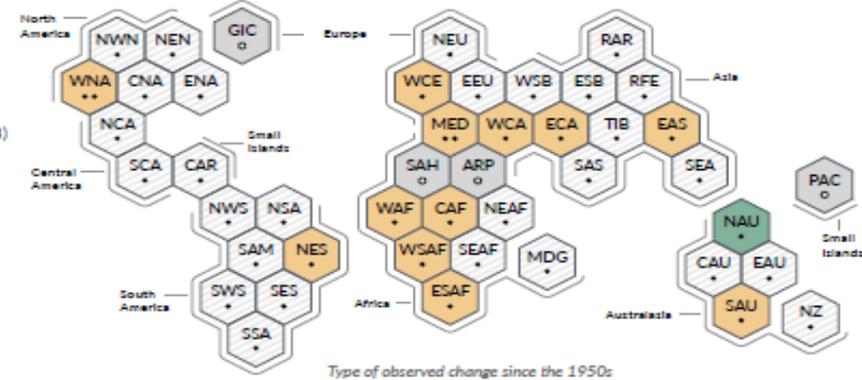
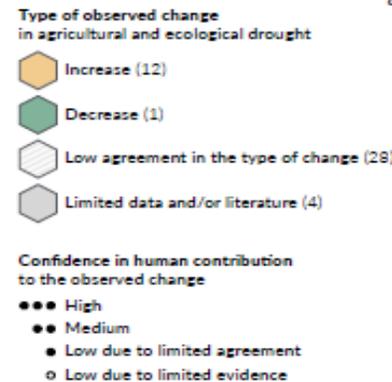
a) Synthesis of assessment of observed change in hot extremes and confidence in human contribution to the observed changes in the world's regions



b) Synthesis of assessment of observed change in heavy precipitation and confidence in human contribution to the observed changes in the world's regions



c) Synthesis of assessment of observed change in agricultural and ecological drought and confidence in human contribution to the observed changes in the world's regions



Alaska's Sea Ice Completely Melted for First Time in Recorded History



People attend a monument unveiling at the site of Okjökull, Iceland's first glacier lost to climate change, in the west of Iceland on August 18, 2019.

Rain on Greenland's Summit For The First Time in Recorded History, 20 AUGUST 2021



Lake of meltwater in Greenland. (Timo Lieber)

ENVIRONMENT

It Just Rained on Greenland's Summit For The First Time in Recorded History

TESSA KOUMOUNDOUROS 20 AUGUST 2021

It has just rained at the summit of Greenland's ice sheet for the first time in recorded history, in yet another worrying milestone in our [ecological unravelling](#).

Like much of the Northern Hemisphere, Greenland's been [experiencing a massive heatwave](#) with temperatures at the glacier's summit rising above freezing for the third time in [less than a decade](#). On 14 August 2021, at a place normally far too frigid for water to fall as a liquid, the National Snow and Ice Data Center's (NSIDC) Summit Station recorded several hours of rain.

<https://www.sciencealert.com/it-rained-on-greenland-s-summit-for-the-first-time-in-recorded-history>



AIT

AGRICULTURE

Summer crops may be damaged this year due to temperature rise: Experts

States accuse the Centre of not taking any initiative to help them increase production of summer crops



NEXT NEWS >

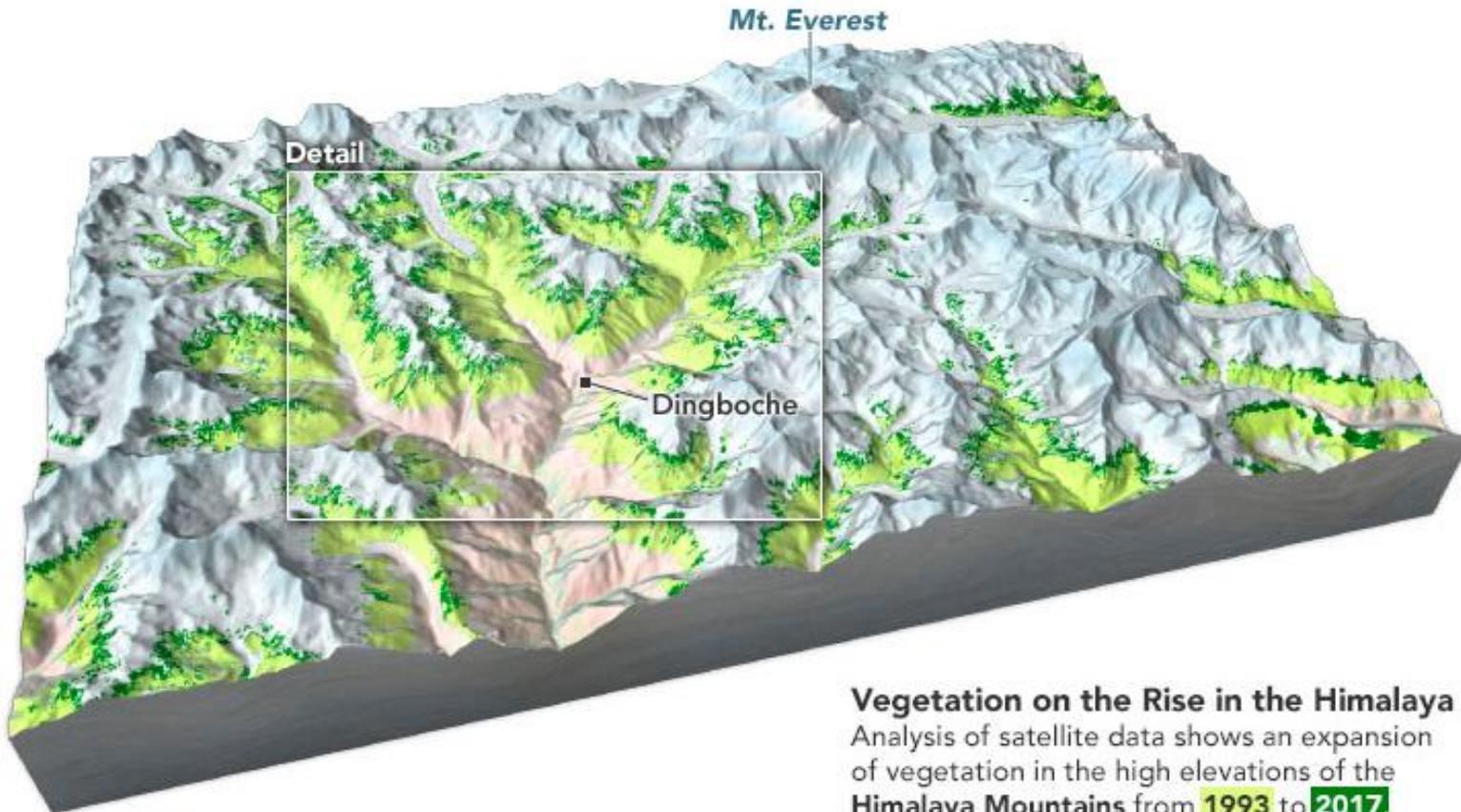
By Raju Sajwan

Published: Tuesday 19 April 2022



https://www.downtoearth.org.in/news/agriculture/summer-crops-may-be-damaged-this-year-due-to-temperature-rise-experts-82458?utm_source=Mailer&utm_medium=Email&utm_campaign=Down%20To%20Earth-5115

Ice melting and plant life spreads



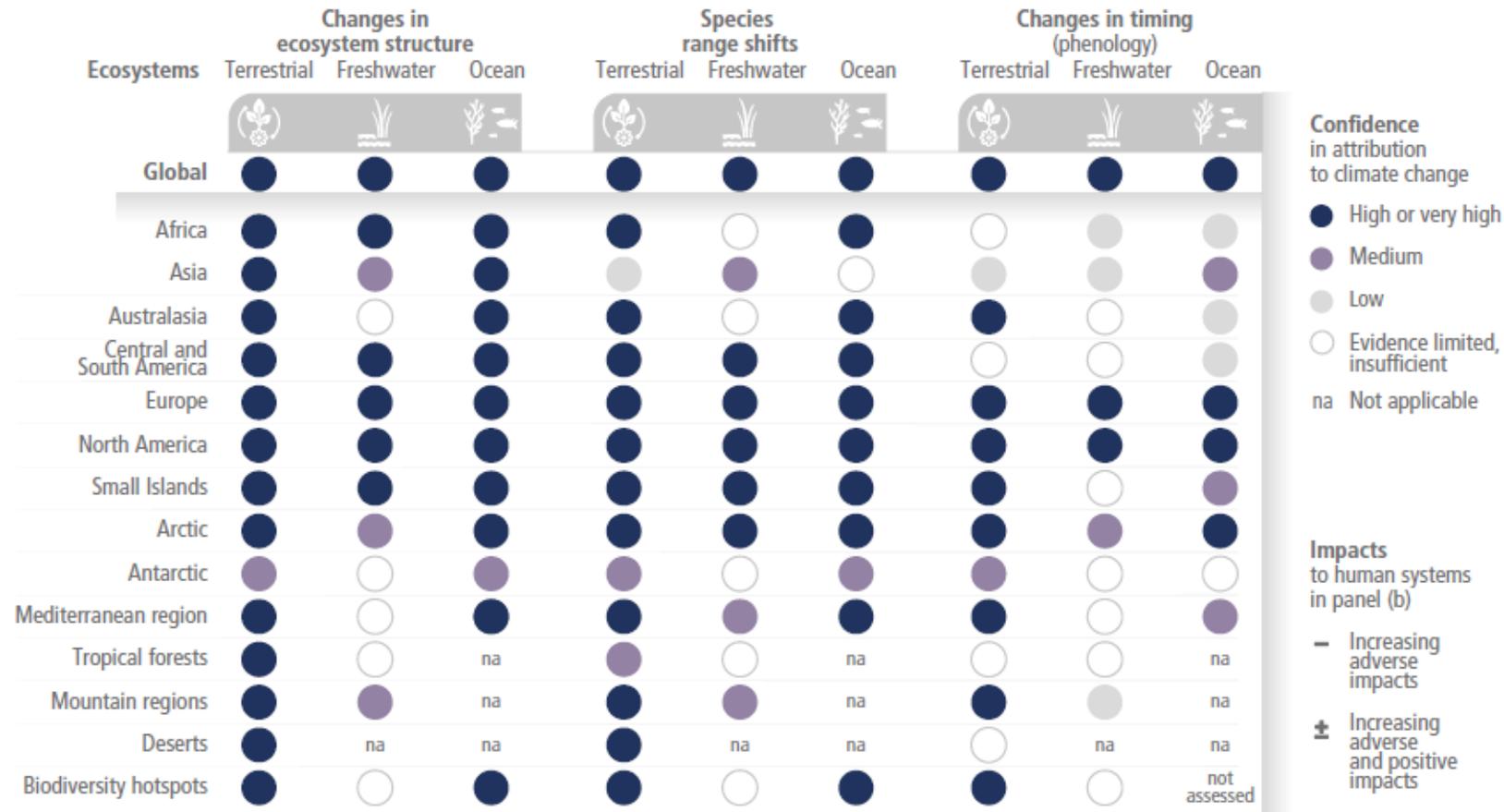
Vegetation on the Rise in the Himalaya
Analysis of satellite data shows an expansion of vegetation in the high elevations of the Himalaya Mountains from 1993 to 2017.



Coral bleaching is a consequence of a warming ocean. This image shows bleached coral off Islamorada, Florida. Credit: Kelsey Roberts/USGS

<https://earthobservatory.nasa.gov/images/149312/everest-area-plant-life-spreads?src=ea-iotd>; 12 Dec 2022

Observed impacts of climate change on ecosystem



Observed impacts of climate change on human systems

Human systems	Impacts on water scarcity and food production				Impacts on health and wellbeing				Impacts on cities, settlements and infrastructure			
	Water scarcity	Agriculture/crop production	Animal and livestock health and productivity	Fisheries yields and aquaculture production	Infectious diseases	Heat, malnutrition and other	Mental health	Displacement	Inland flooding and associated damages	Flood/storm induced damages in coastal areas	Damages to infrastructure	Damages to key economic sectors
Global	±	-	○	-	-	-	-	-	-	-	-	-
Africa	-	-	-	-	-	-	-	-	-	-	-	-
Asia	±	±	-	-	-	-	-	-	-	-	-	-
Australasia	±	-	±	-	-	-	-	not assessed	-	-	-	-
Central and South America	±	-	±	-	-	-	-	not assessed	-	-	-	-
Europe	±	±	-	±	-	-	-	-	-	-	-	-
North America	±	±	-	±	-	-	-	-	-	-	-	-
Small Islands	-	-	-	-	-	-	-	-	-	-	-	-
Arctic	±	±	-	-	-	-	-	-	-	-	-	±
Cities by the sea	○	○	○	-	○	-	-	not assessed	○	-	-	-
Mediterranean region	-	-	-	-	-	-	-	not assessed	±	-	○	-
Mountain regions	±	±	-	○	-	-	-	-	-	na	-	-

Projected future emissions cause future additional warming

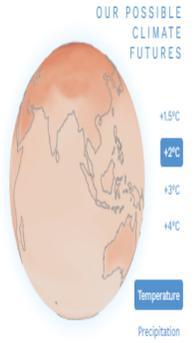


<https://interactive-atlas.ipcc.ch/>

IPCC WGI Interactive Atlas

A novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the Working Group I contribution to the Sixth Assessment Report, including regional synthesis for Climatic Impact-Drivers (CIDs).

- Participate in the user testing survey
- Errata and problem reporting
- License and citation
- Contact



Simple (CLIMATE FUTURES)

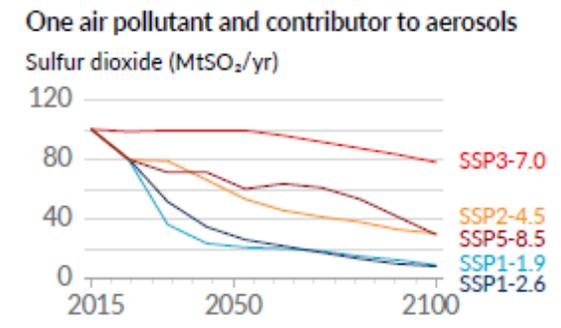
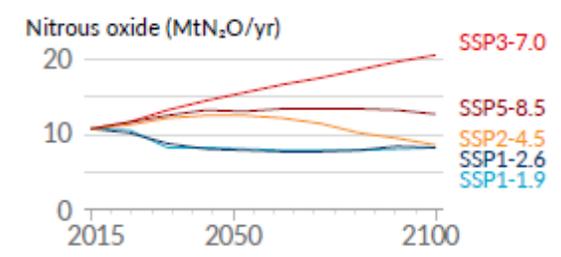
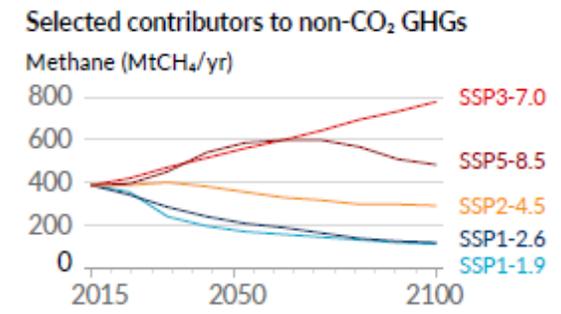
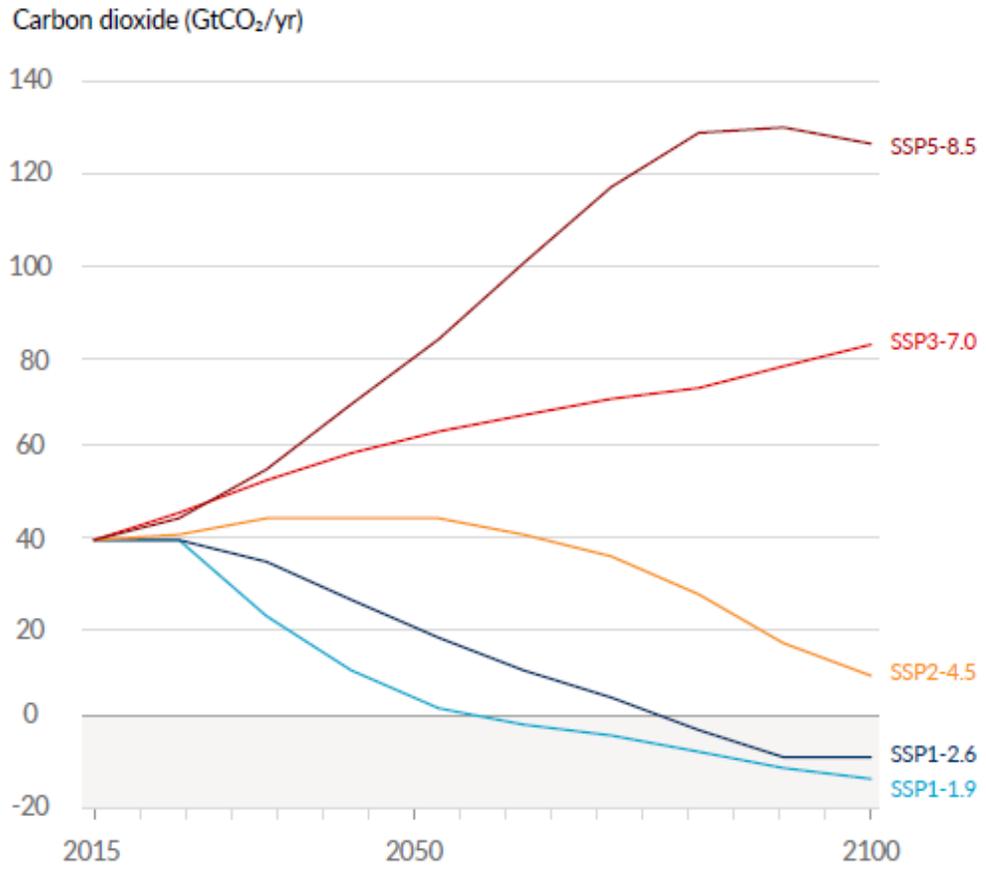
Advanced

REGIONAL INFORMATION

REGIONAL SYNTHESIS

DOCUMENTATION

a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios

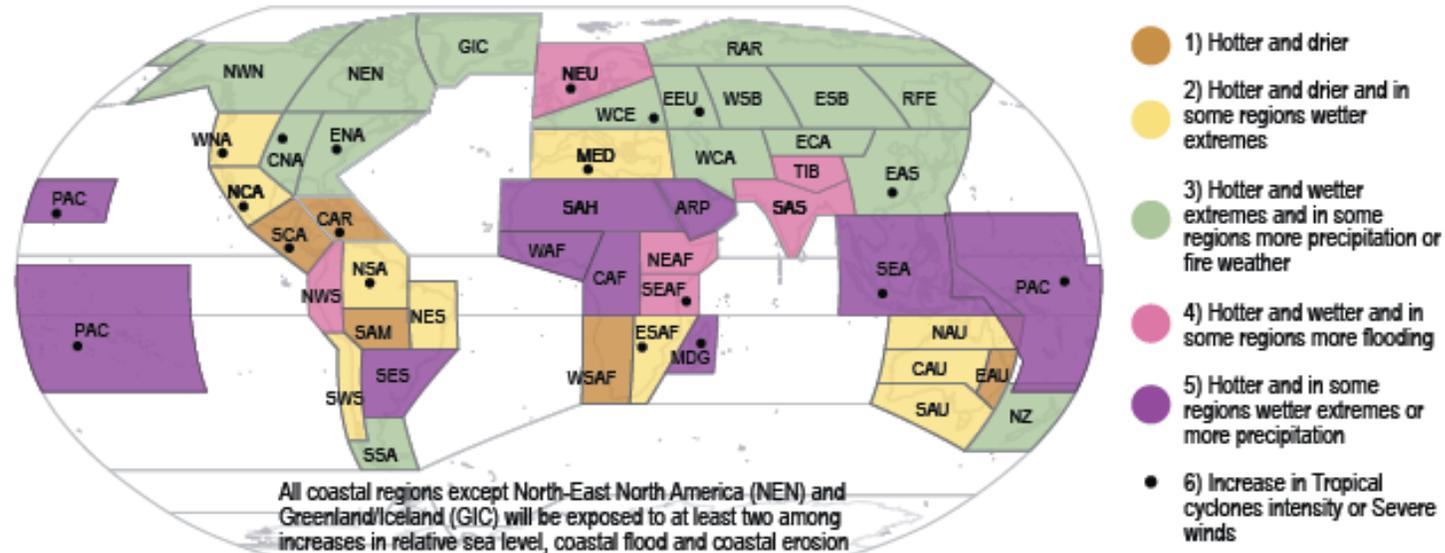


Projected impacts

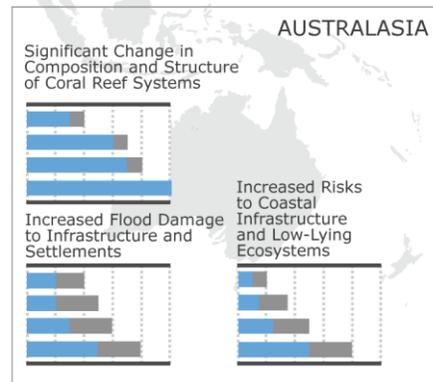
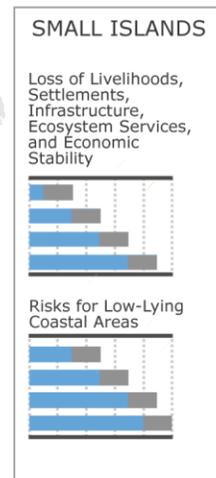
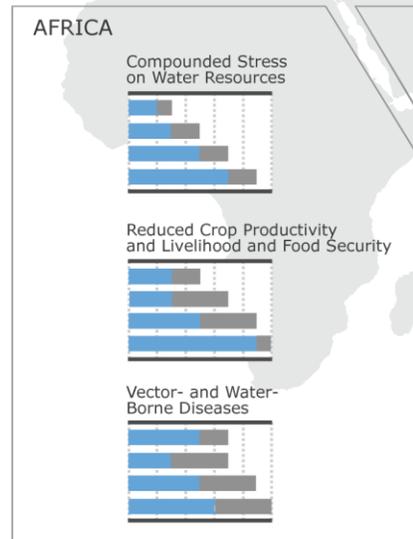
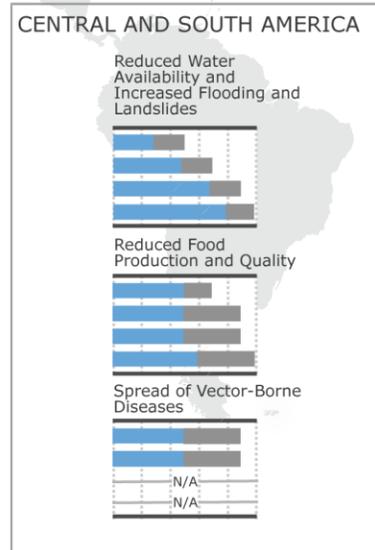
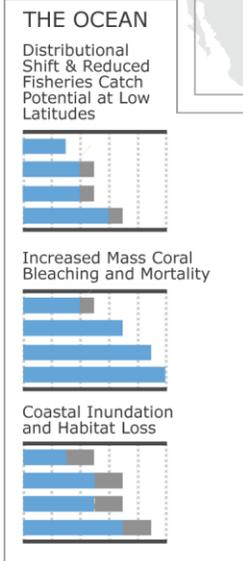
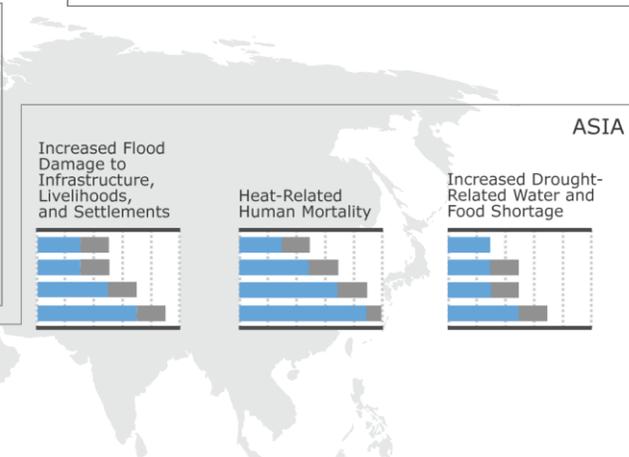
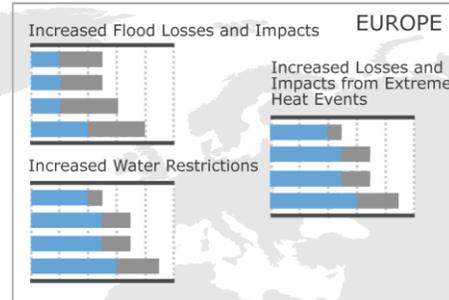
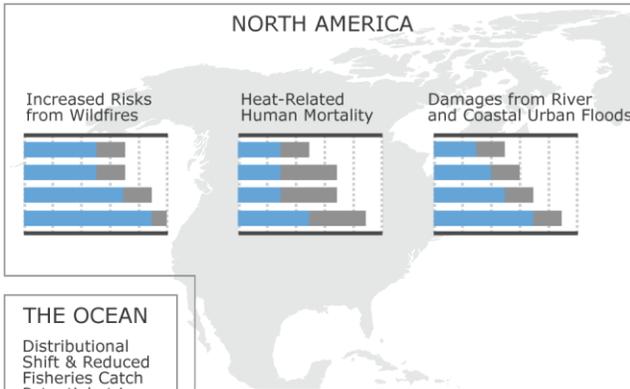
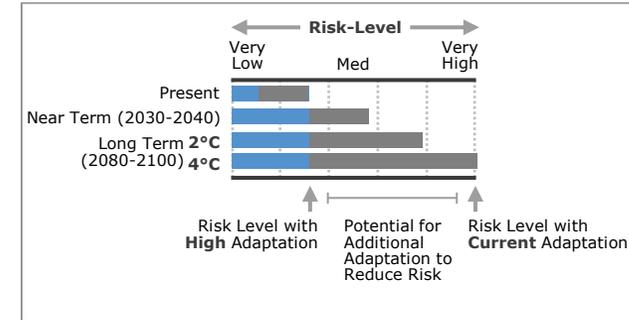
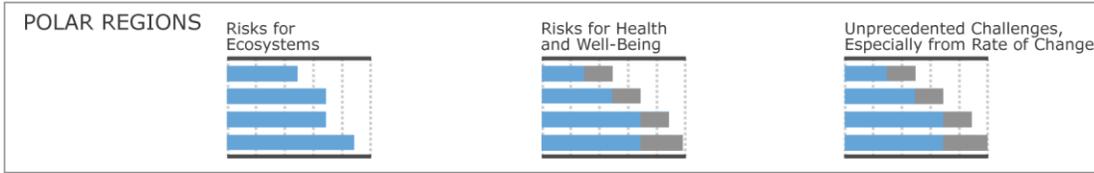
While changes in climatic impact-drivers are projected everywhere, there is a specific combination of changes each region would experience

(a) World regions grouped into five clusters, each one based on a combination of changes in climatic impact-drivers

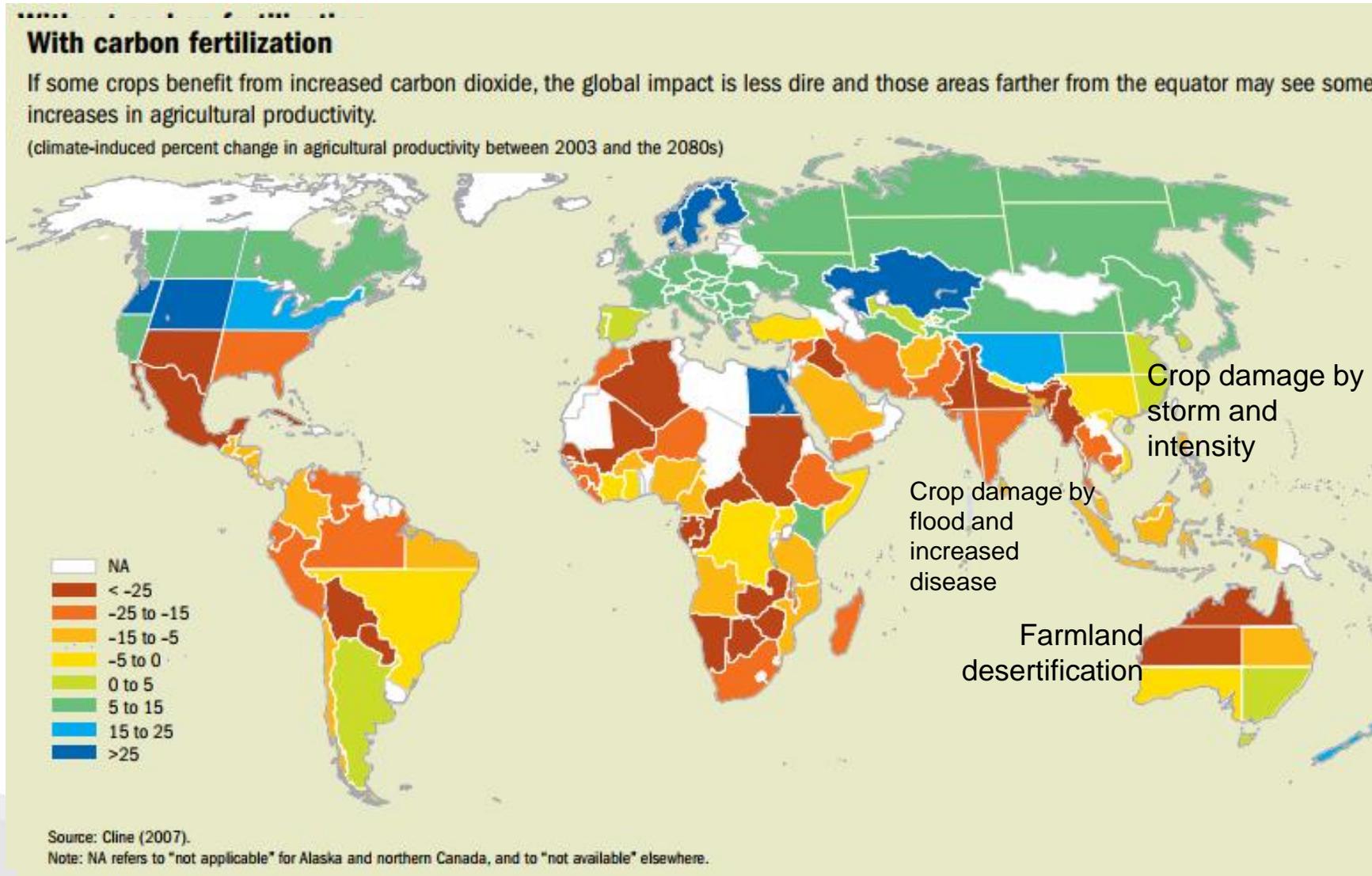
Assessed future changes: Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960–2014 or 1850–1900.



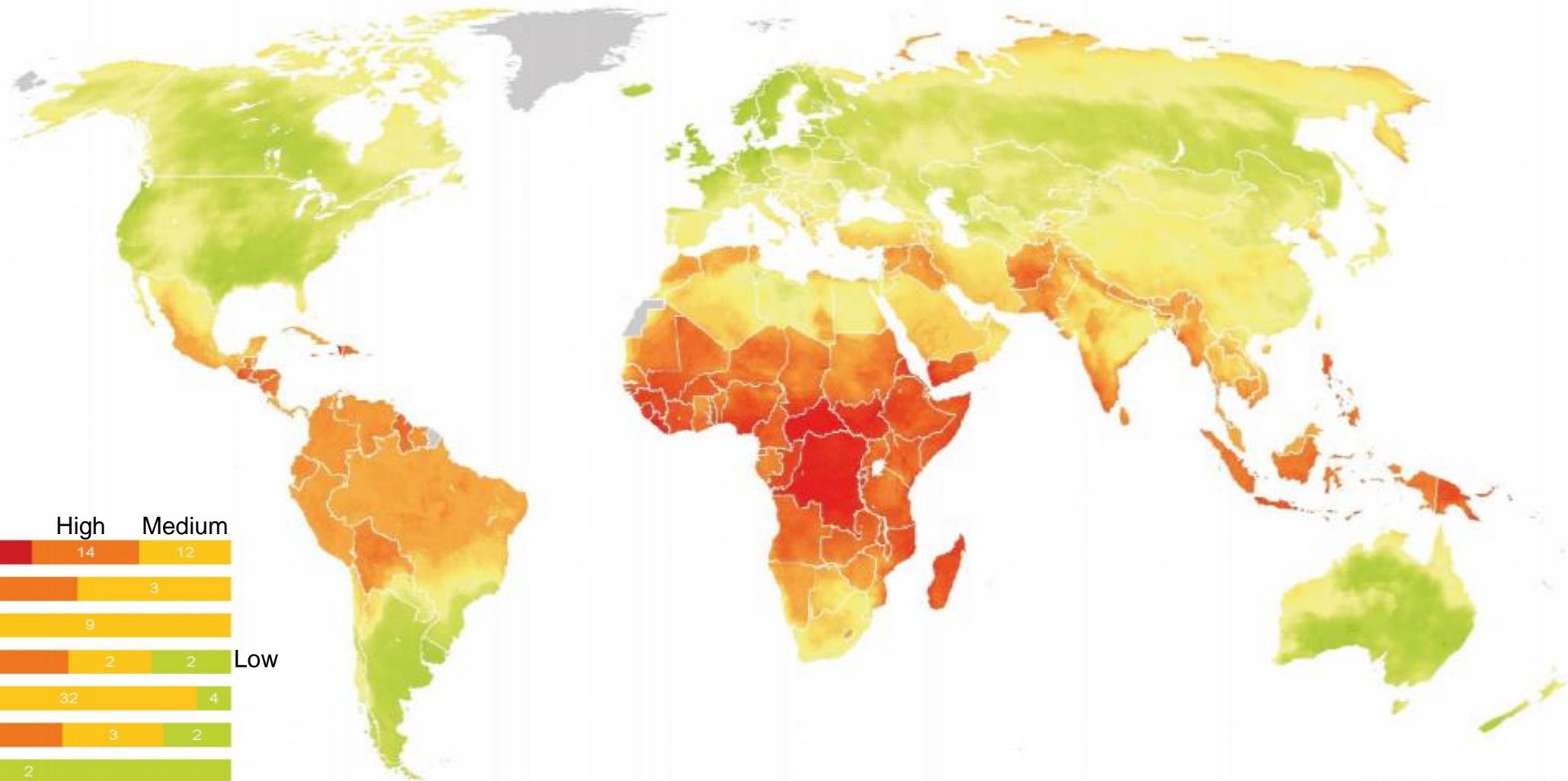
Projected impacts



Impact on Agricultural Yield [2007-2080]



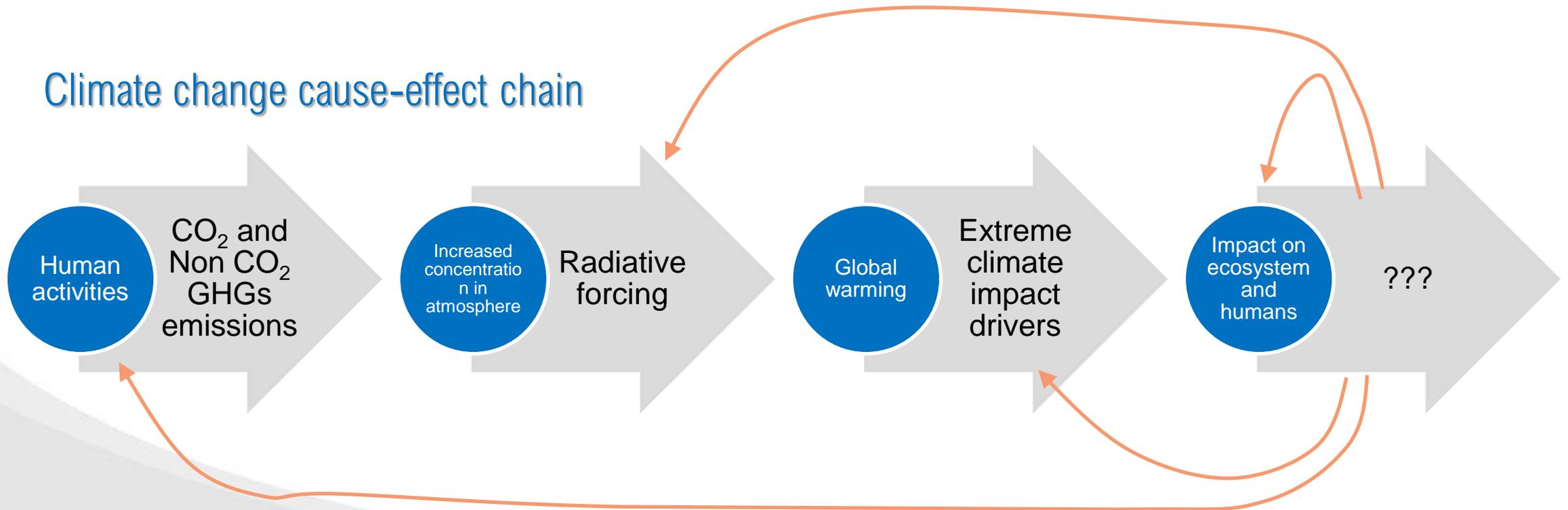
Climate change vulnerability



Takeaway

- Science is very certain: Human influence on the climate system is now an established fact (AR6)
- Climate change has widespread impacts in climate system, ecosystem and human system
- Future climate risk depends on socioeconomic development pathways and climate change responses we adopt, which calls for higher efforts

Climate change cause-effect chain



References

- Climate Change 2021: The Physical Science Basis
(https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf)
- Climate Change 2022: Impacts, Adaptation and Vulnerability.
(<https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/>)
- Climate data <https://www.climate.gov/maps-data/climate-data-primer>