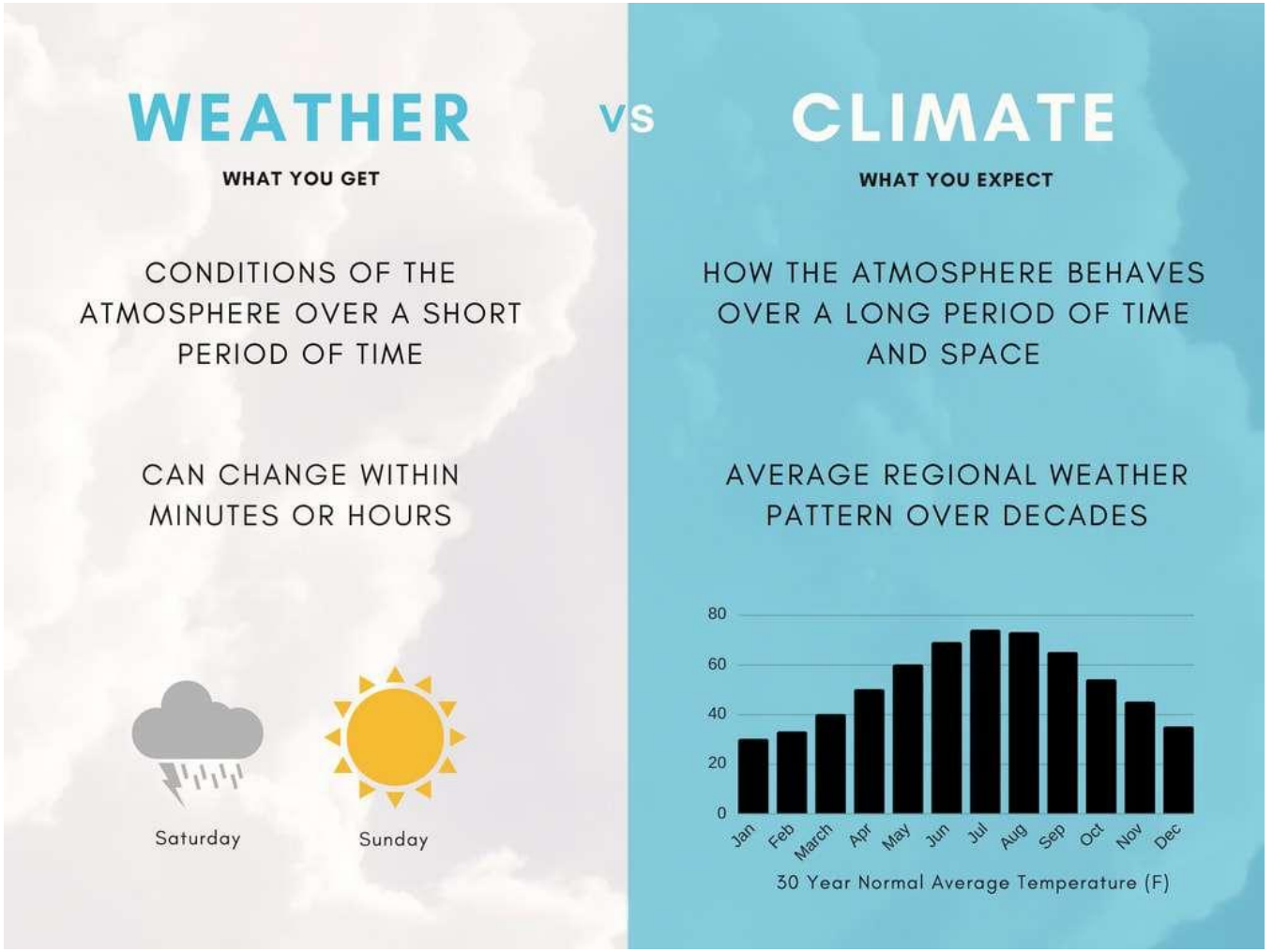
Global Warming and Climate Change

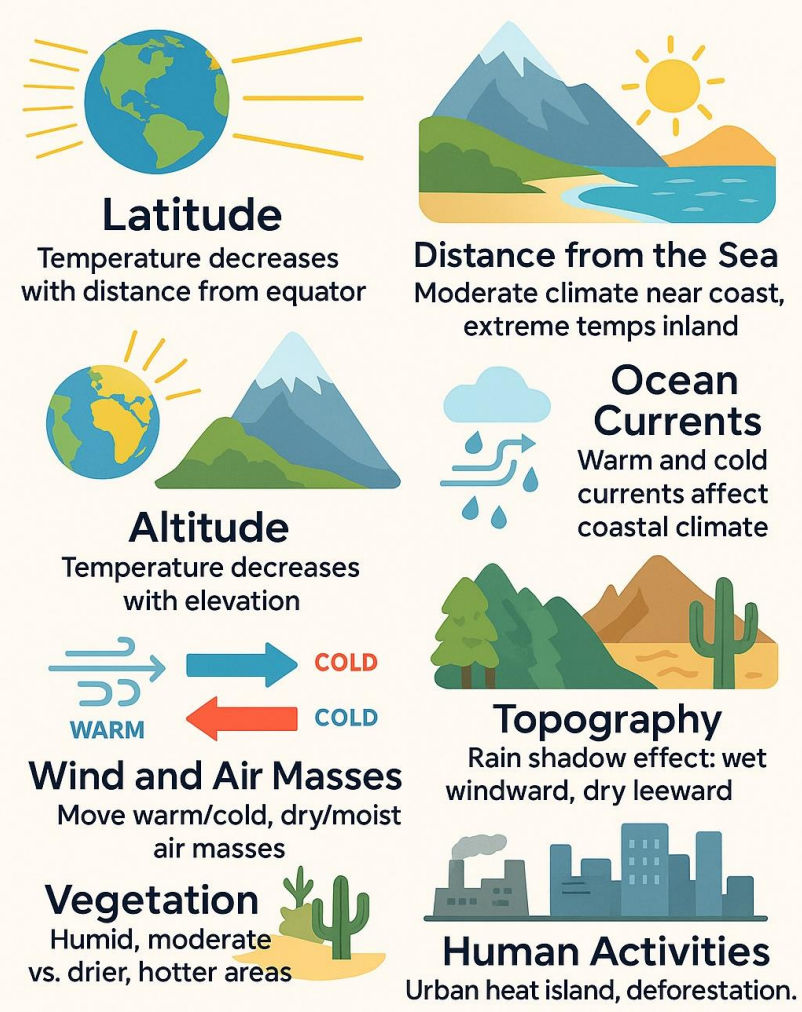
Dr. Praveen Kumar Singh
WRI India

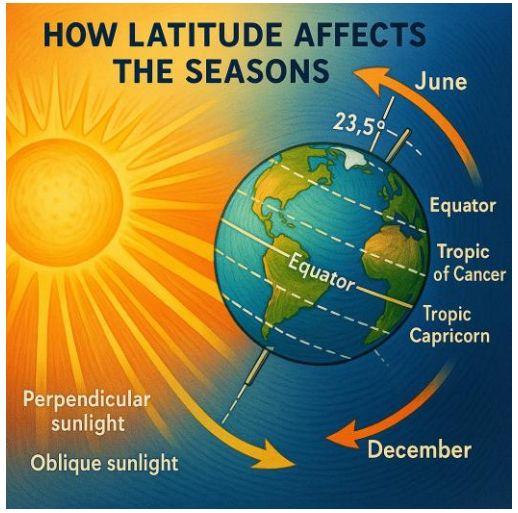
Weather vs. Climate

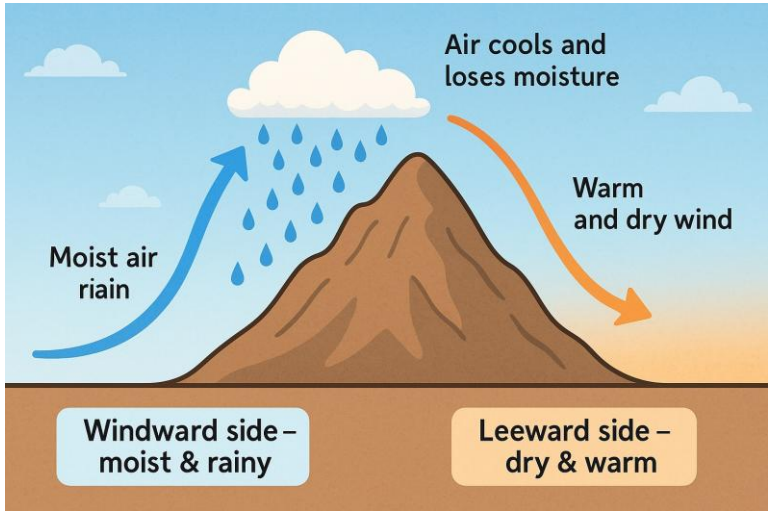
"If you don't like the weather in New England, just wait a few minutes." – Mark Twain

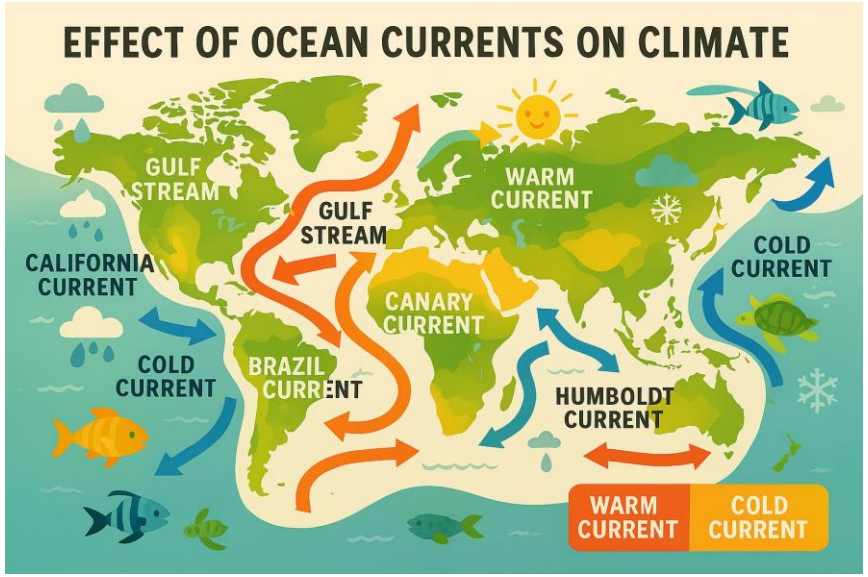


Factors Affecting Climate of a Region

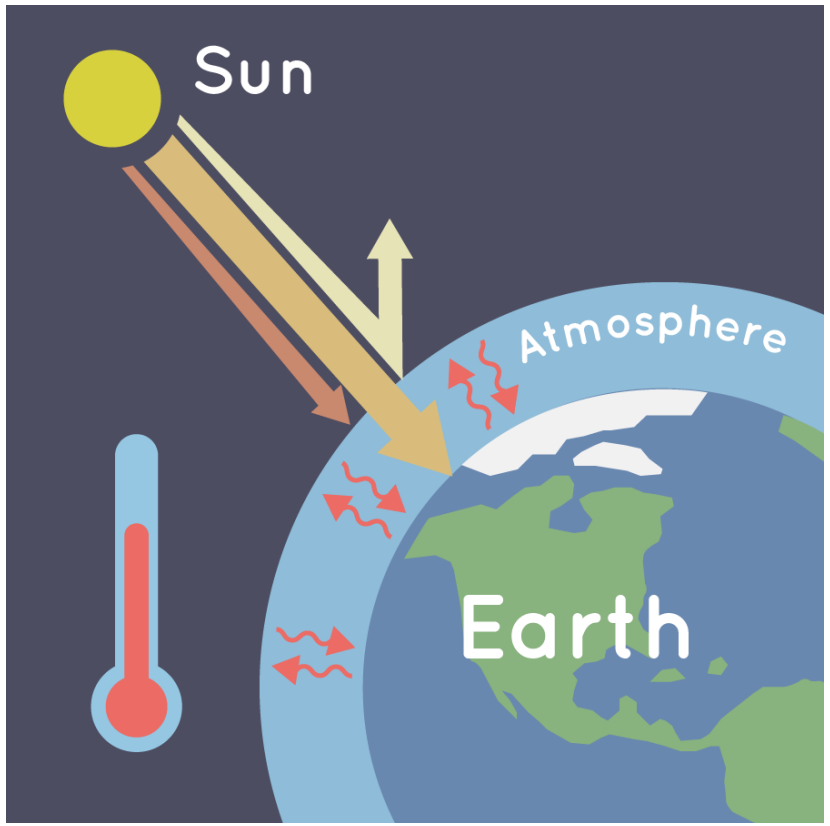






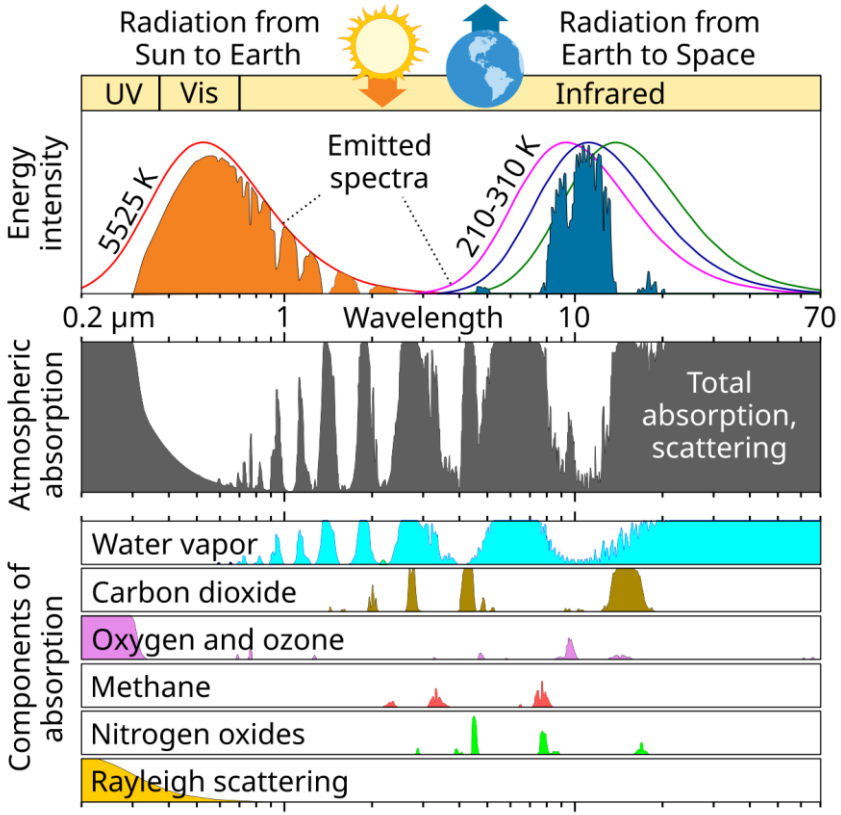


The greenhouse effect



climate.nasa.gov

- Planet with very little greenhouse effect is Mars. Average temp is – 65 ^{o}C and diurnal temp varies between 20 ^{o}C to – 153 ^{o}C.
- Planet with most severe greenhouse effect is Venus. Average temp is 464 ^{o}C.



Wikipedia

The greenhouse effect

Global Warming Potential (GWP) is a measure of how much energy a greenhouse gas traps in the atmosphere relative to carbon dioxide CO_2 over a specific time period, typically 100 years.

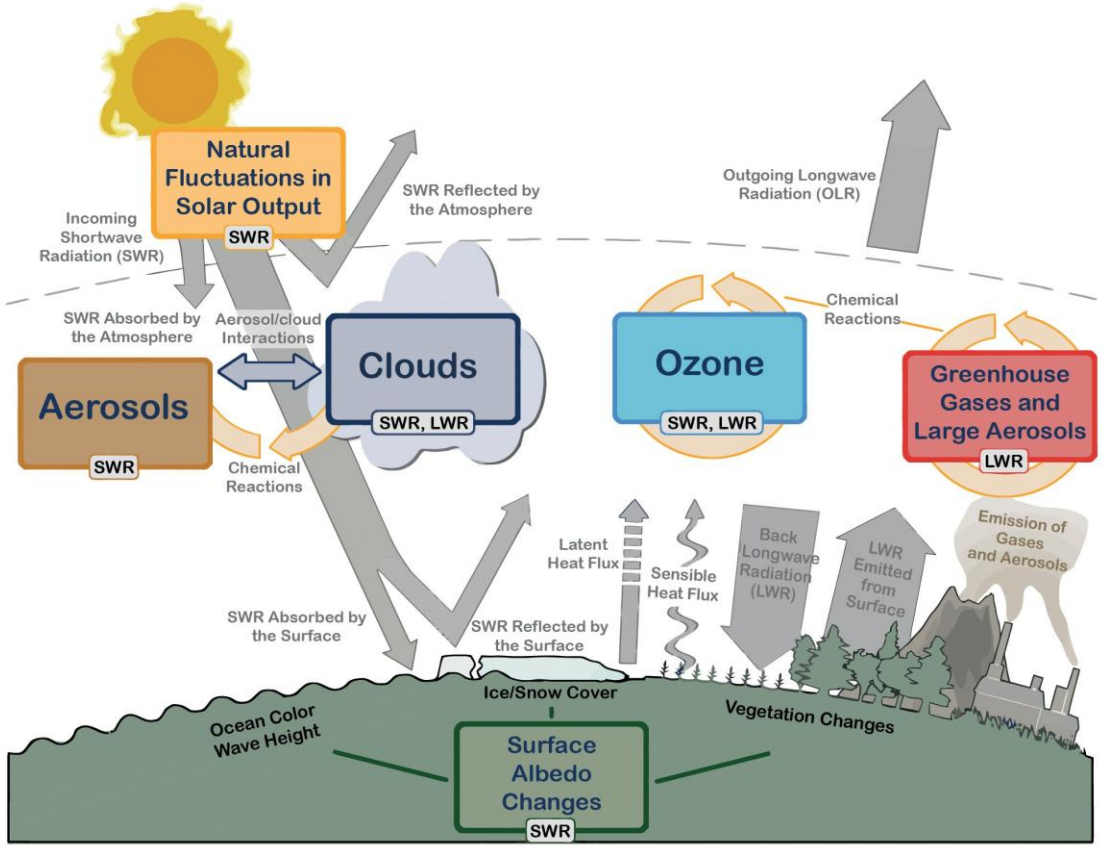
CO_2, by definition, has a GWP of 1. its remains in the climate system for a very long time typically thousands of years.

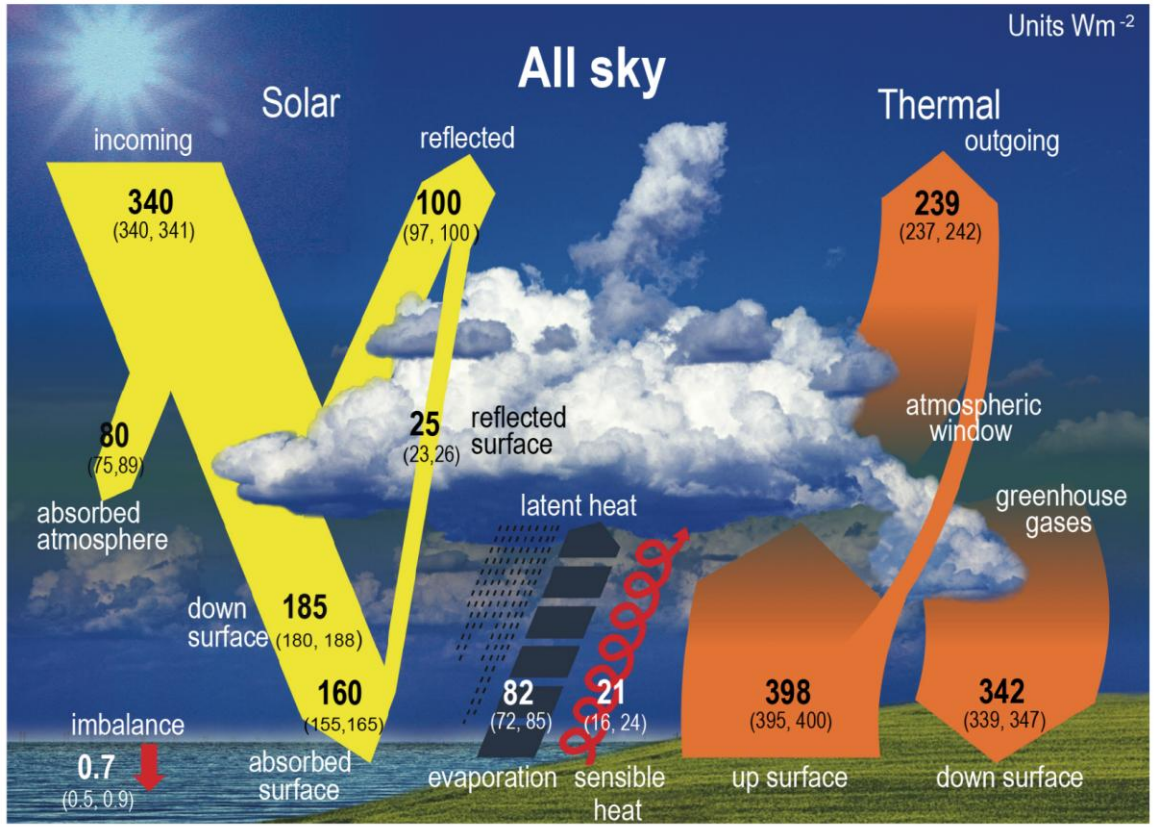
Methane (CH_4) is estimated to have a GWP of 27 to 30 and lifespan of 7 – 12 years, which is much less time than CO_2. The CH_4 GWP also accounts for some indirect effects, because it is a precursor to ozone, and ozone is itself a GHG.

Nitrous Oxide (N_2O) has a GWP 273 and a lifespan of more than 100 years, on average.

Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) , and nitrogen trifluoride (NF_3) are called high-GWP gases because, the GWPs for these gases can be in the thousands or tens of thousands. Once emitted, PFCs, SF_6, and NF_3 persist in the atmosphere for hundreds or thousands of years.

Earth's radiation budget

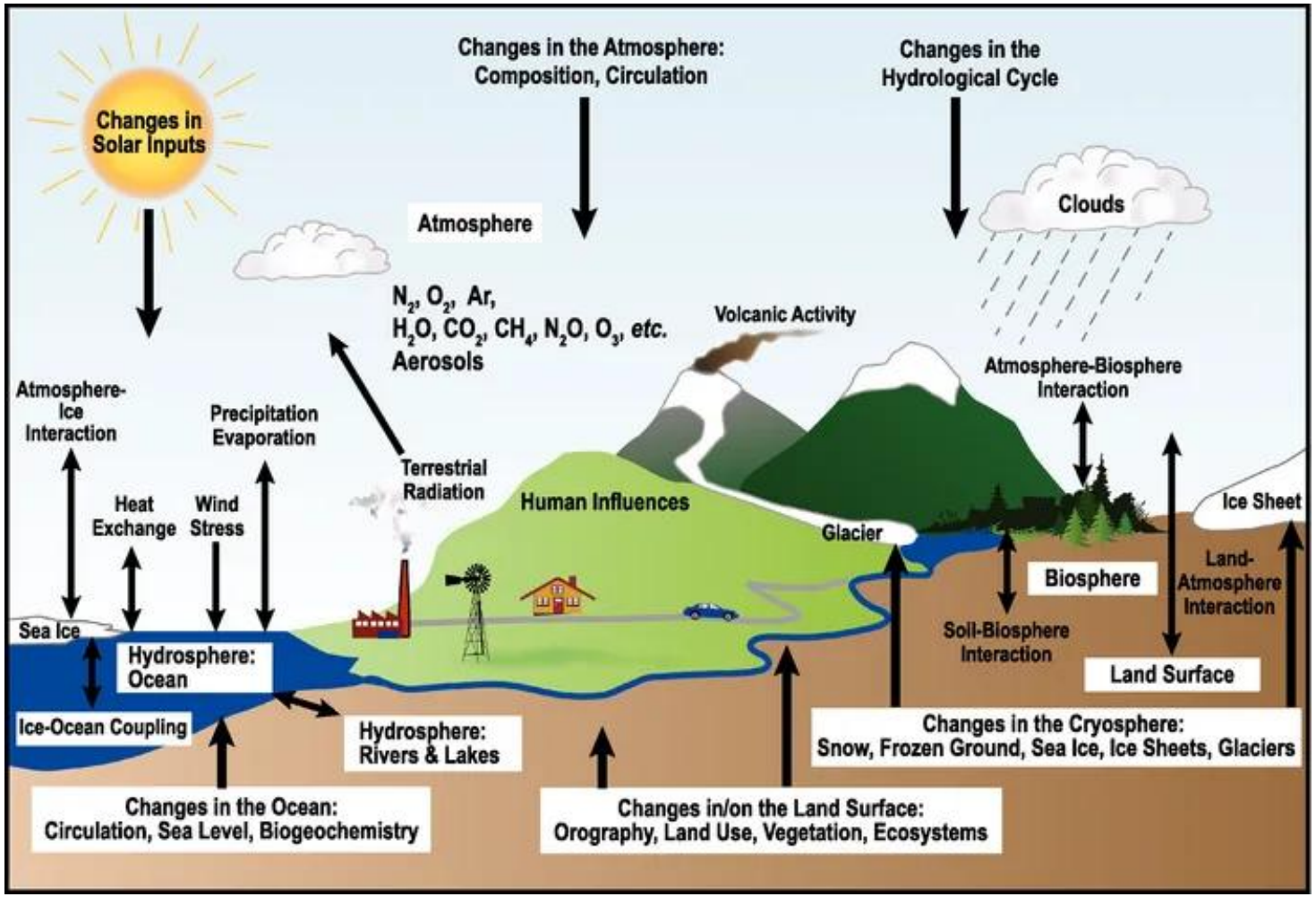




IPCC, AR6

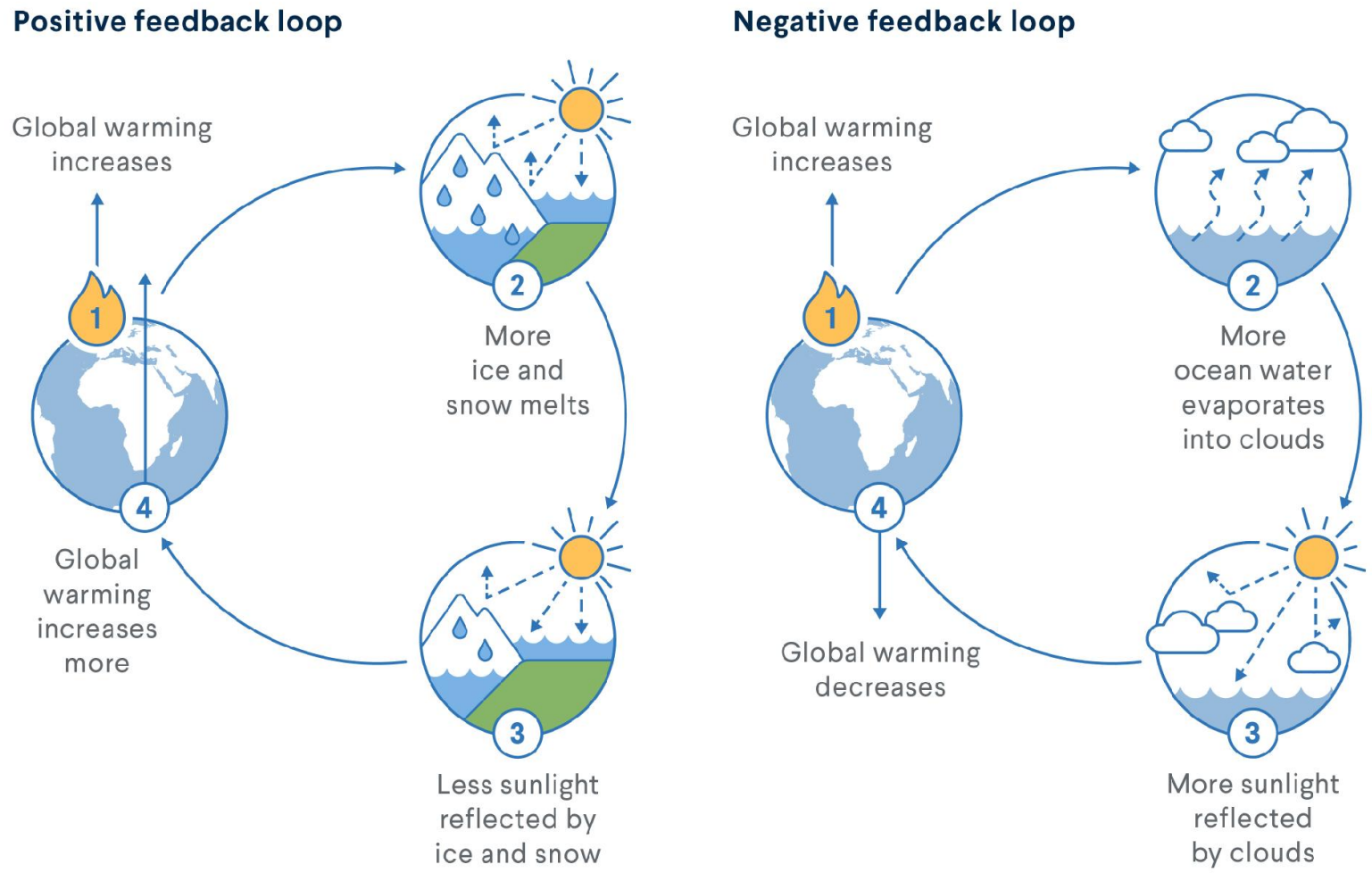
The climate system

Our planet's climate depends on the whole Earth system. The Sun, land (geosphere), ocean (hydrosphere), ice (cryosphere), and living organisms (biosphere) interact with the atmosphere as part of the climate system in many complex ways.



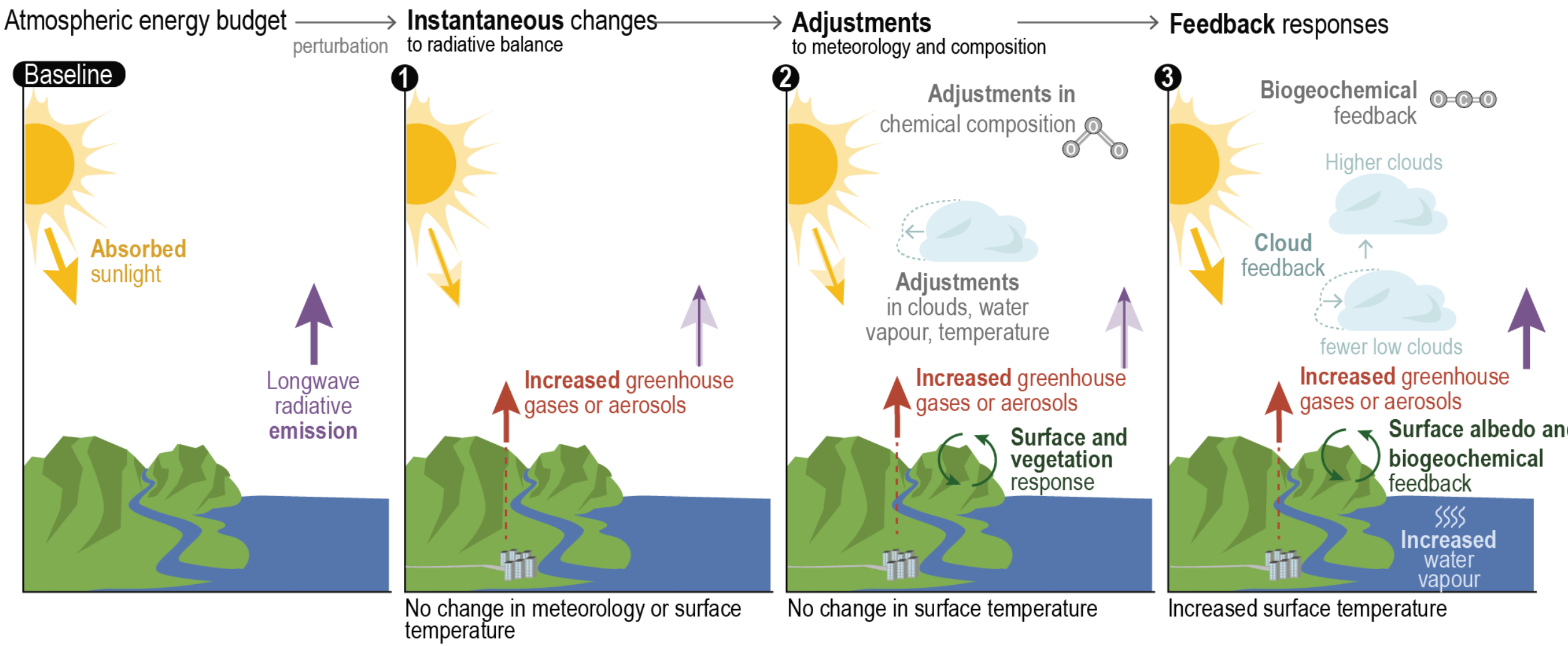
scied.ucar.edu

What are climate feedback loops?



CFR Education
Global Matters

What are climate feedback loops?

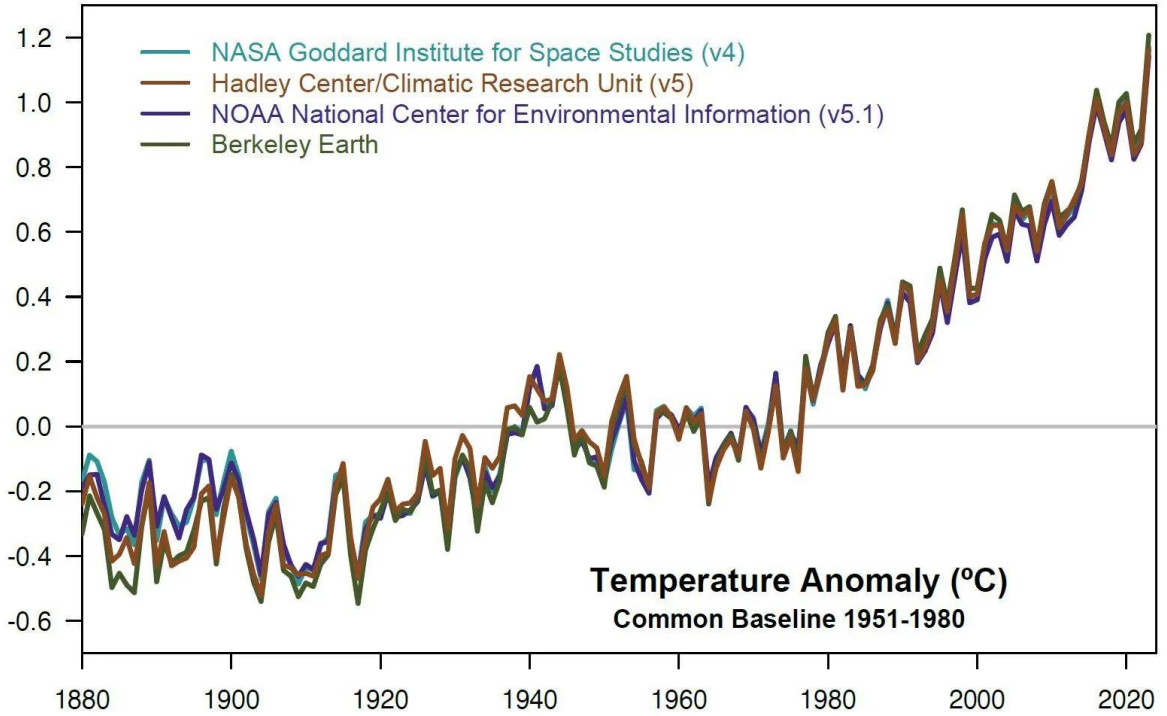


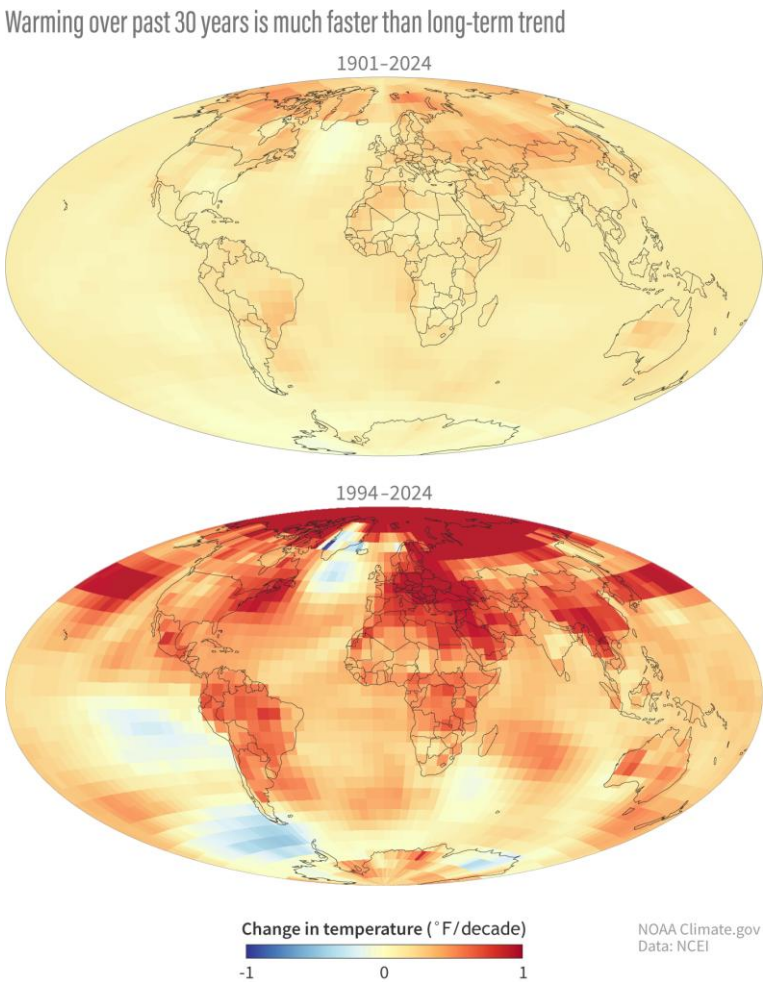
IPCC, AR6

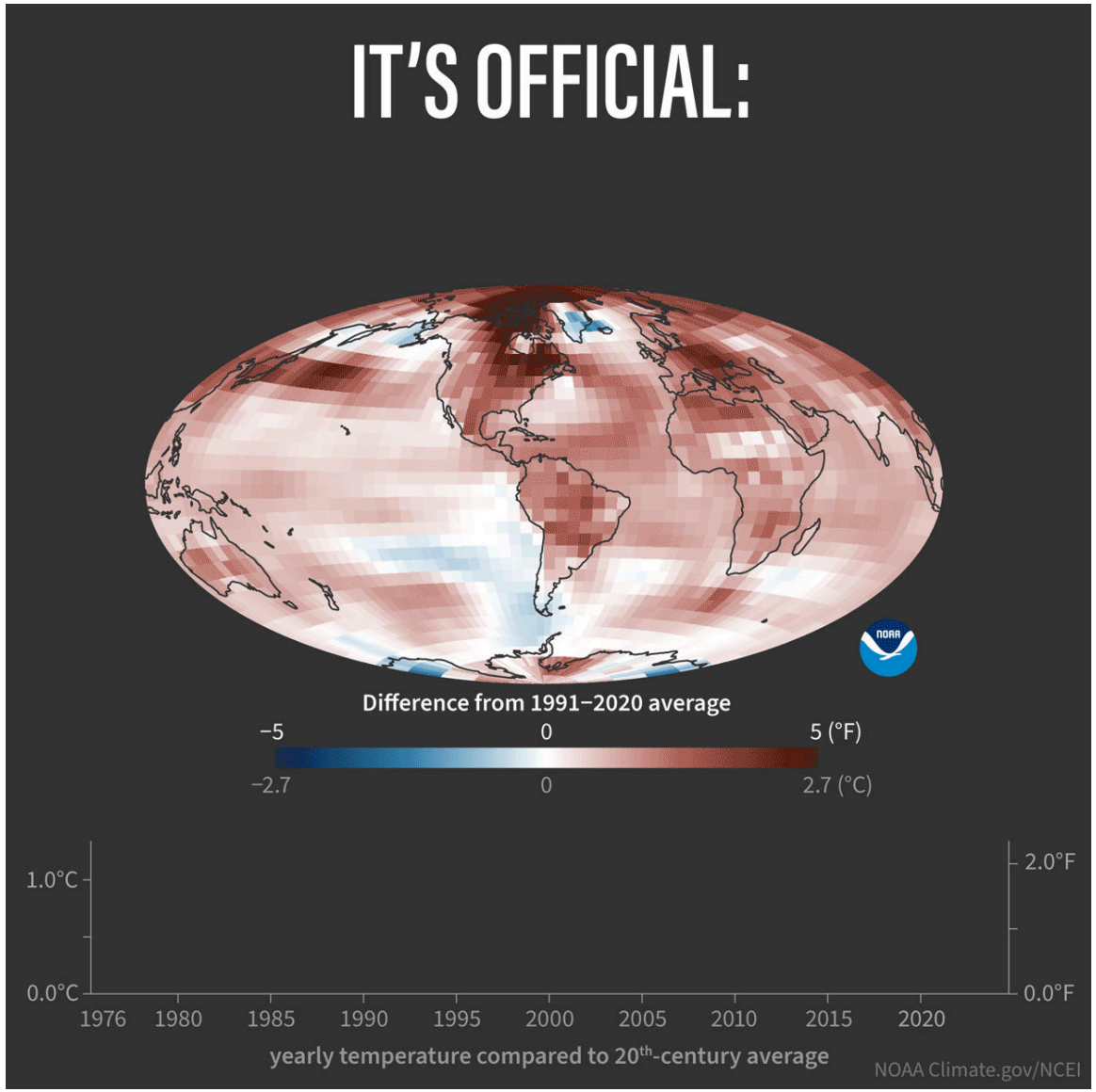
Global warming vs Climate change

Global warming is the long-term heating of Earth's surface observed since the pre-industrial period due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere.

Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the term.

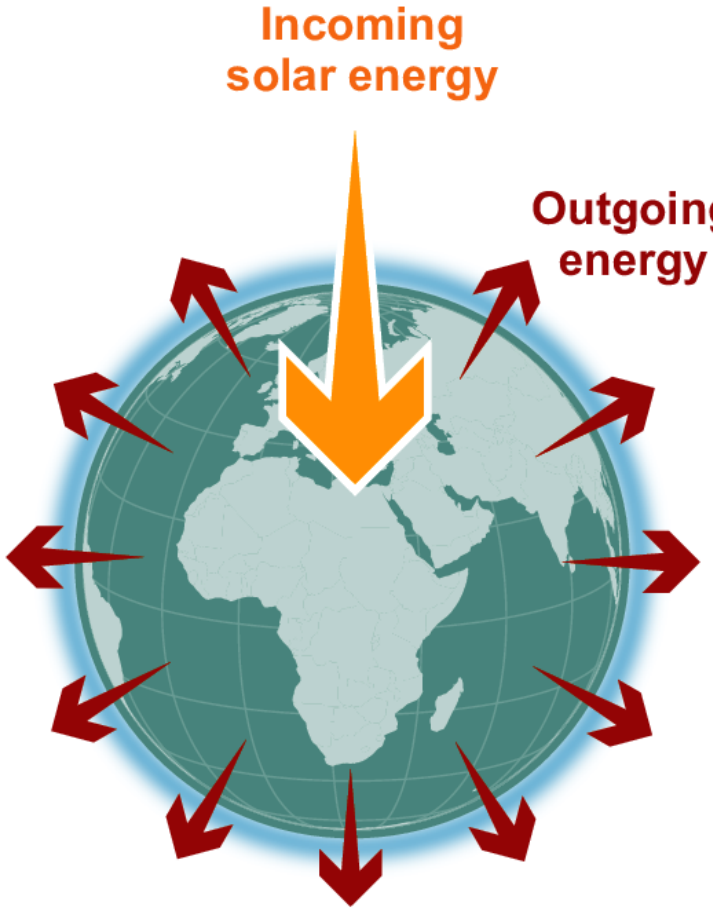



Warming over past 30 years is much faster than long-term trend
1901–2024
1994–2024
Change in temperature (˚F/decade)
-1
0
1
NOAA Climate.gov
Data: NCEI

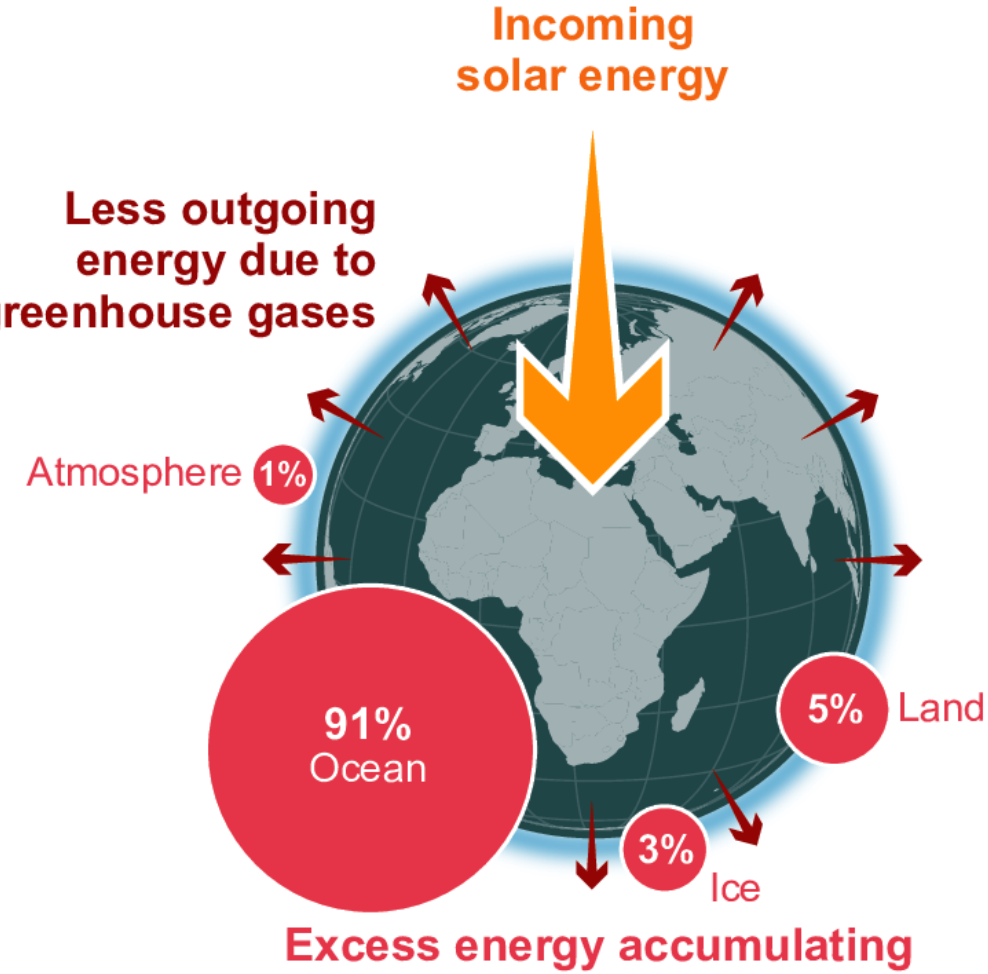

IT'S OFFICIAL:
Difference from 1991–2020 average
−5
0
5 (°F)
−2.7
0
2.7 (°C)
1.0°C
0.0°C
2.0°F
0.0°F
1976
1980
1985
1990
1995
2000
2005
2010
2015
2020
yearly temperature compared to 20th-century average
NOAA Climate.gov/NCEI

Since at least 1970, there has been a persistent imbalance in the energy flows that has led to excess energy being absorbed by different components of the climate system.

Stable climate: in balance



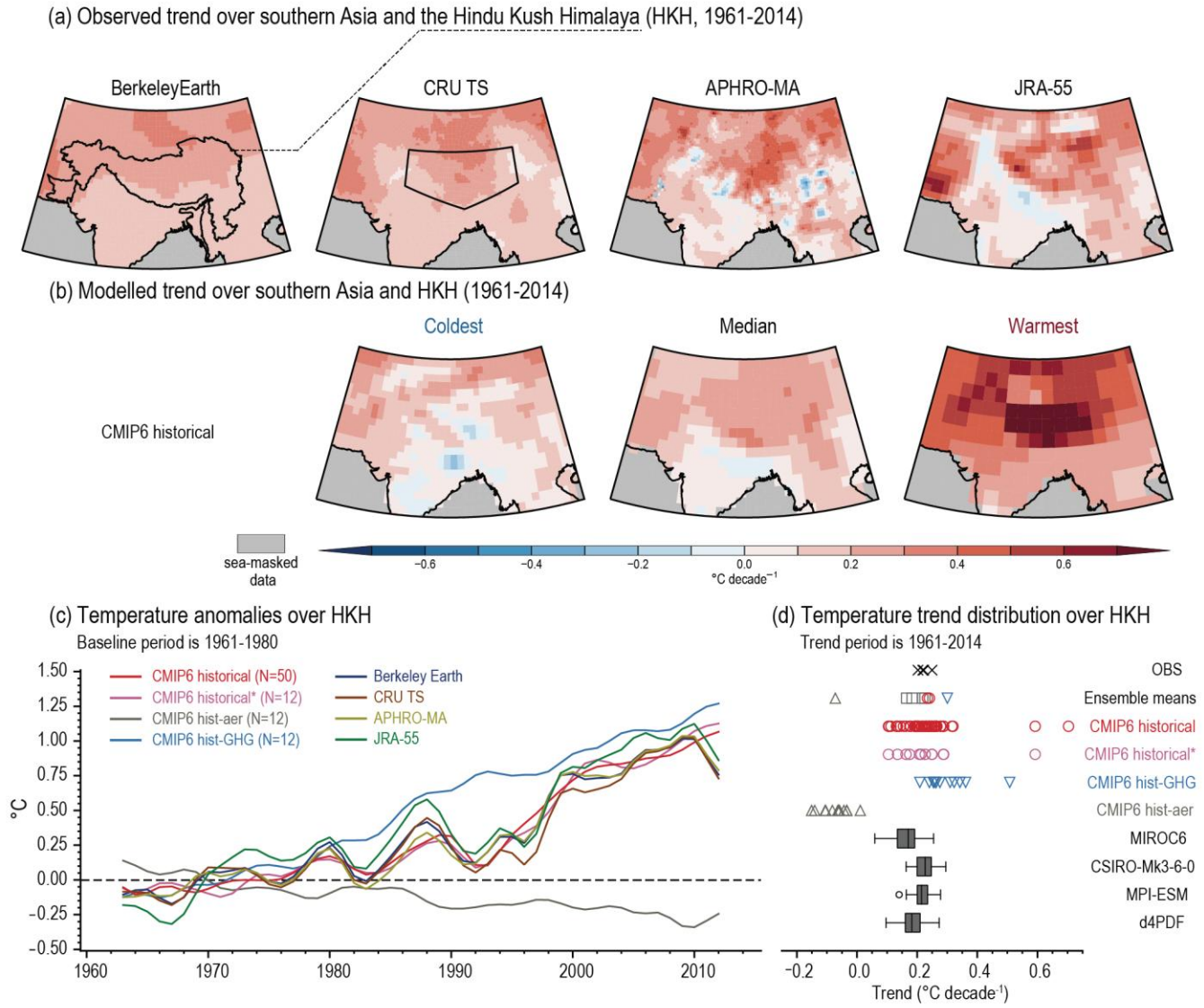
Today: imbalanced



IPCC, AR6

Evidence for climate change

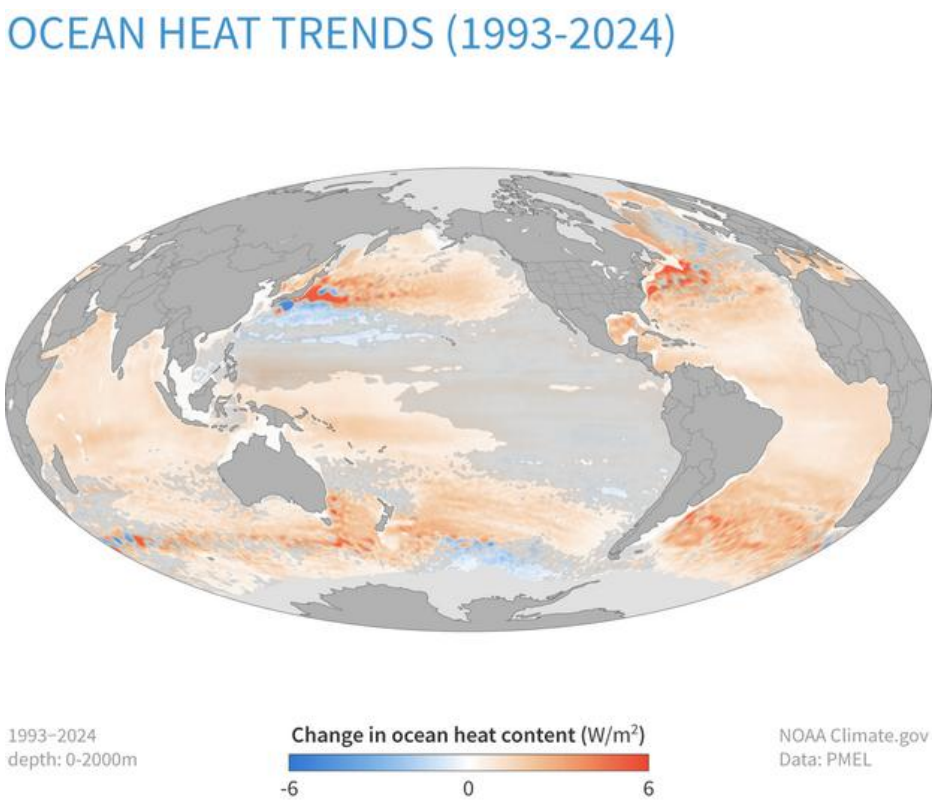
Global temperature is rising

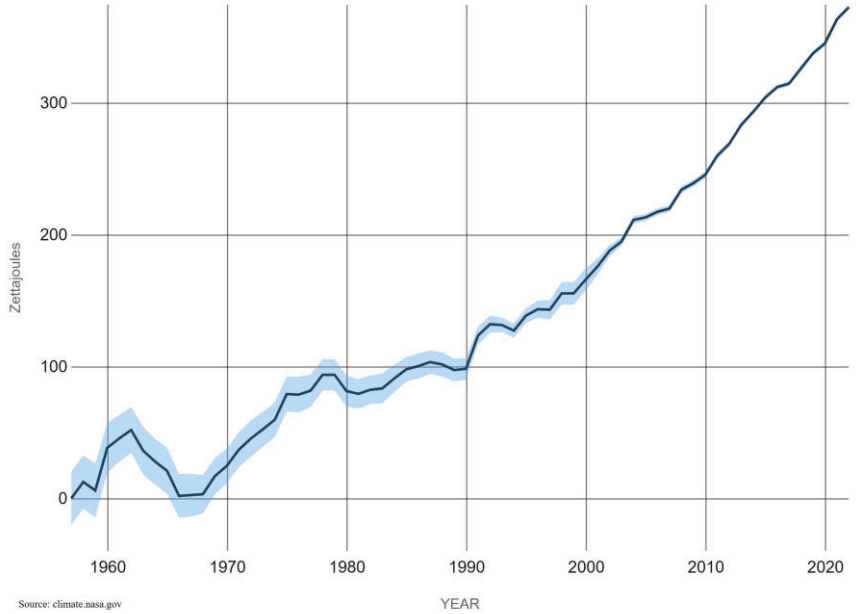


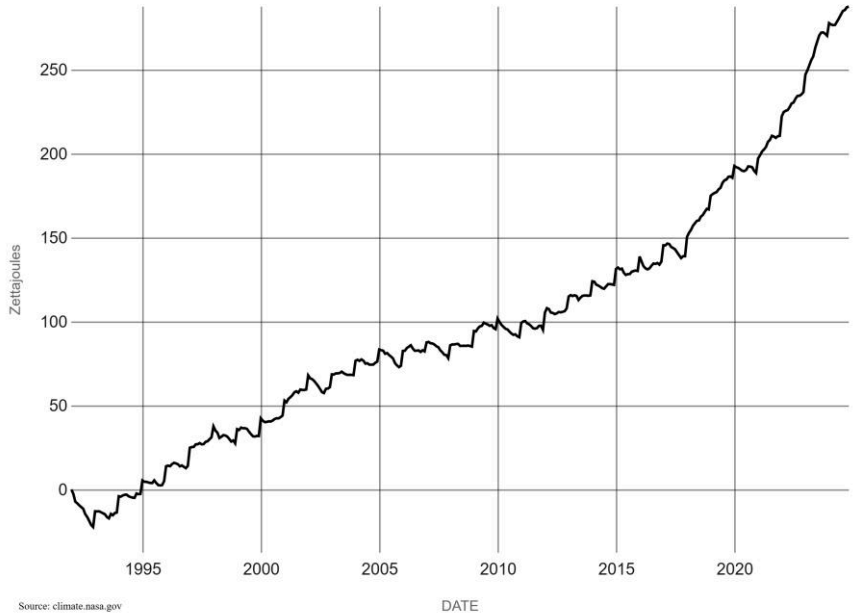
IPCC, AR6

Evidence for climate change

The ocean is getting warmer

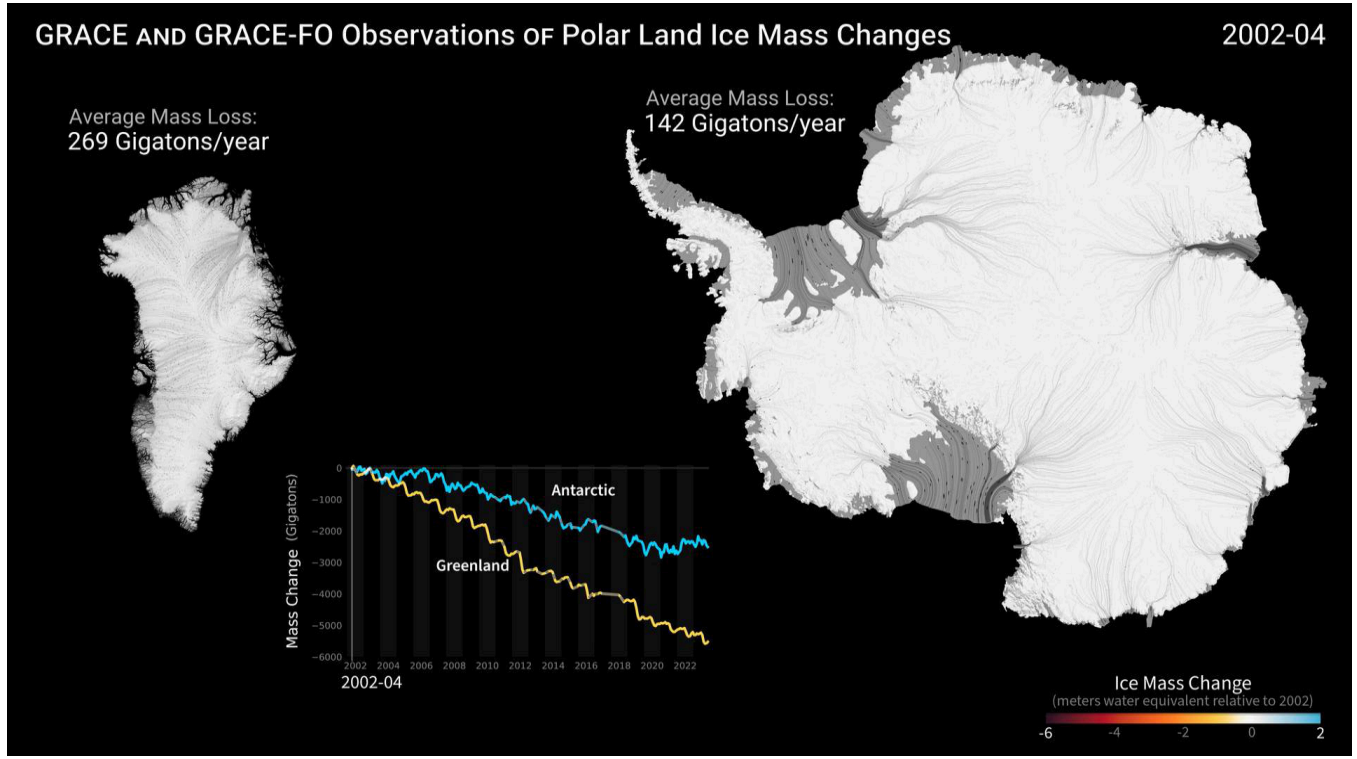


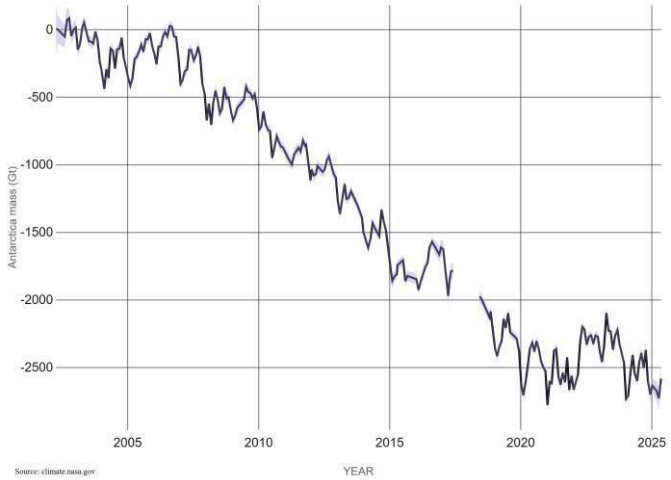




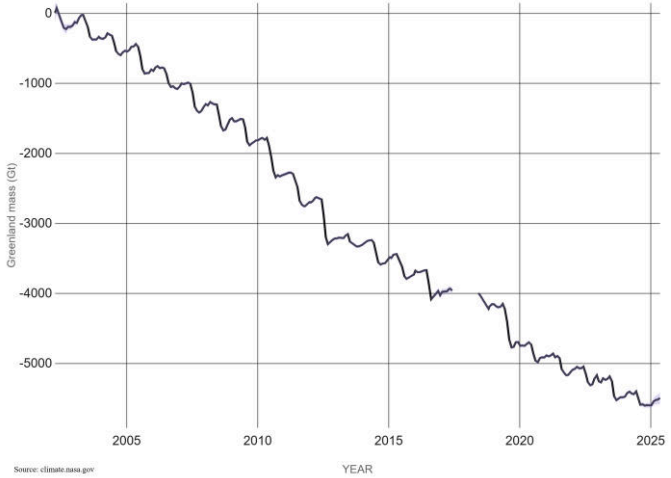
Evidence for climate change

The ice sheets are shrinking





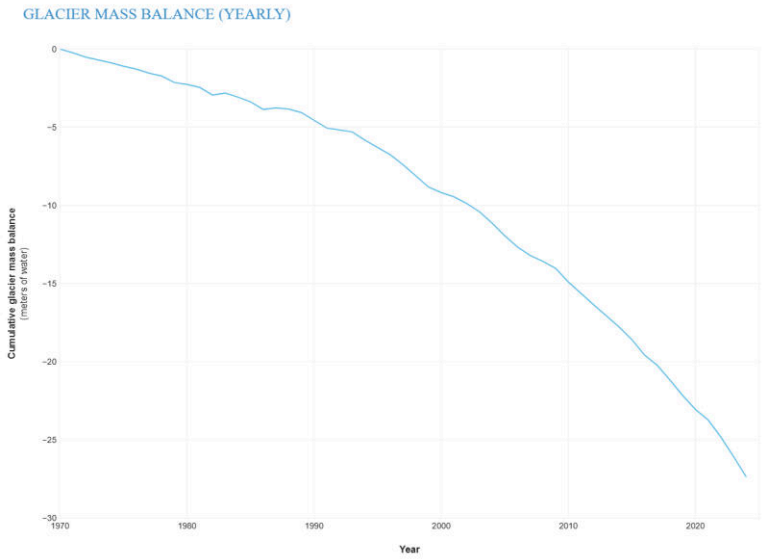
Rate of Change
135 billion metric tons per year since 2002



Rate of Change
266 billion metric tons per year since 2002

Evidence for climate change

Glaciers are retreating





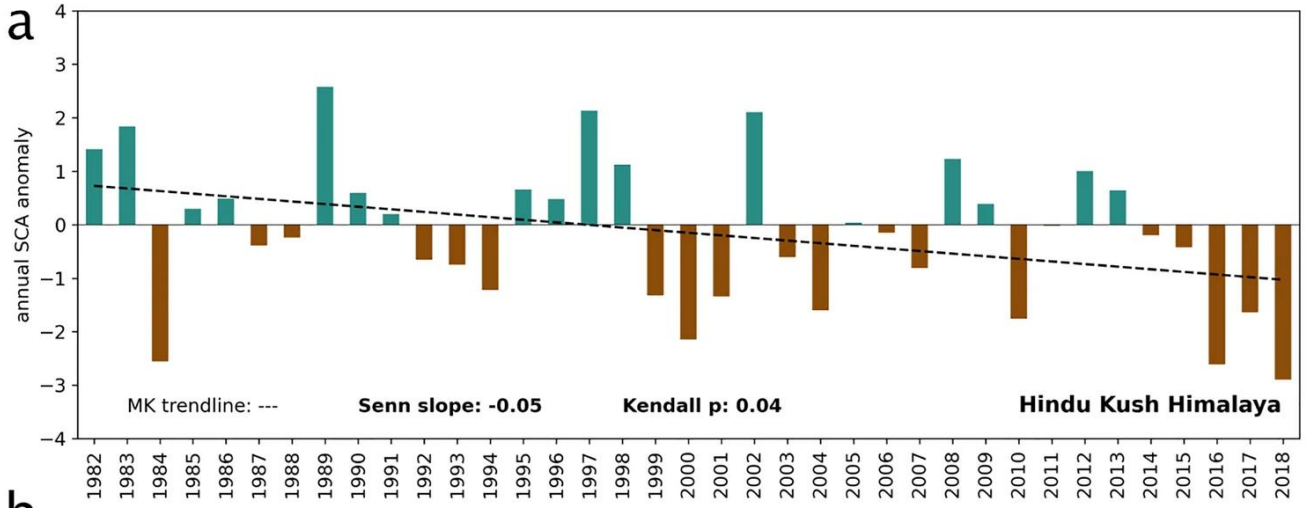




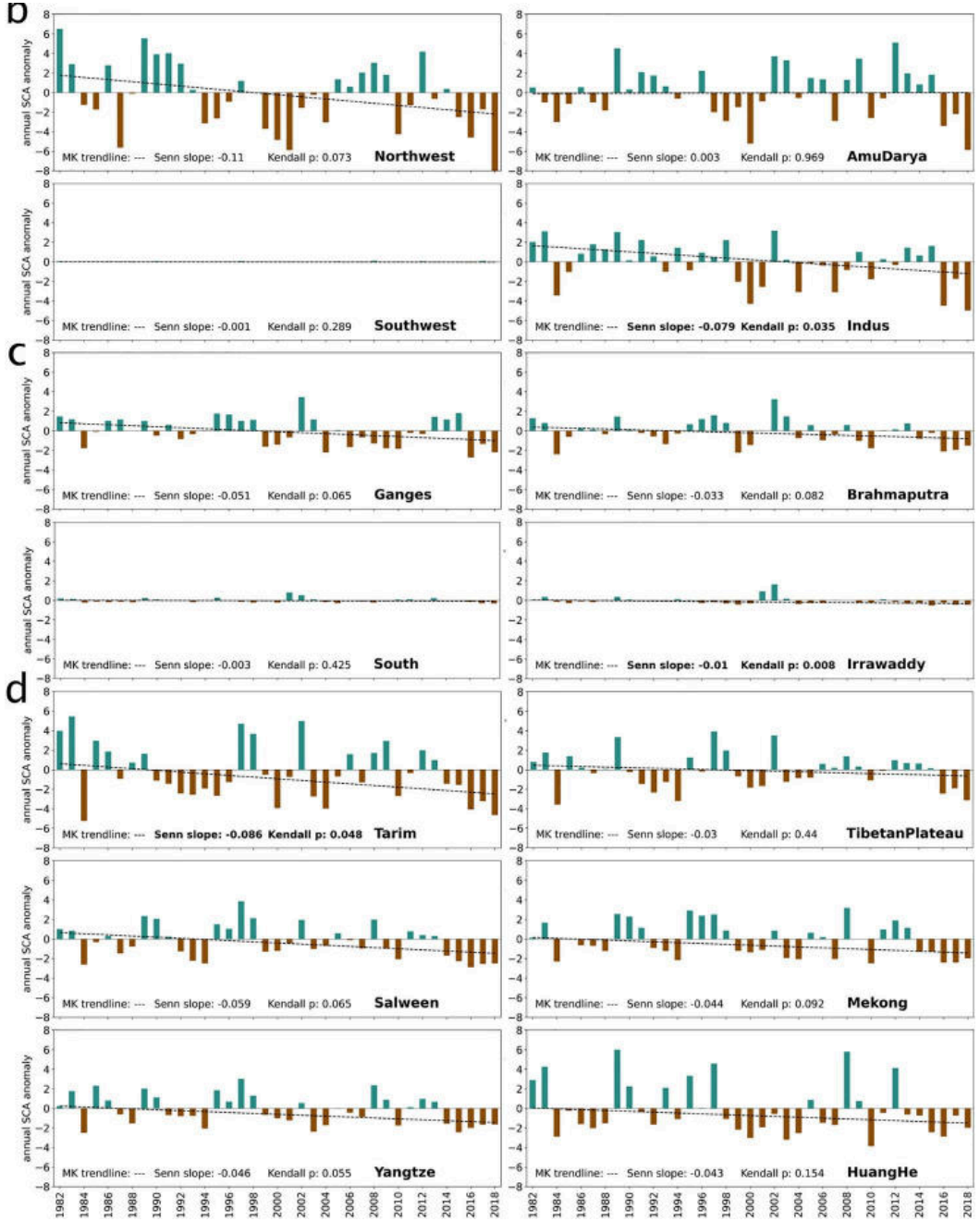


Evidence for climate change

Snow cover is decreasing

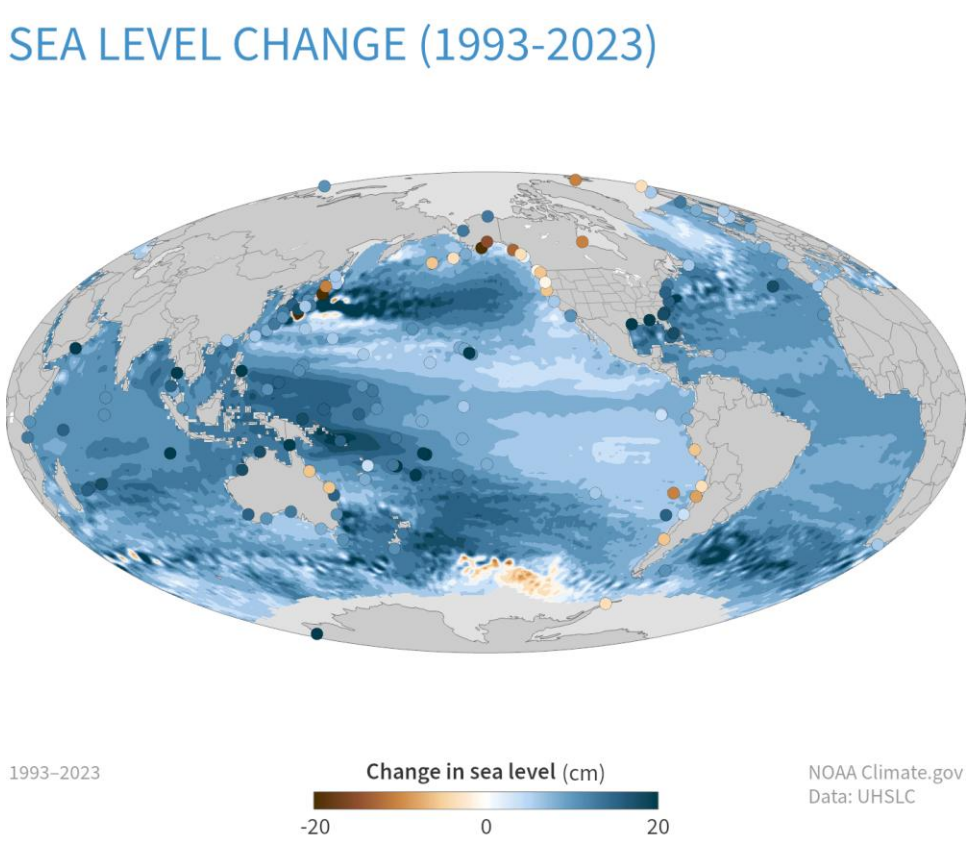


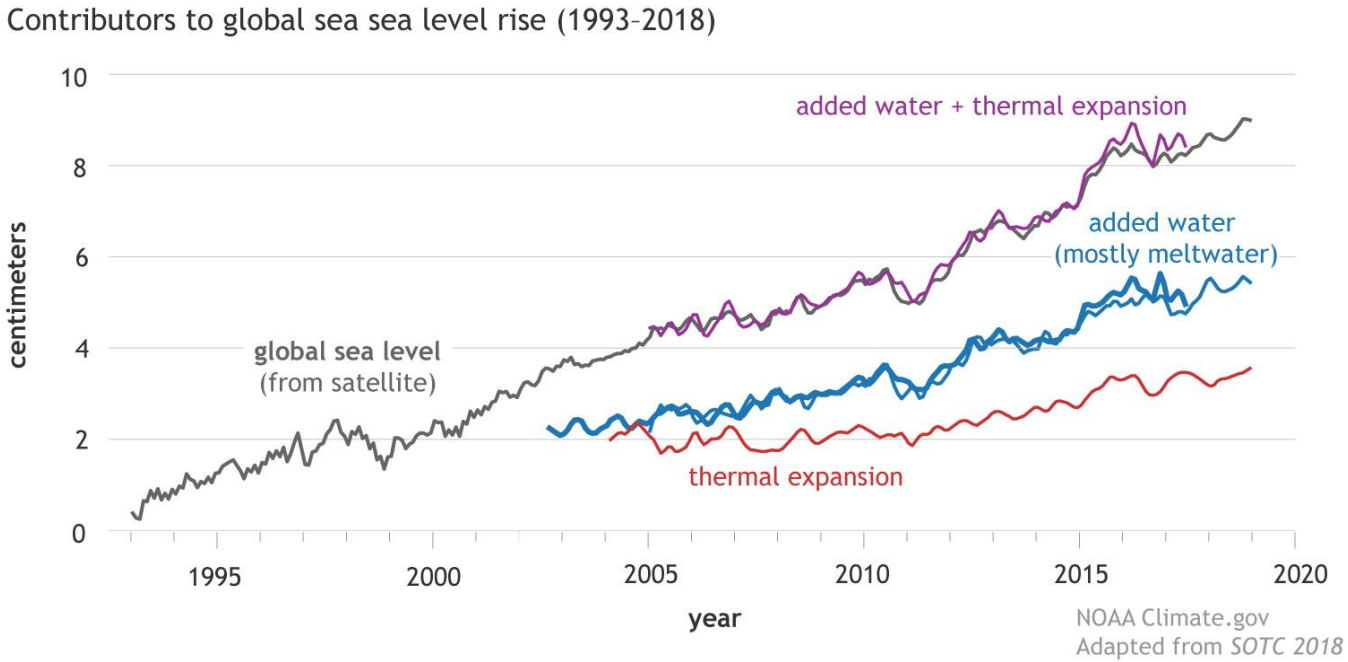
Naegeli et al., 2022



Evidence for climate change

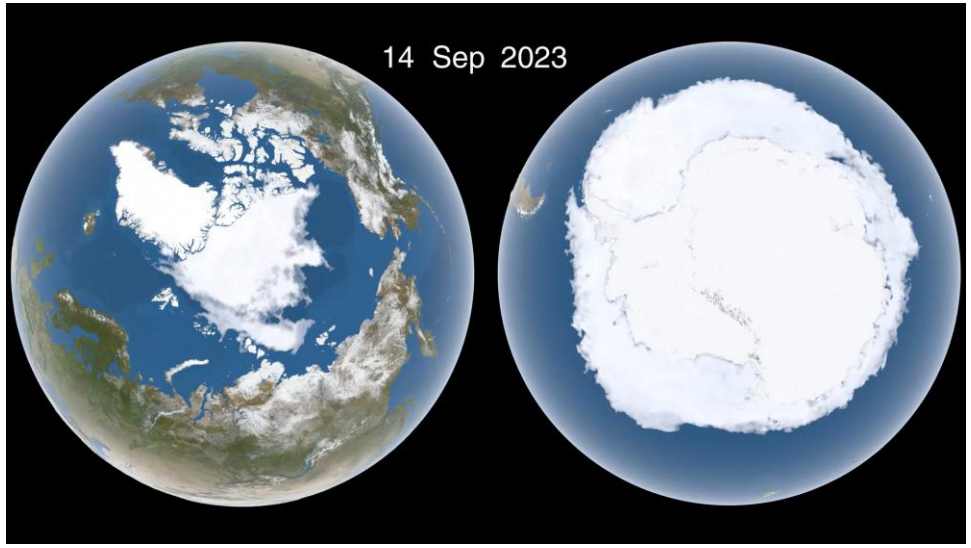
Sea level is rising



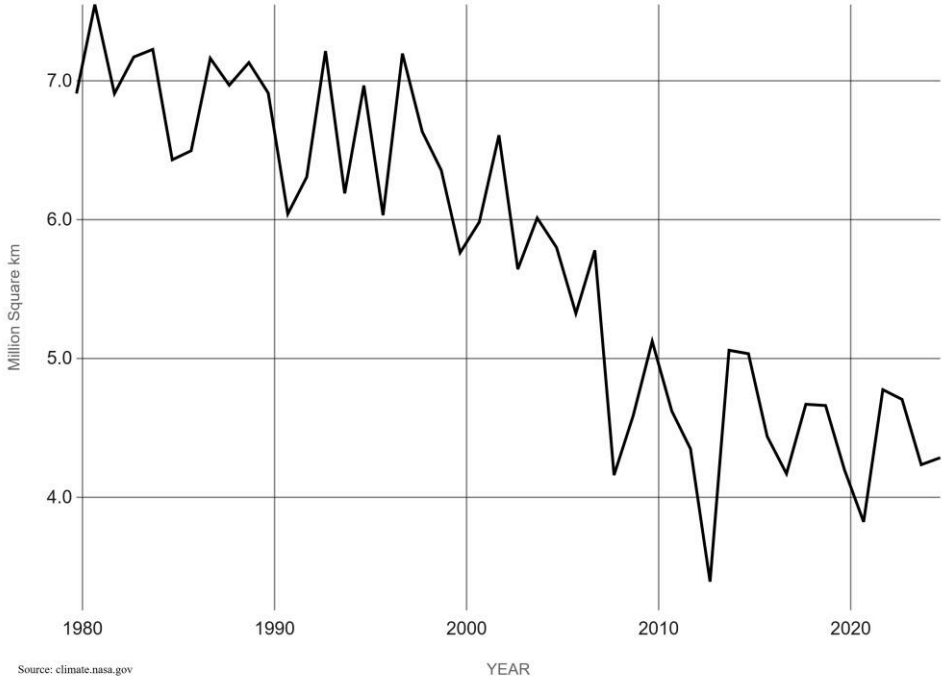


Evidence for climate change

Arctic sea ice is declining



climate.nasa.gov



Rate of Change
12.2 percent per decade

climate.nasa.gov

Evidence for climate change

Extreme events are increasing in frequency

80%

Extreme heatwaves in 2003 and 2010 accounted for 80% of weather-related deaths in Europe from 1970-2019.

40+°C

Extreme temperatures of 40+°C and even 50°C are becoming increasingly frequent worldwide.

1.5°C

Limiting global warming to 1.5°C instead of 2°C could significantly reduce the number of people affected by extreme weather.

1°C

Every degree of global warming is projected to cause a 7% increase in extreme daily rainfall.

2°C

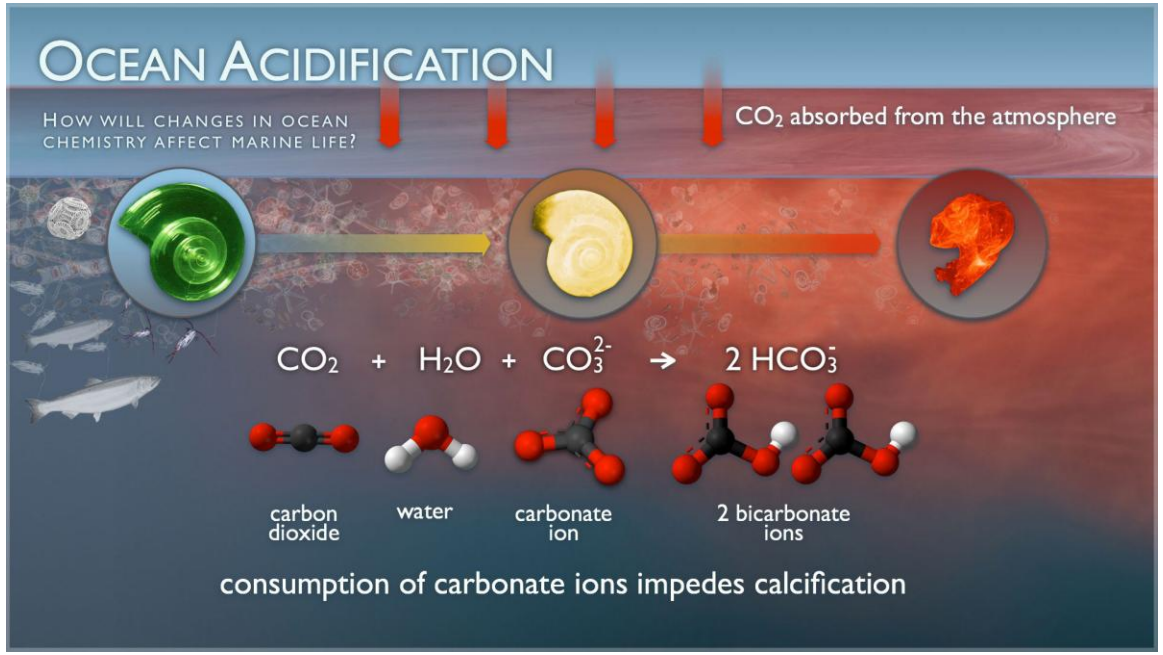
Limiting global warming to 1.5 °C instead of 2 °C could result in around 420 million fewer people being frequently exposed.

390,000 ha

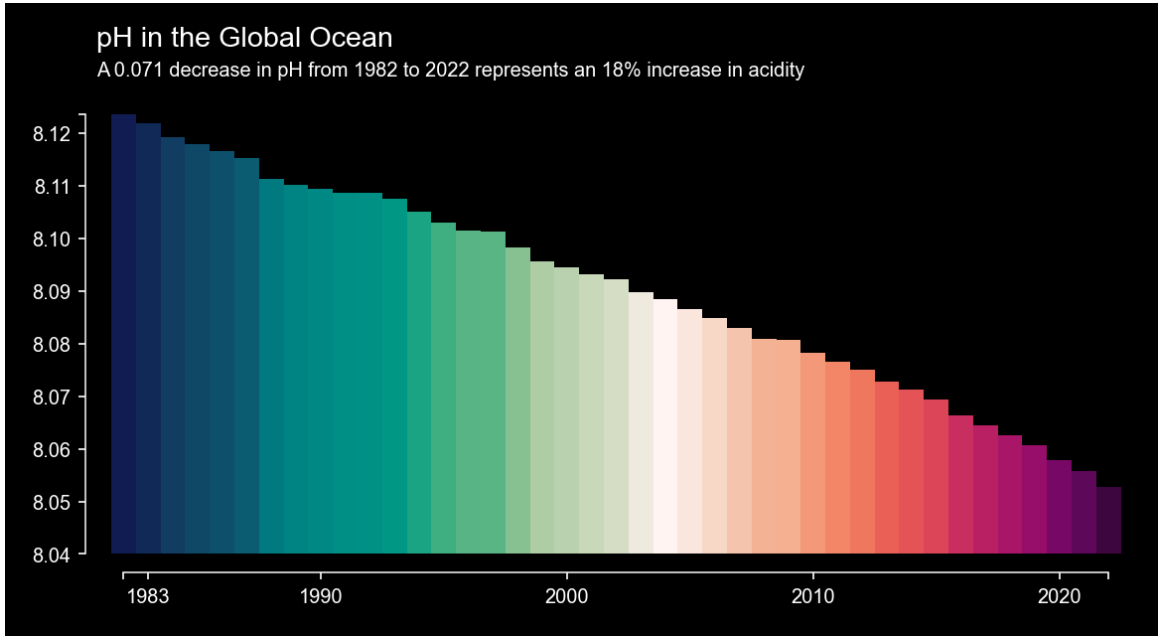
In 2021, the Dixie fire in California burnt a record-breaking 390,000 hectares.

Evidence for climate change

Ocean acidification is increasing



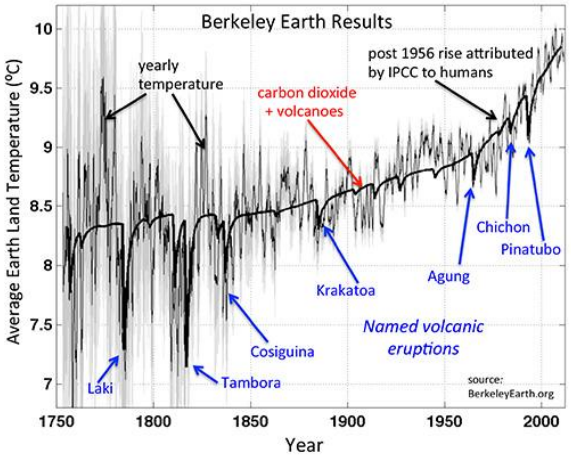
NOAA

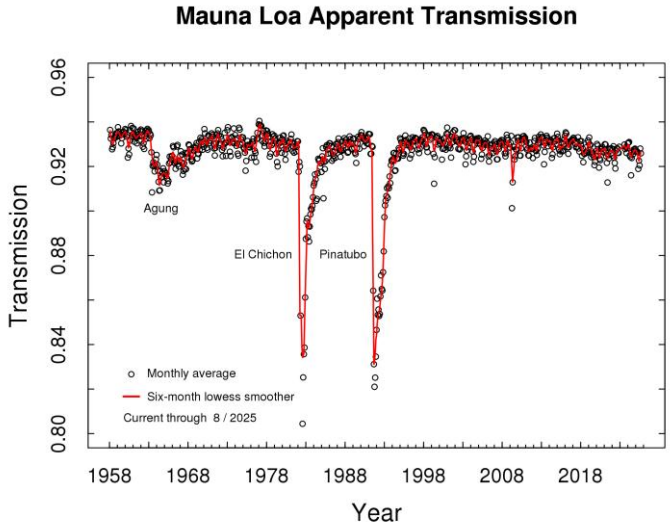


www.esa.int

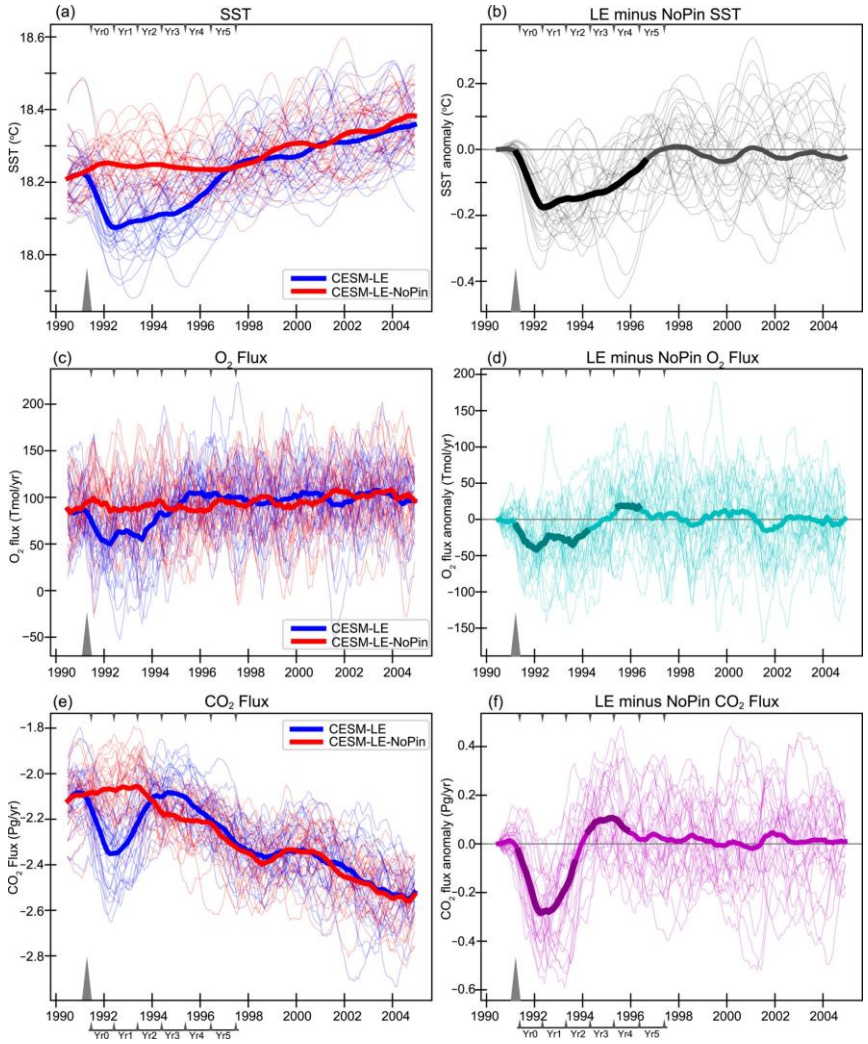
Natural causes of climate change

- ***Volcanic eruptions & activity***
  - The Ilopango volcano in El Salvador in 539 or 540 AD, Indonesia's Mount Tambora in 1816, or, more recently, the 1991 eruption of Mount Pinatubo in the Philippines.
  - Ilopango eruption lasted for 20 years, causing a drop of 2 degrees Celsius globally,
  - the Mount Tambora explosion caused snowfall in Northeastern USA and Canada in June.
  - The Mount Pinatubo eruption in 1991 resulted in a 0.5 – 0.6 ºC global temperature drop that lasted for almost two years.





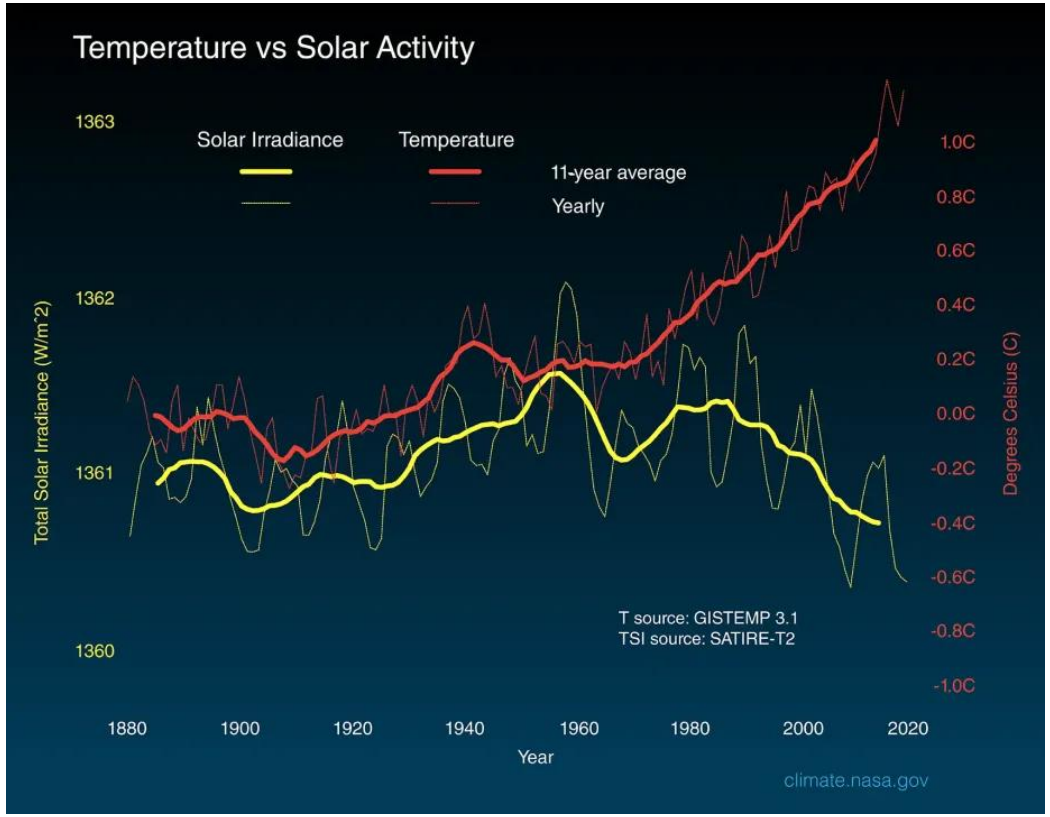
NOAA/GML



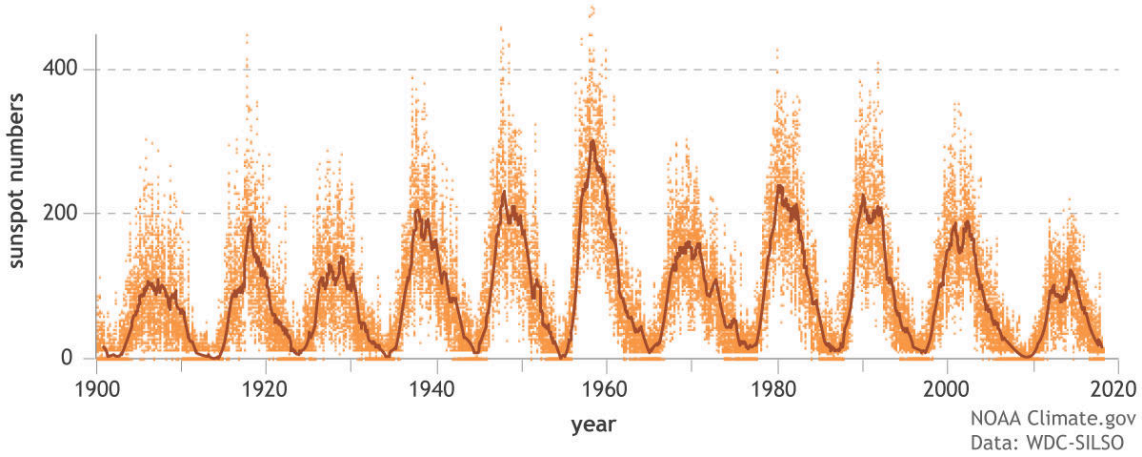
Fay et al., 2023

Natural causes of climate change

- ***Variations in solar output***
  - The amount of energy the Sun produces varies over an 11-year cycle.
  - At the peak of the cycle, called the solar maximum, the Sun is extremely active, with many sunspots and solar storms.
  - After the peak, solar activity decreases for about 11 years until it reaches the solar minimum.

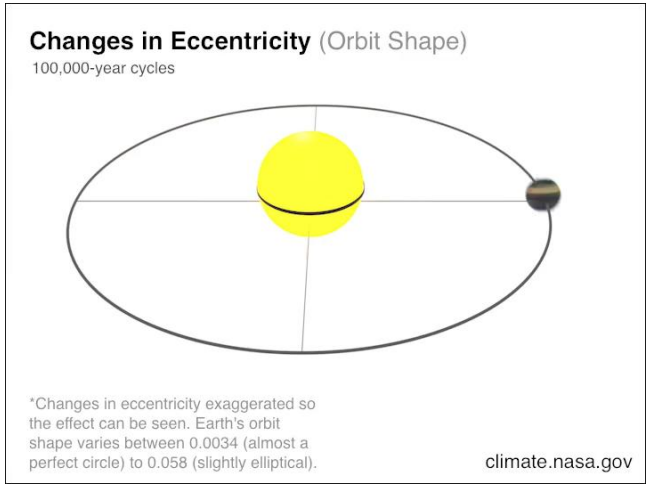


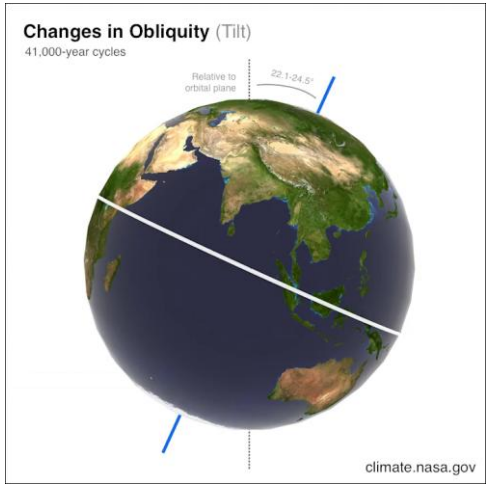
Solar activity over the past 11 sunspot cycles

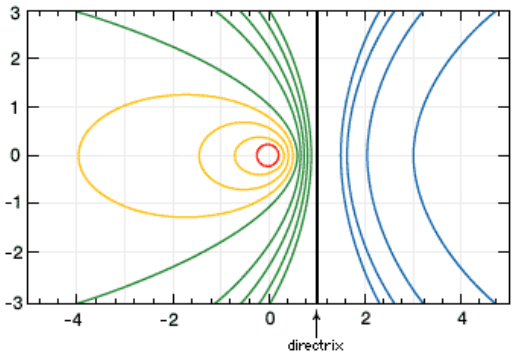


Natural causes of climate change

- ***Orbital variations of Earth,*** also know as the Milankovitch cycles which include,
  - *Eccentricity* – Earth's orbit around the Sun change the shape of around the Sun from circular to elliptical. Currently its value is about 0.0167 and ranges approximately 0.0034 to 0.058.
  - *Obliquity* – the angle Earth's axis of rotation is tilted as it travels around the Sun and varied between 22.1 and 24.5 degrees with respect to Earth's orbital plane. Current value is 23.4 degrees.
  - *Axial precession or wobbling effect of Earth* – As Earth rotates, it wobbles slightly upon its rotational axis, like a slightly off-center spinning toy top. This wobble is due to tidal forces caused by the gravitational influences of the Sun and Moon that cause Earth to bulge at the equator, affecting its rotation.



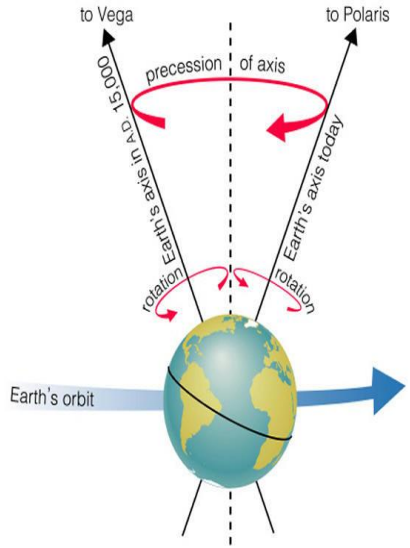


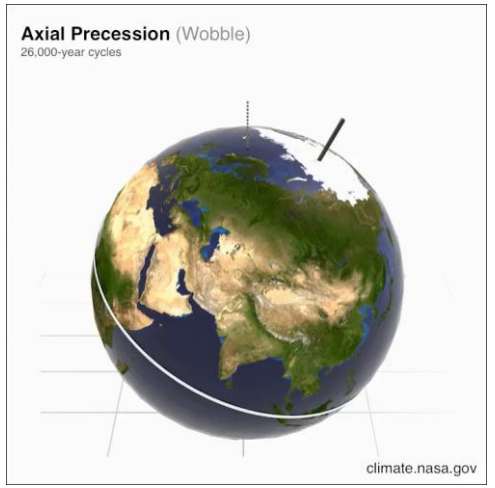


eccentricity = e (a constant) = $\frac{\text{distance to focus}}{\text{distance to directrix}}$

- $e = 0$ for circle
- $0 < e < 1$ for ellipse
- $1 = e$ for parabola
- $1 < e$ for hyperbola

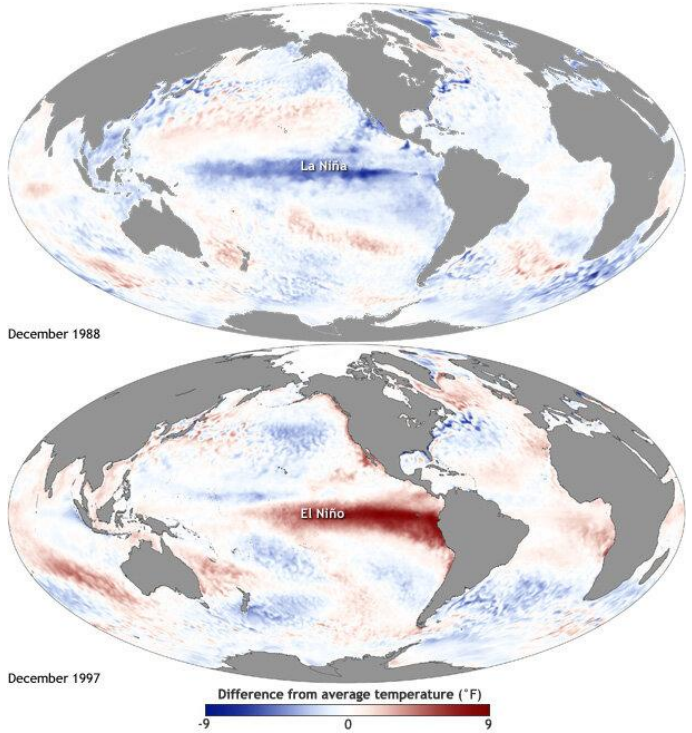
© 2000 Encyclopædia Britannica, Inc.

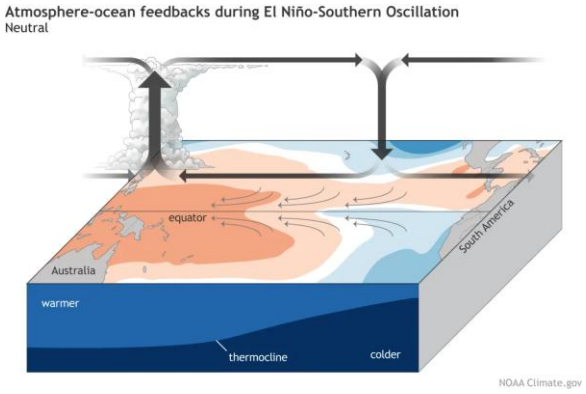


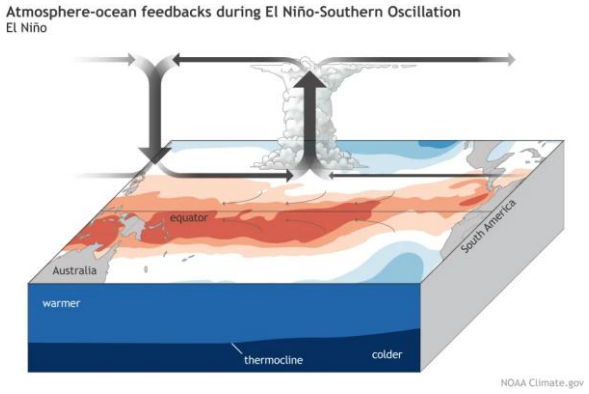


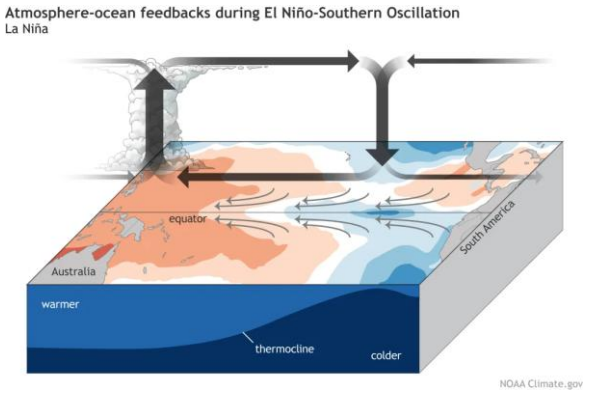
Natural causes of climate change

- ***Internal Variability,*** refers to natural, unpredictable climate fluctuations arising from interactions within the Earth's system.
  - *El Niño-Southern Oscillation (ENSO):* A cycle of ocean-atmosphere climate interactions in the tropical Pacific that influences weather patterns globally.
  - *North Atlantic Oscillation (NAO):* A pattern of sea-level pressure variation in the northern Atlantic that affects weather in Europe and North America.
  - *Other oscillations:* These include the Pacific Decadal Oscillation (PDO), the Indian Ocean Dipole, and the Arctic Oscillation, all of which involve natural, multi-year cycles.



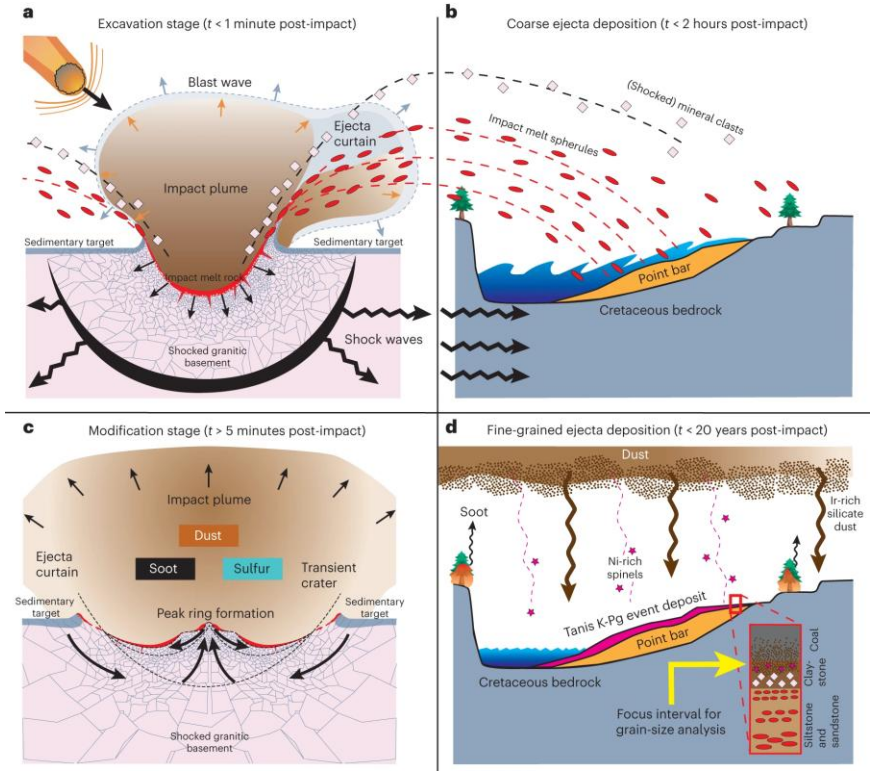




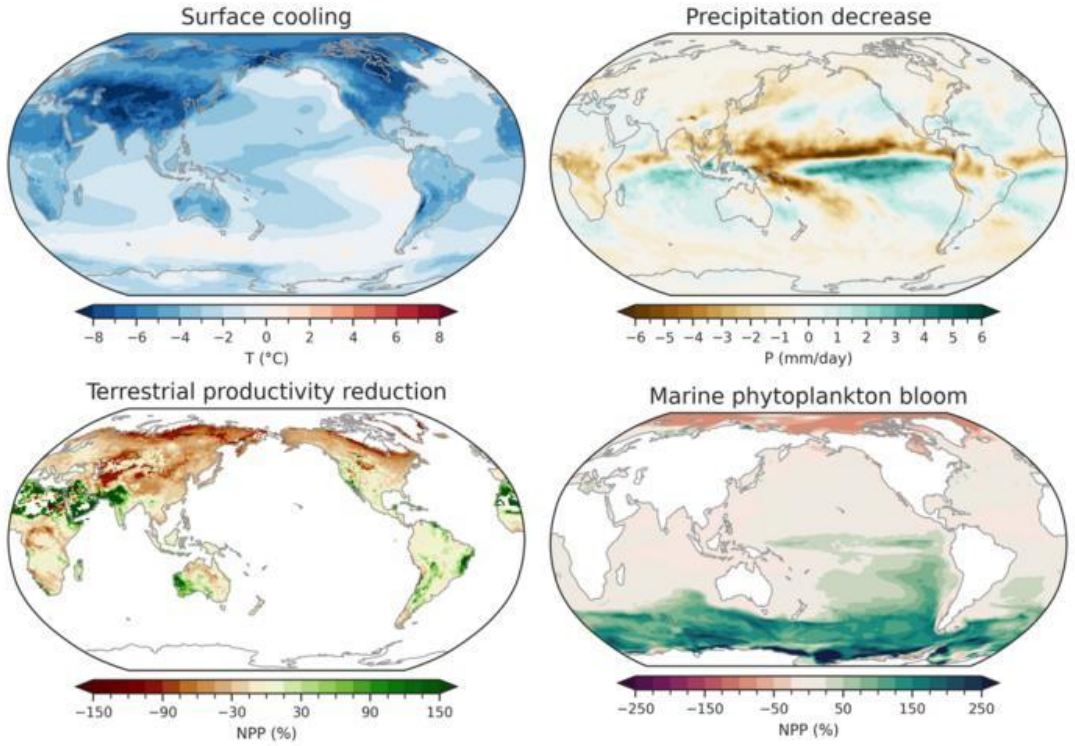


Natural causes of climate change

- ***Asteroids,*** impacts can cause significant climate change by ejecting massive amounts of dust, soot, and sulfate aerosols into the atmosphere, which block sunlight and lead to a prolonged "impact winter" of global cooling.



Senel et al., 2023



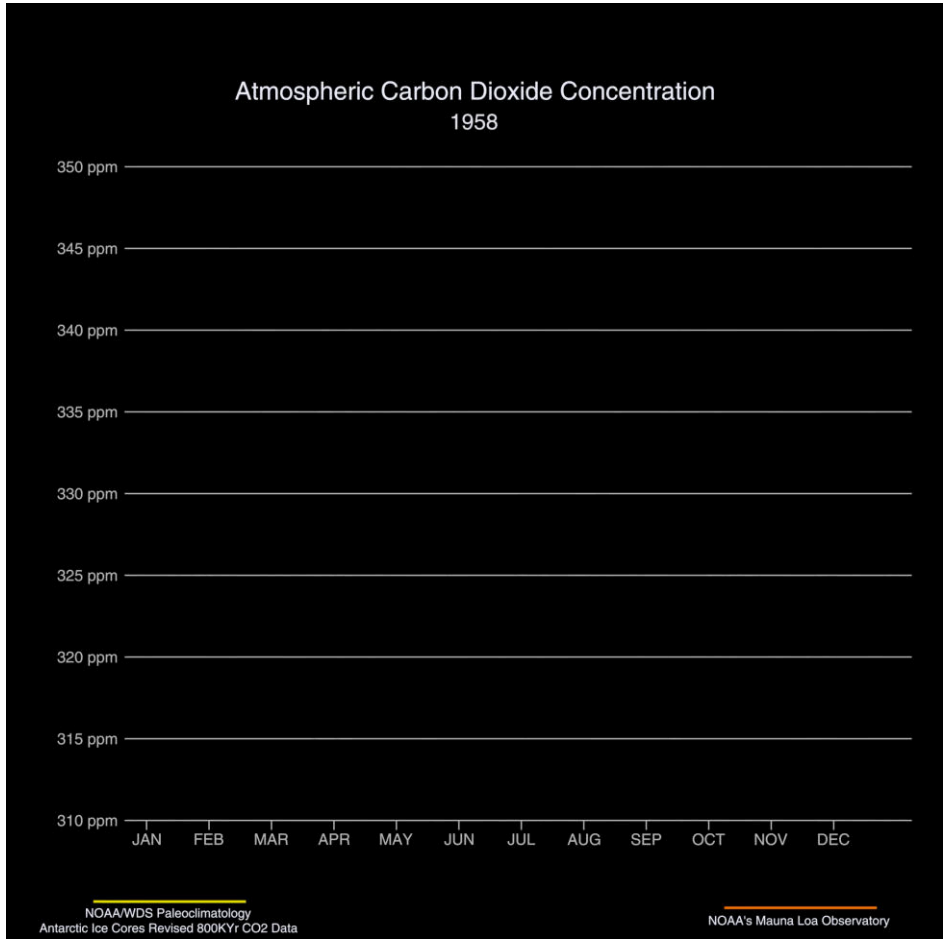
Institute for Basic Science (IBS)

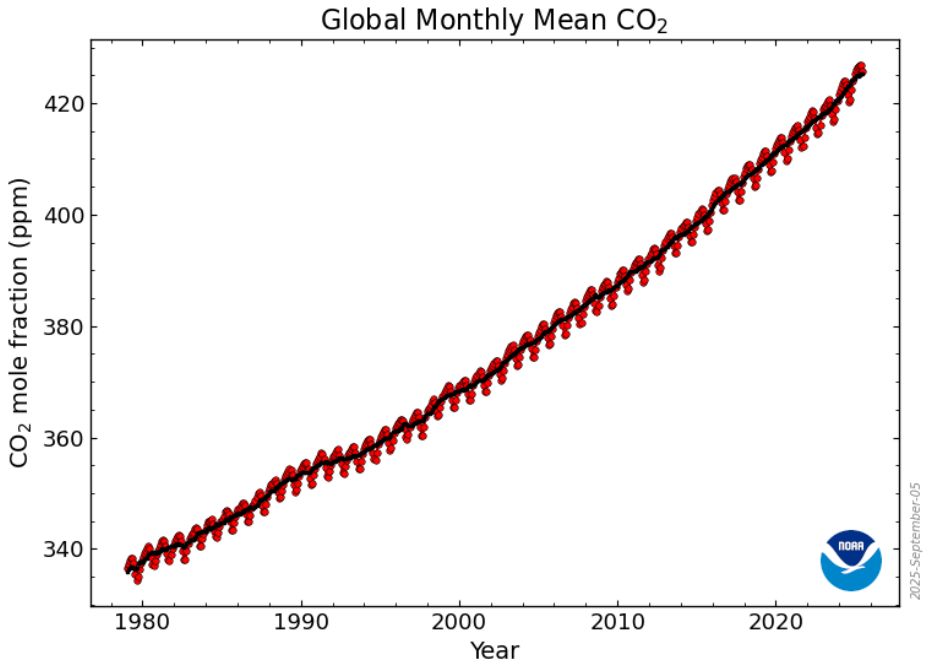
Human-driven causes of climate change

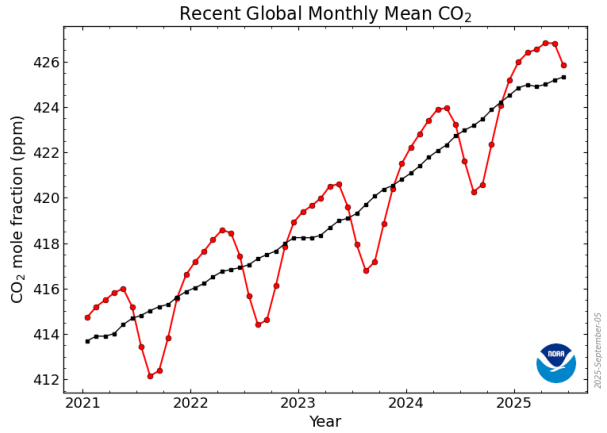


Human-driven causes of climate change

CO_2 produced by human activities is the largest contributor to global warming. By 2023, its concentration in the atmosphere had risen to 51% above its pre-industrial level.

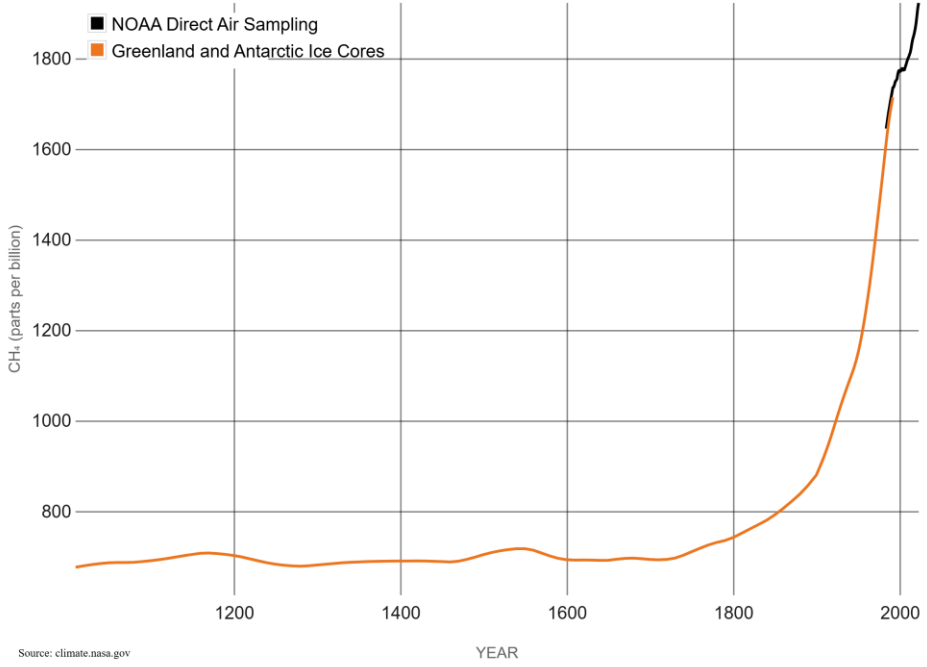


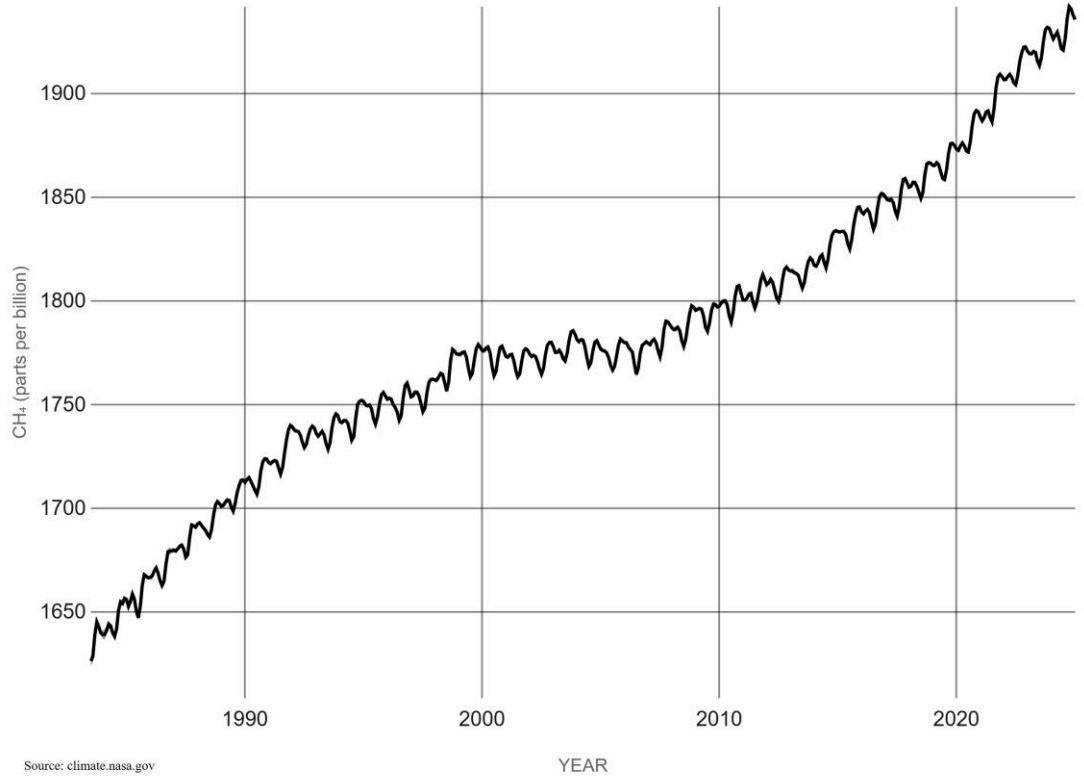




Human-driven causes of climate change

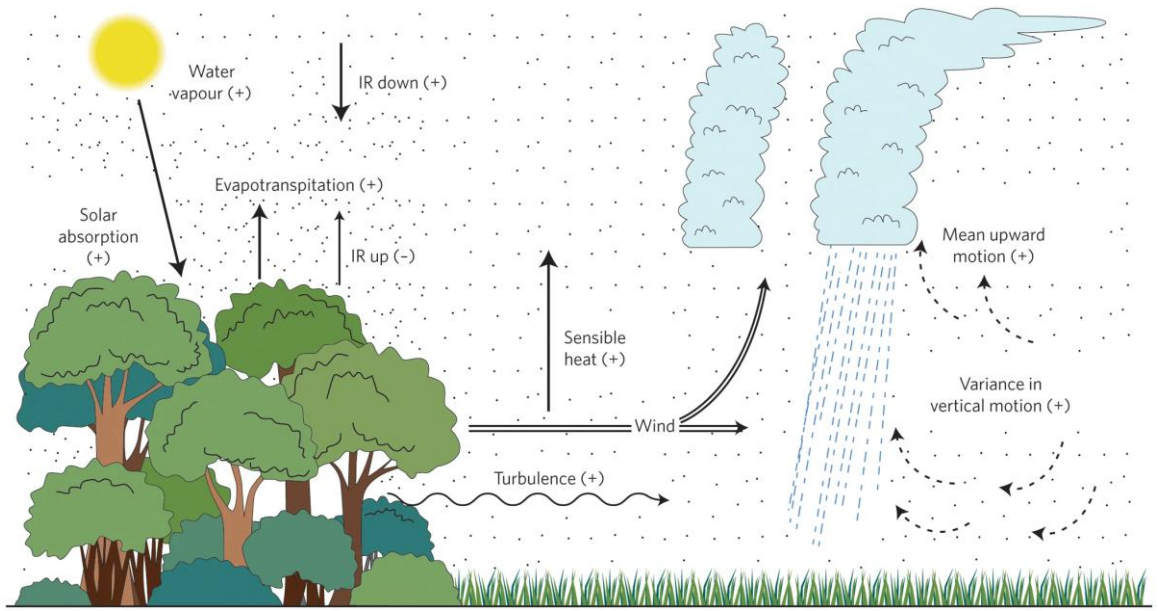
Methane is contributing to about 30% of the rise in global temperatures since the industrial revolution. An estimated 60% of today's methane emissions are the result of human activities.



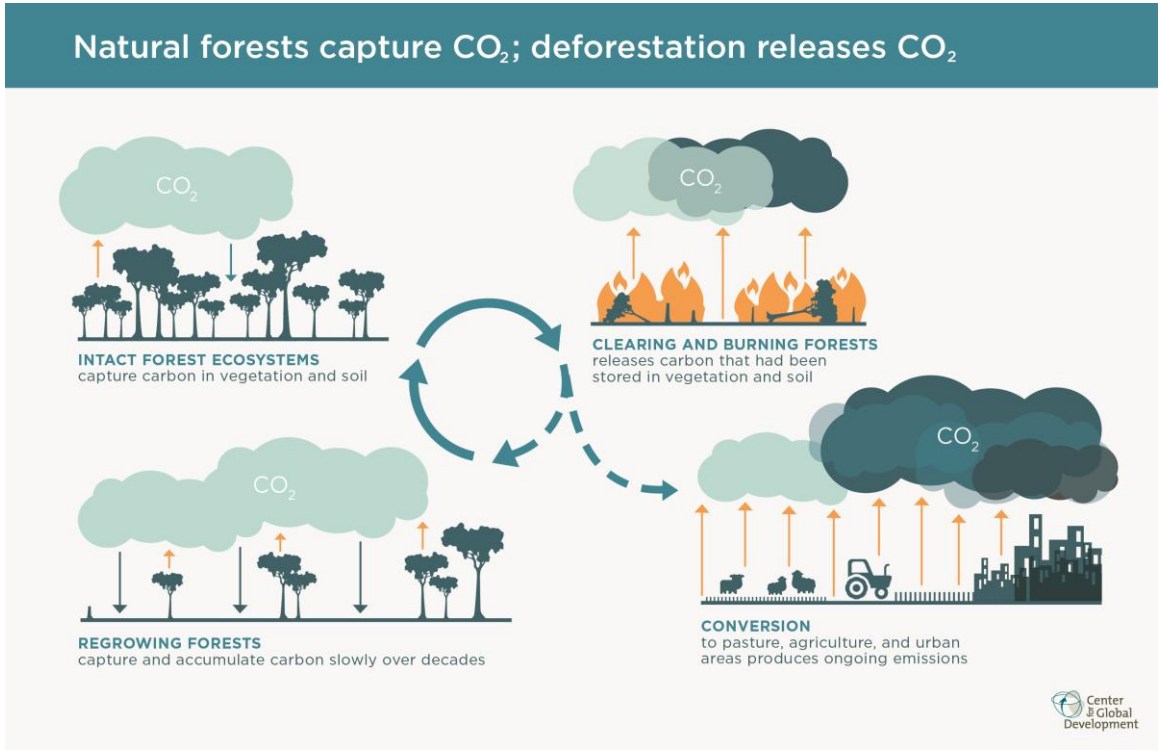


Human-driven causes of climate change

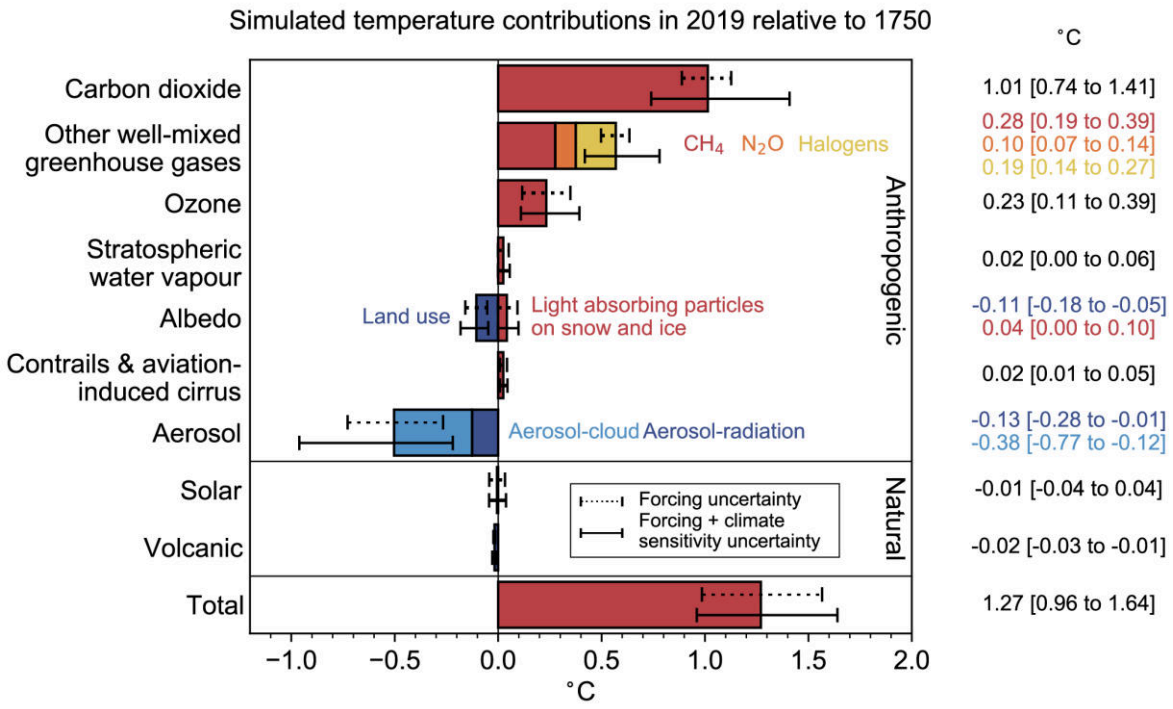
Deforestation contributes to climate change primarily by releasing stored carbon dioxide and by reducing the number of trees that can absorb carbon dioxide from the atmosphere.

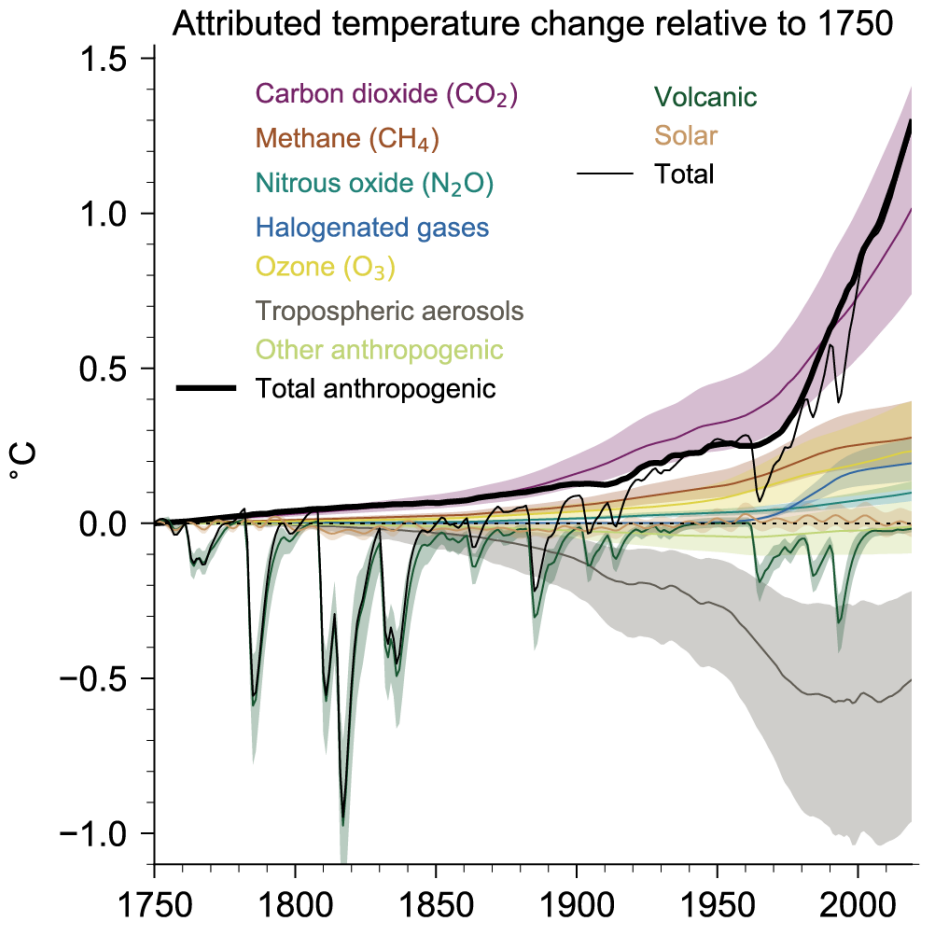


Lawrence and Vandecar, 2015



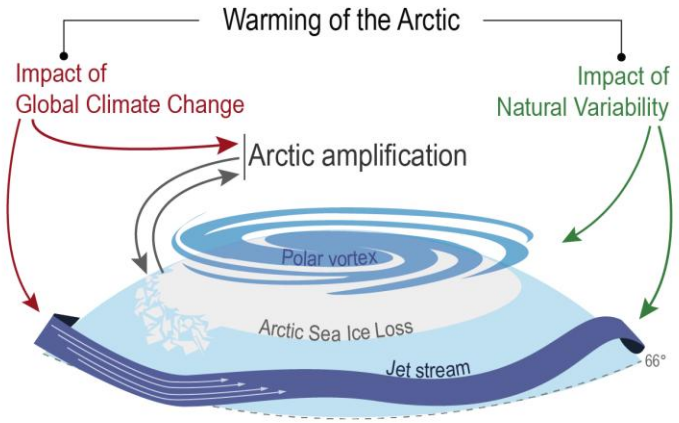
Human-driven causes of climate change

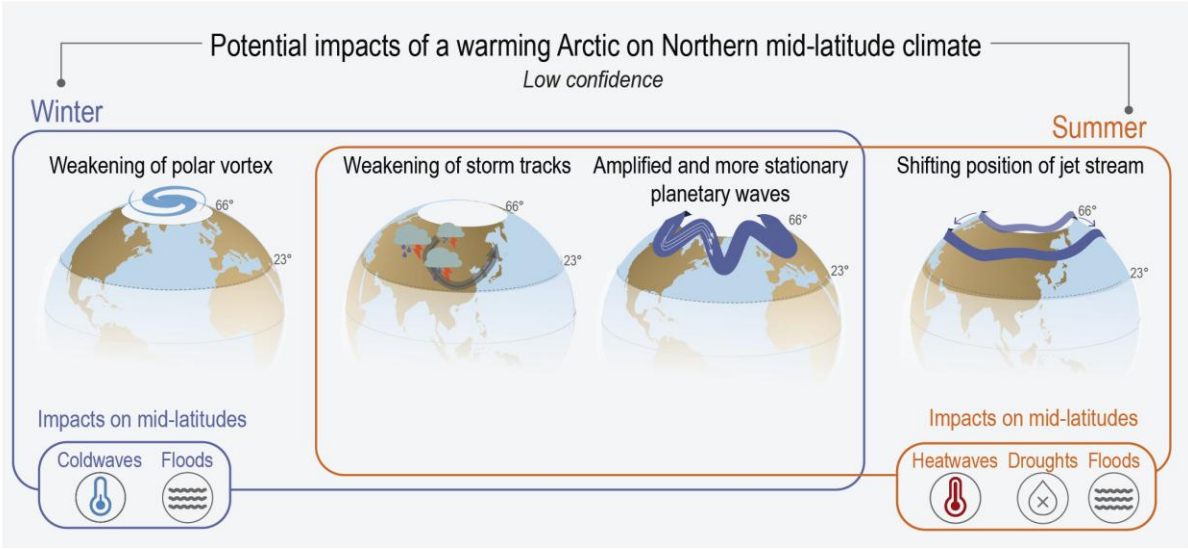




IPCC, AR6

Impact of climate change



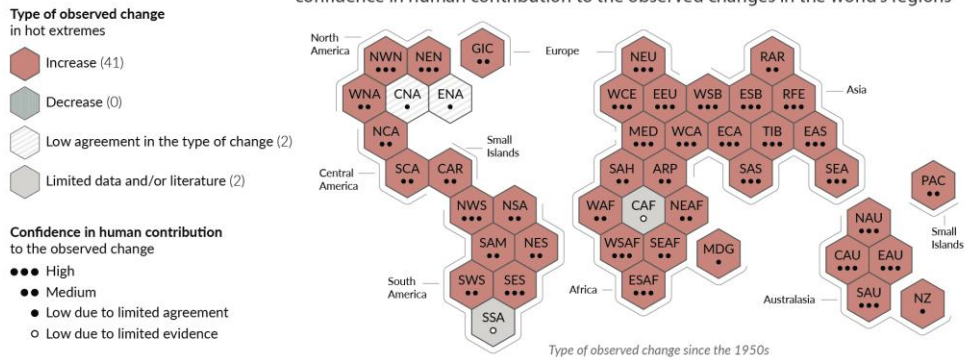


IPCC, AR6

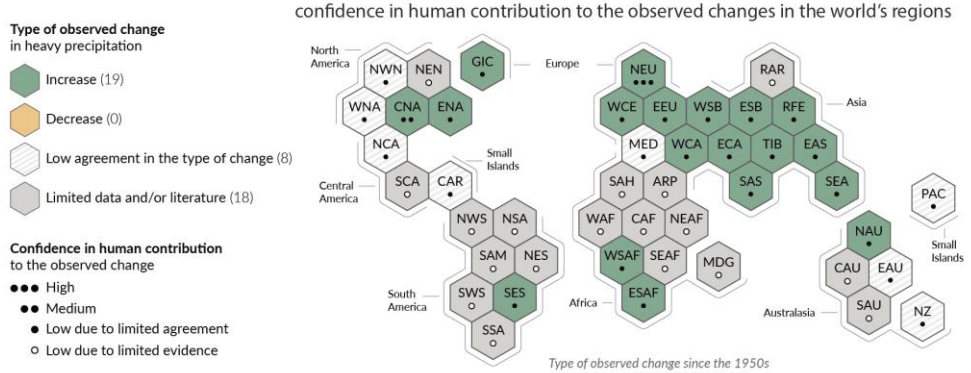
Impact of climate change

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

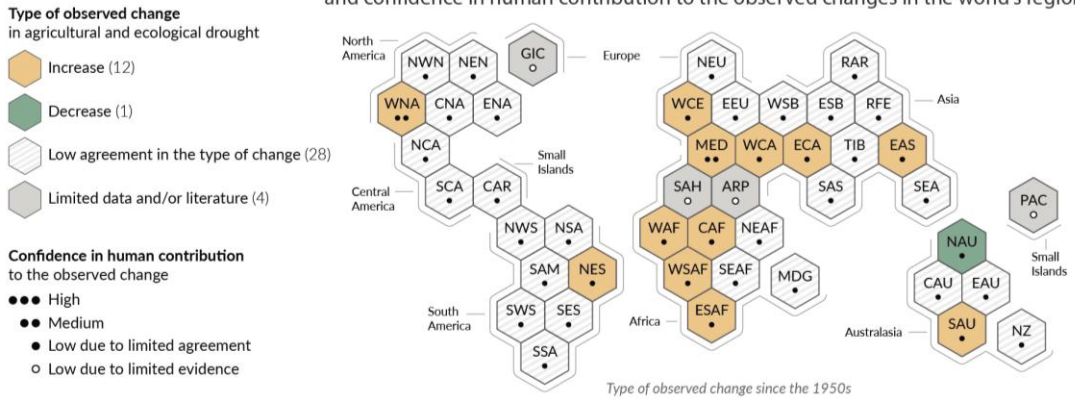
(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions



(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



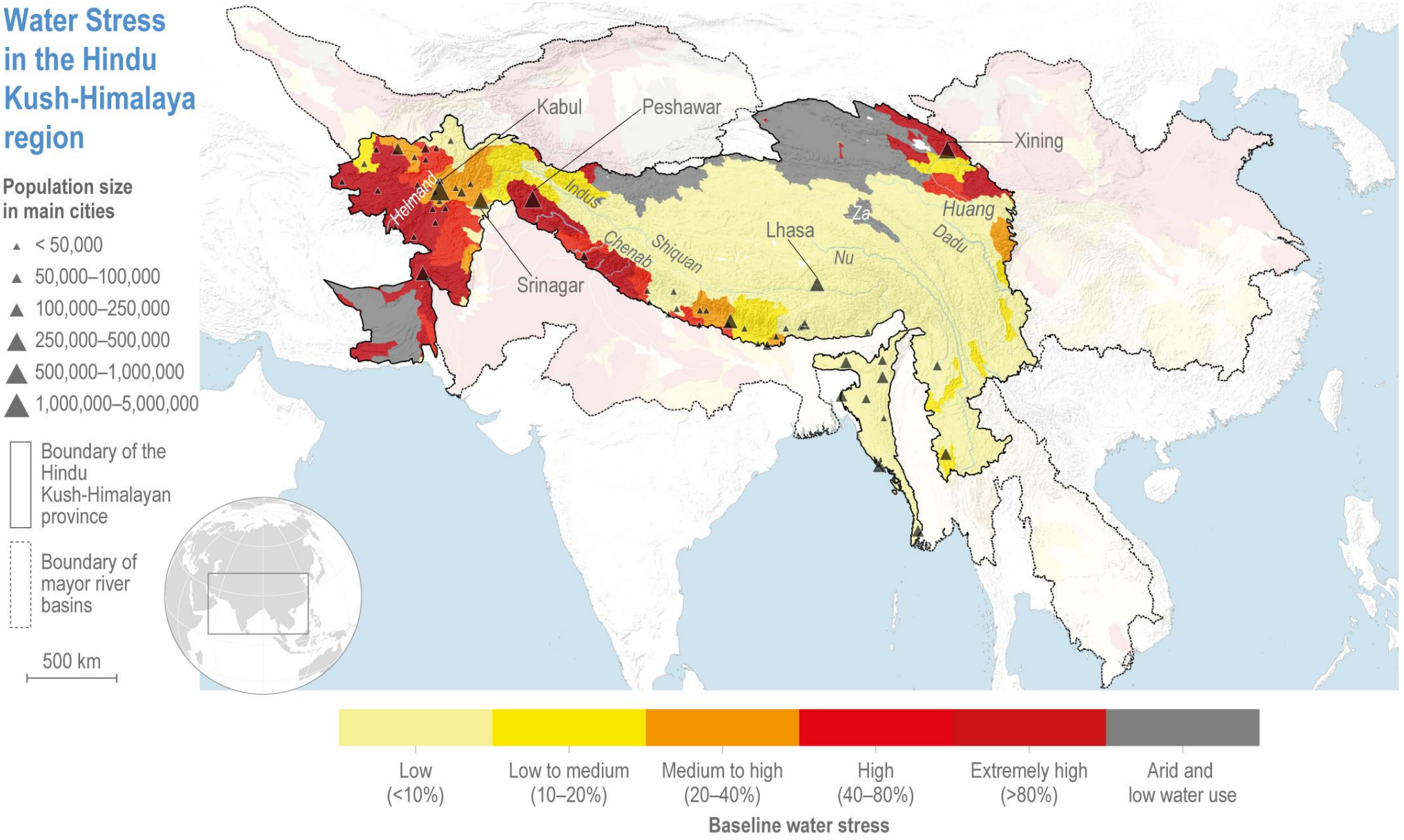
Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

NWN *North-Western North America*

IPCC AR6 WGI reference regions: **North America:** ***NWN*** *(North-Western North America),* ***NEN*** *(North-Eastern North America),* ***WNA*** *(Western North America),* ***CNA*** *(Central North America),* ***ENA*** *(Eastern North America),* **Central America:** ***NCA*** *(Northern Central America),* ***SCA*** *(Southern Central America),* ***CAR*** *(Caribbean),* **South America:** ***NWS*** *(North-Western South America),* ***NSA*** *(Northern South America),* ***NES*** *(North-Eastern South America),* ***SAM*** *(South American Monsoon),* ***SWS*** *(South-Western South America),* ***SES*** *(South-Eastern South America),* ***SSA*** *(Southern South America),* **Europe:** ***GIC*** *(Greenland/Iceland),* ***NEU*** *(Northern Europe),* ***WCE*** *(Western and Central Europe),* ***EEU*** *(Eastern Europe),* ***MED*** *(Mediterranean),* **Africa:** ***MED*** *(Mediterranean),* ***SAH*** *(Sahara),* ***WAF*** *(Western Africa),* ***CAF*** *(Central Africa),* ***NEAF*** *(North Eastern Africa),* ***SEAF*** *(South Eastern Africa),* ***WSAF*** *(West Southern Africa),* ***ESAF*** *(East Southern Africa),* ***MDG*** *(Madagascar),* **Asia:** ***RAR*** *(Russian Arctic),* ***WSB*** *(West Siberia),* ***ESB*** *(East Siberia),* ***RFE*** *(Russian Far East),* ***WCA*** *(West Central Asia),* ***ECA*** *(East Central Asia),* ***TIB*** *(Tibetan Plateau),* ***EAS*** *(East Asia),* ***ARP*** *(Arabian Peninsula),* ***SAS*** *(South Asia),* ***SEA*** *(South East Asia),* **Australasia:** ***NAU*** *(Northern Australia),* ***CAU*** *(Central Australia),* ***EAU*** *(Eastern Australia),* ***SAU*** *(Southern Australia),* ***NZ*** *(New Zealand),* **Small Islands:** ***CAR*** *(Caribbean),* ***PAC*** *(Pacific Small Islands)*

IPCC, AR6

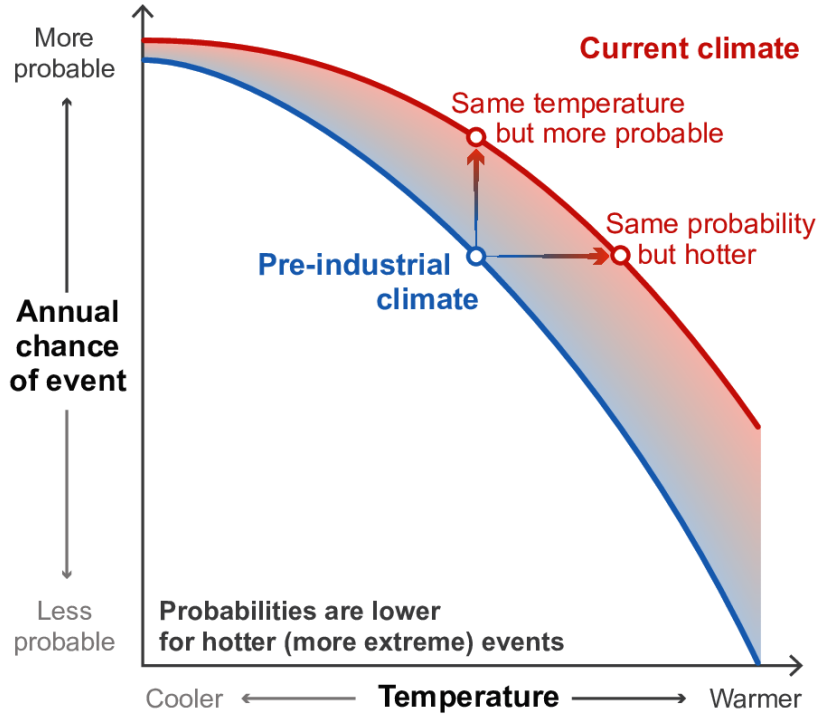
Impact of climate change



IPCC, AR6

Impact of climate change

Extreme events have become more probable and more intense. Many of these changes can be attributed to human influence on the climate.



Yes, in a changing climate, extreme events may be unprecedented when they occur with...



Larger magnitude



Increased frequency



New locations

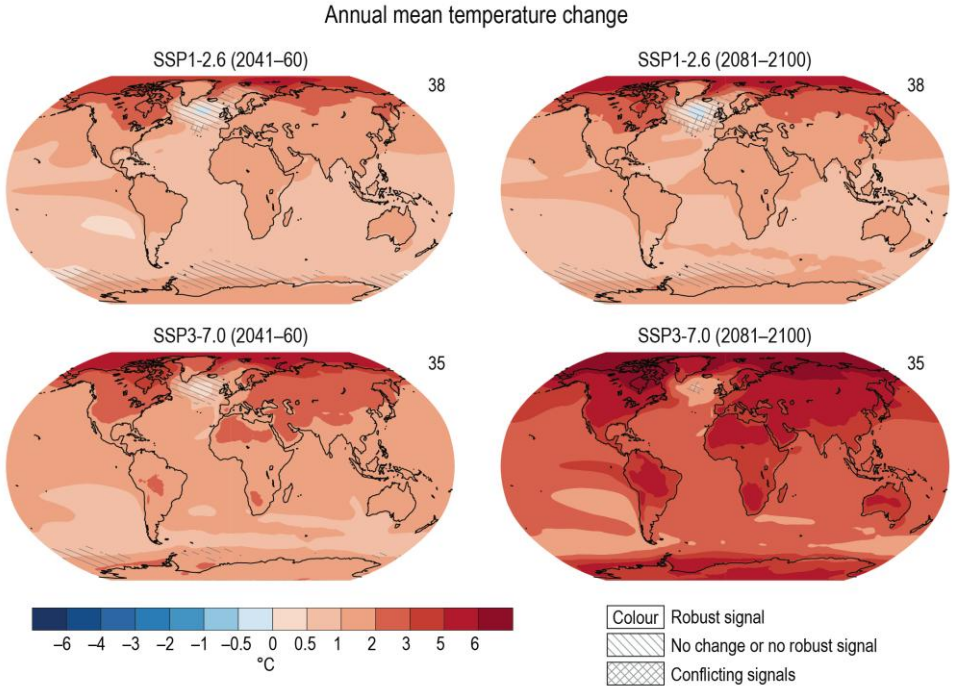


Different timing

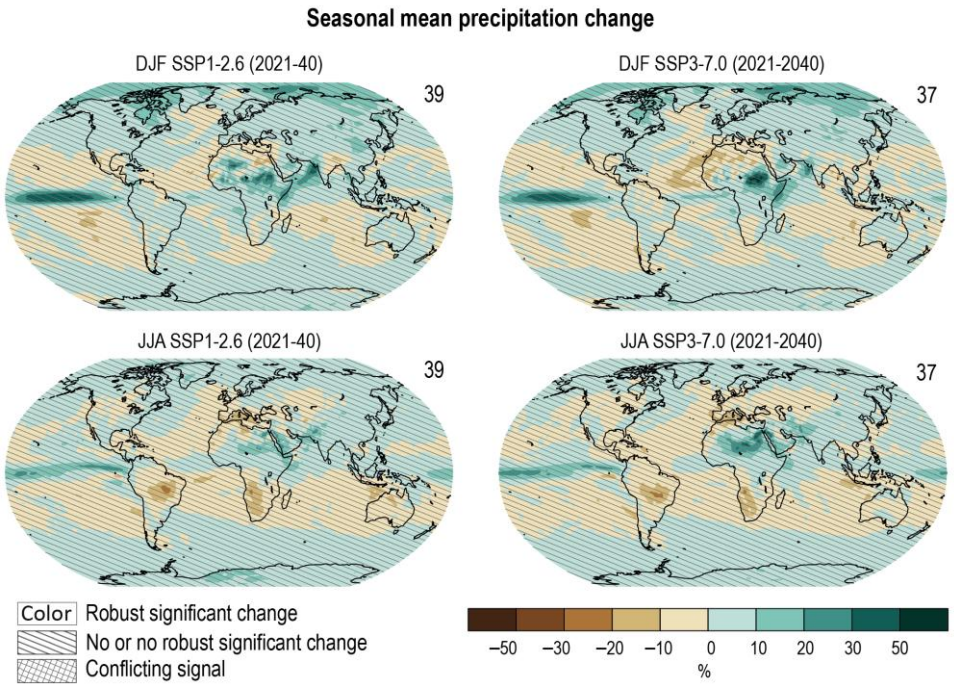


New combinations (compound)

Climate change projections



Mid-and long-term change of annual mean surface temperature



Near-term change of seasonal mean precipitation

thank you for listening

For questions, collaborations, and further discussions

praveenglaciology@gmail.com

singhpraveenk.github.io