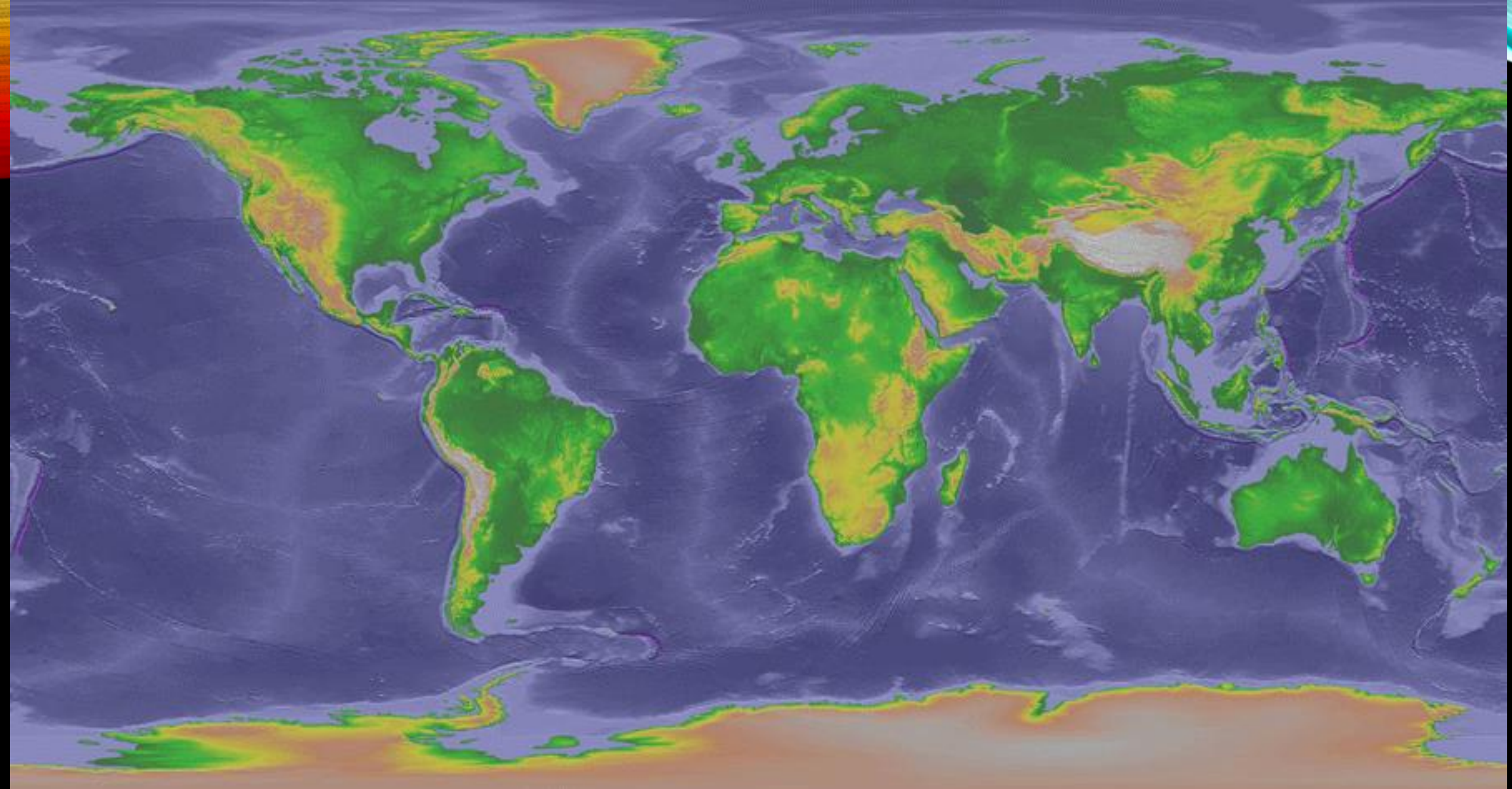
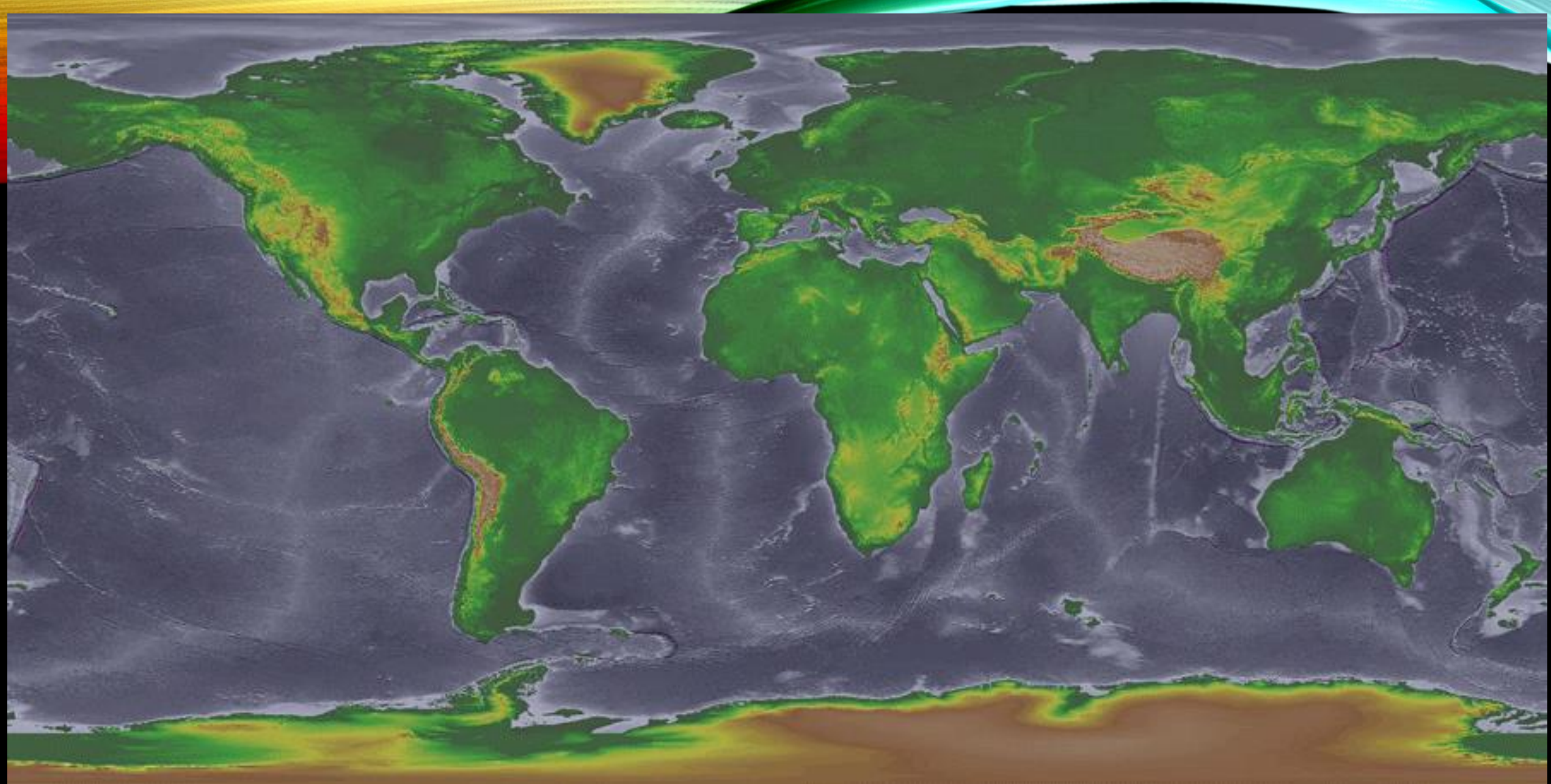


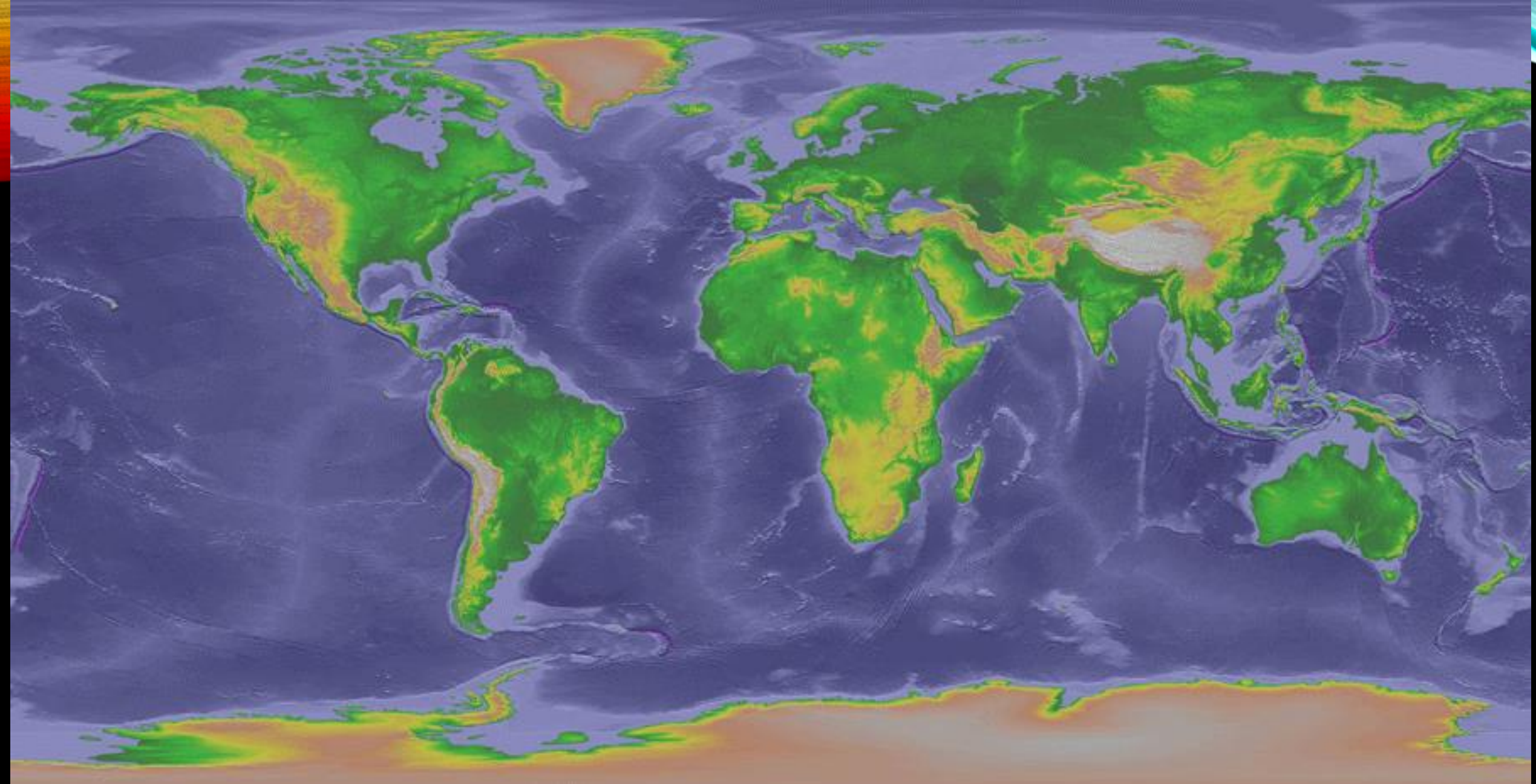
What do you see....



What do you see now....



What do you see.... **Glaciation**...sea levels drop



Interglacial, rise in sea levels, less land, climate warming

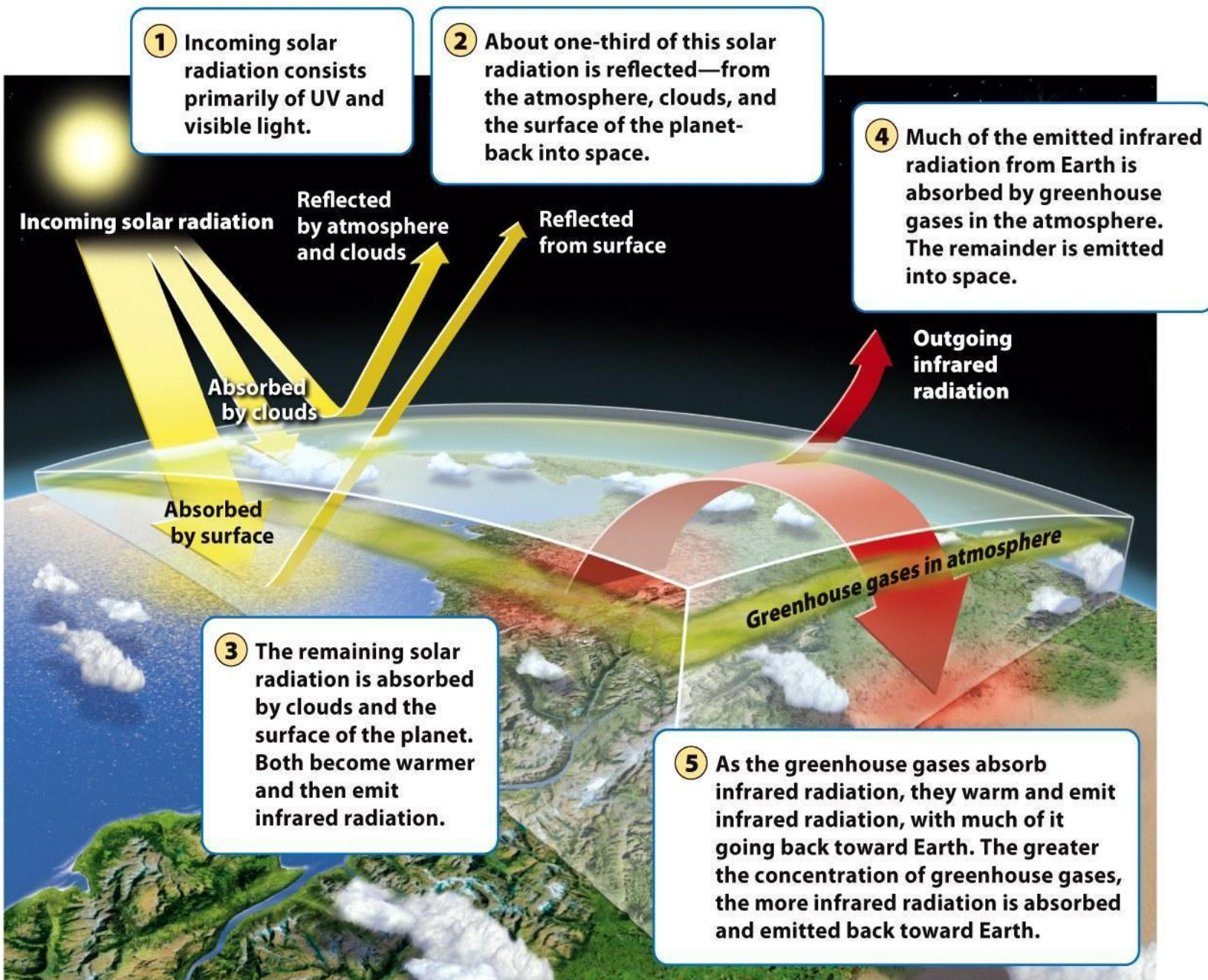
THE ARCTIC  
OCEAN  
PHOTOGRAPHED  
IN THE SAME PLACE  
105 YEARS AGO  
VS. TODAY





## Chapter 19

**Global Change** long-term shifts in temperatures and weather patterns, mainly caused by human activities, especially the burning of fossil fuels.



On average, Earth is about 55-60°F (13°C); w/o atmosphere it would be -243 °F (lifeless moon)

About 30% of solar energy is reflected back into space, 70% absorbs by Earth atmosphere (Earth's oceans and land masses eventually radiate heat back out in the form of infrared radiation).

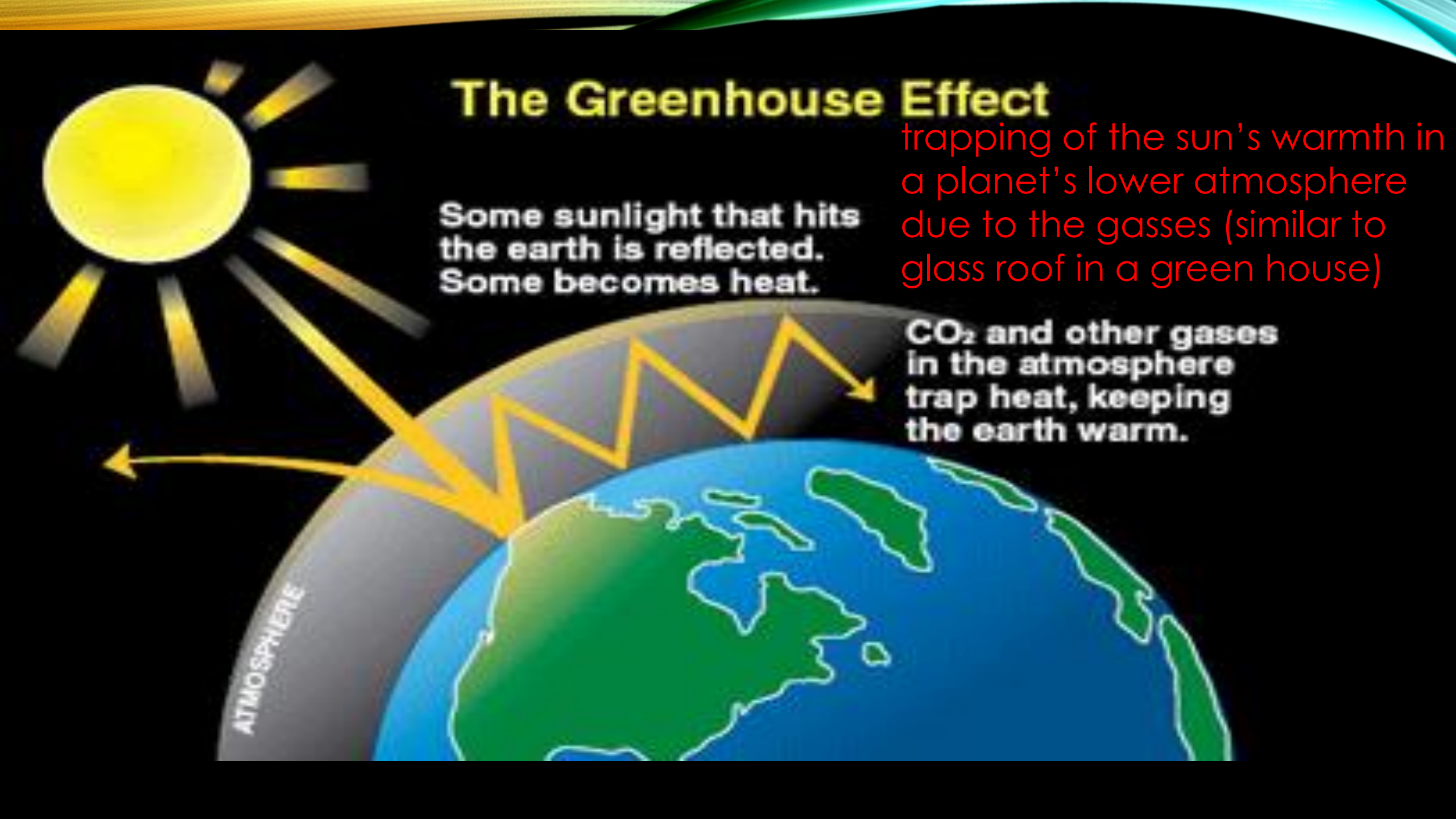
# The Greenhouse Effect

Some sunlight that hits the earth is reflected. Some becomes heat.

trapping of the sun's warmth in a planet's lower atmosphere due to the gasses (similar to glass roof in a green house)

CO<sub>2</sub> and other gases in the atmosphere trap heat, keeping the earth warm.

ATMOSPHERE

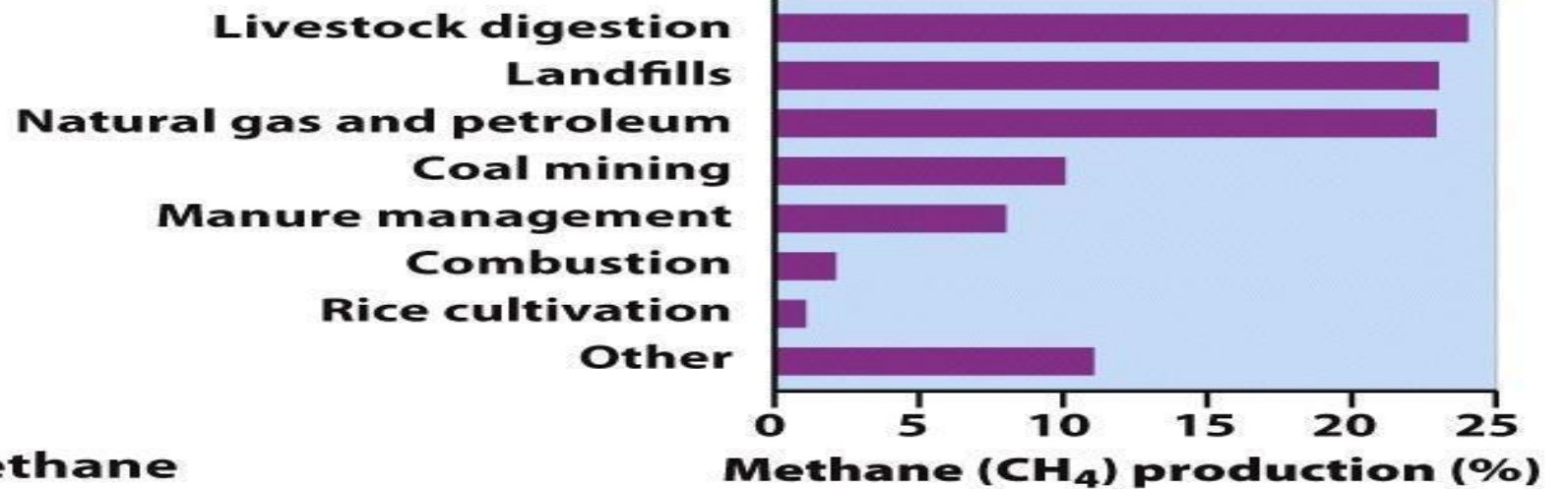




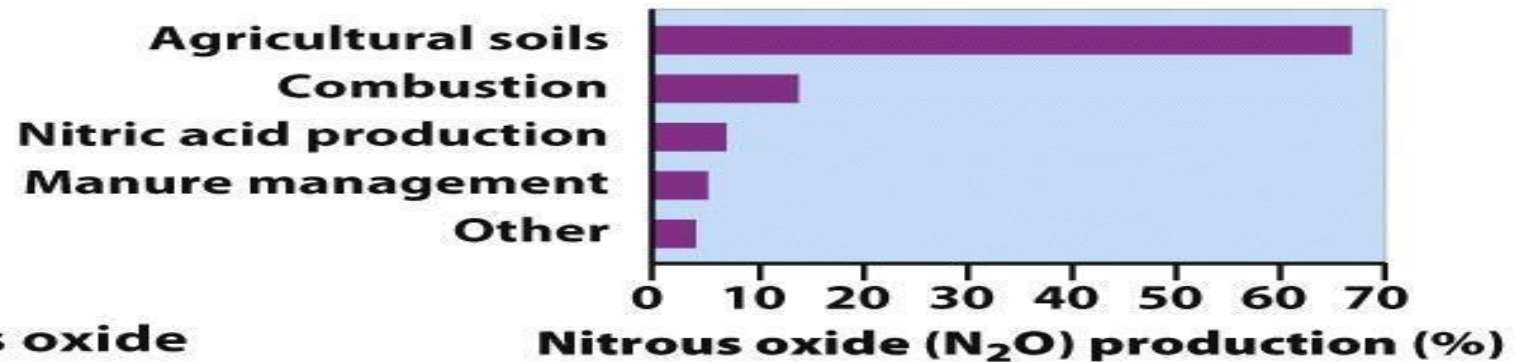
# Common Greenhouse gases...

d. Water vapor  
(occurs naturally)

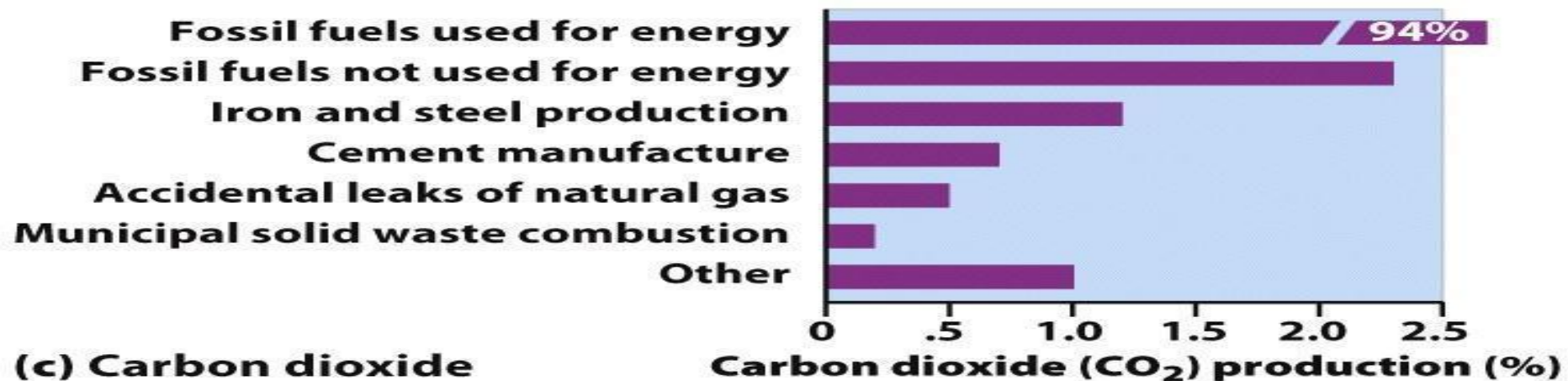
(a) Methane



(b) Nitrous oxide

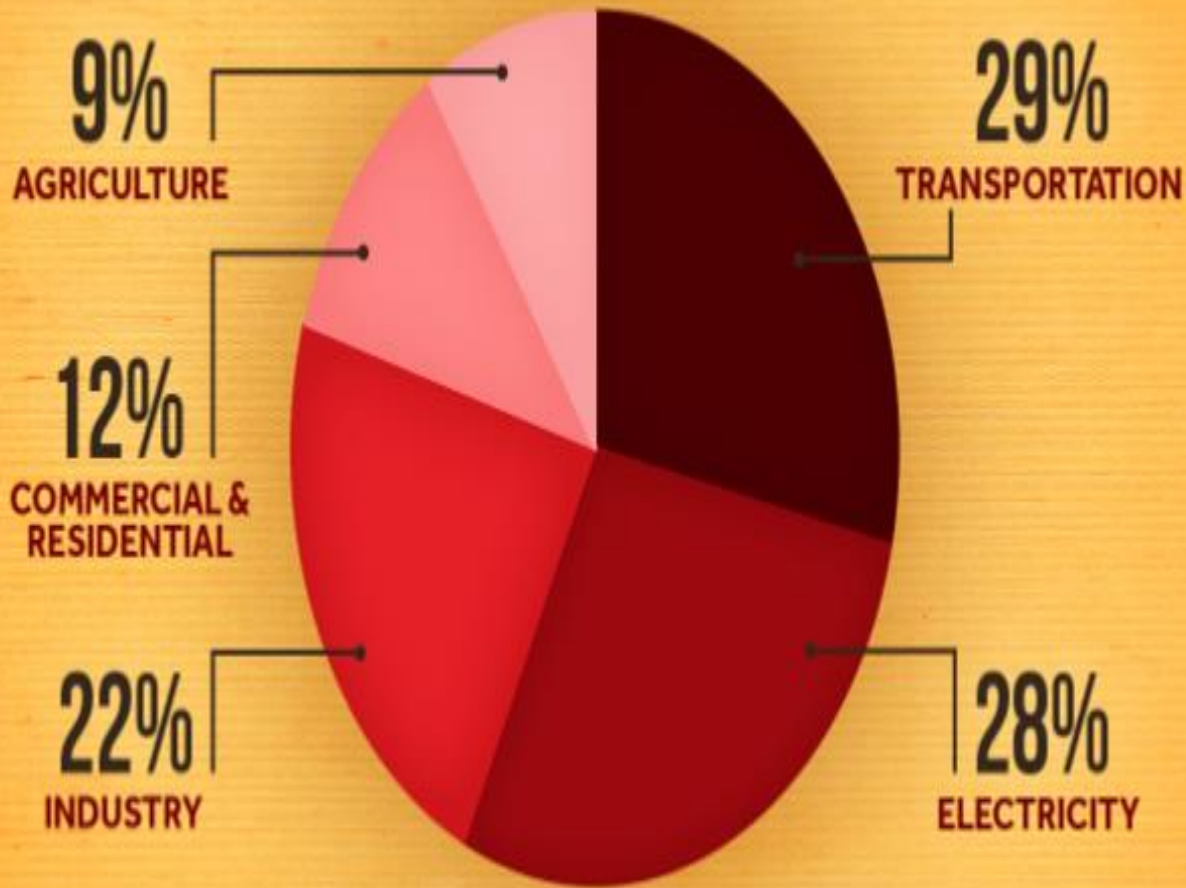


(c) Carbon dioxide



# GREENHOUSE GAS SOURCES

## UNITED STATES EMISSIONS BY SECTOR



Source: U.S. EPA 2017 (released 2019)

CLIMATE  CENTRAL

### Where are greenhouse gas emissions coming from?

The continued rise of global greenhouse gas emissions is mainly from **human activities** (including fossil fuel combustion, industrial processes, and land use):

**Energy/Electricity sector:** production, transmission, and distribution of energy and electricity to power our homes and economy

**Industry sector:** production and manufacturing of products and raw materials

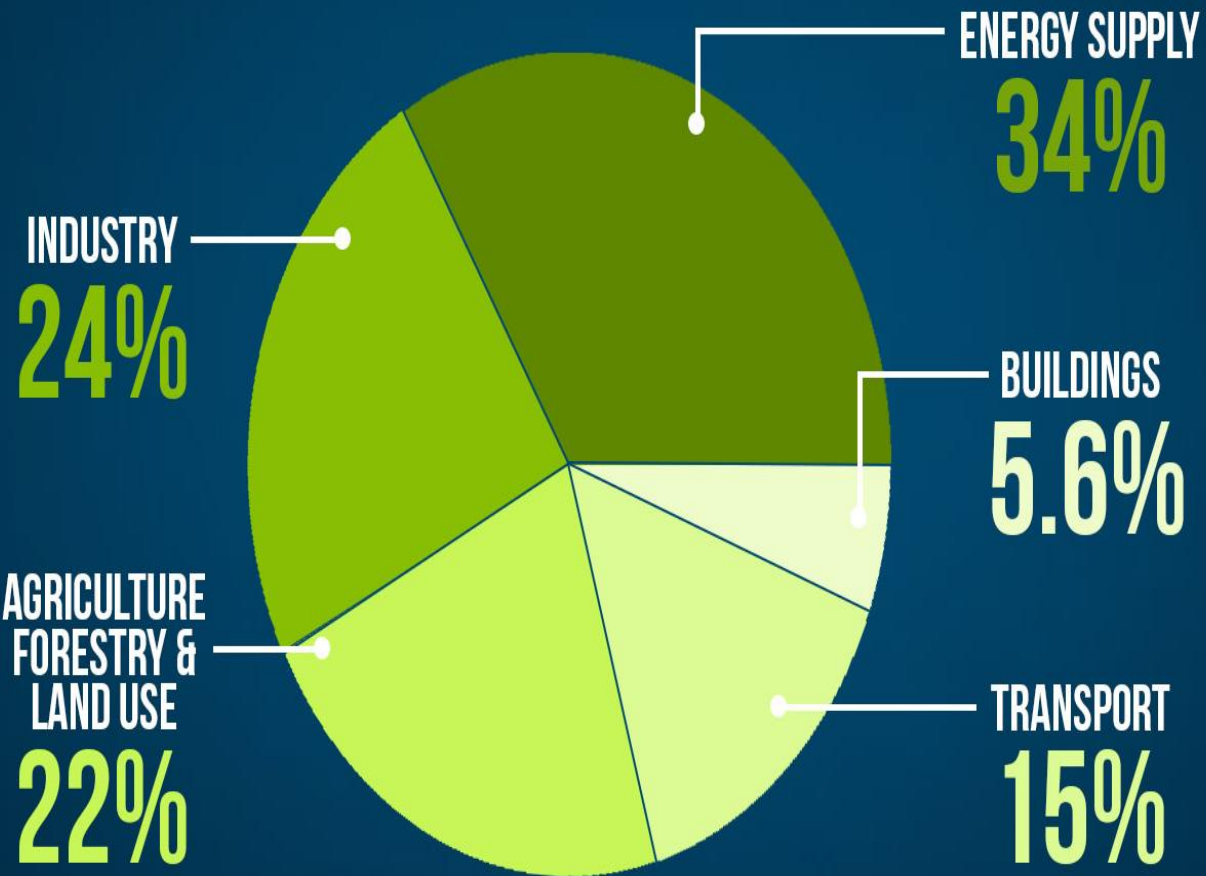
**Agriculture sector:** growing, maintaining, and harvesting our crops and livestock

**Transportation sector:** modes of public and private transport like cars, trucks, and airplanes

**Buildings/Commercial and Residential sector:** powering, heating, cooling, and other activities related to commercial buildings and homes

# GREENHOUSE GAS EMISSIONS

Global Emissions by Sector

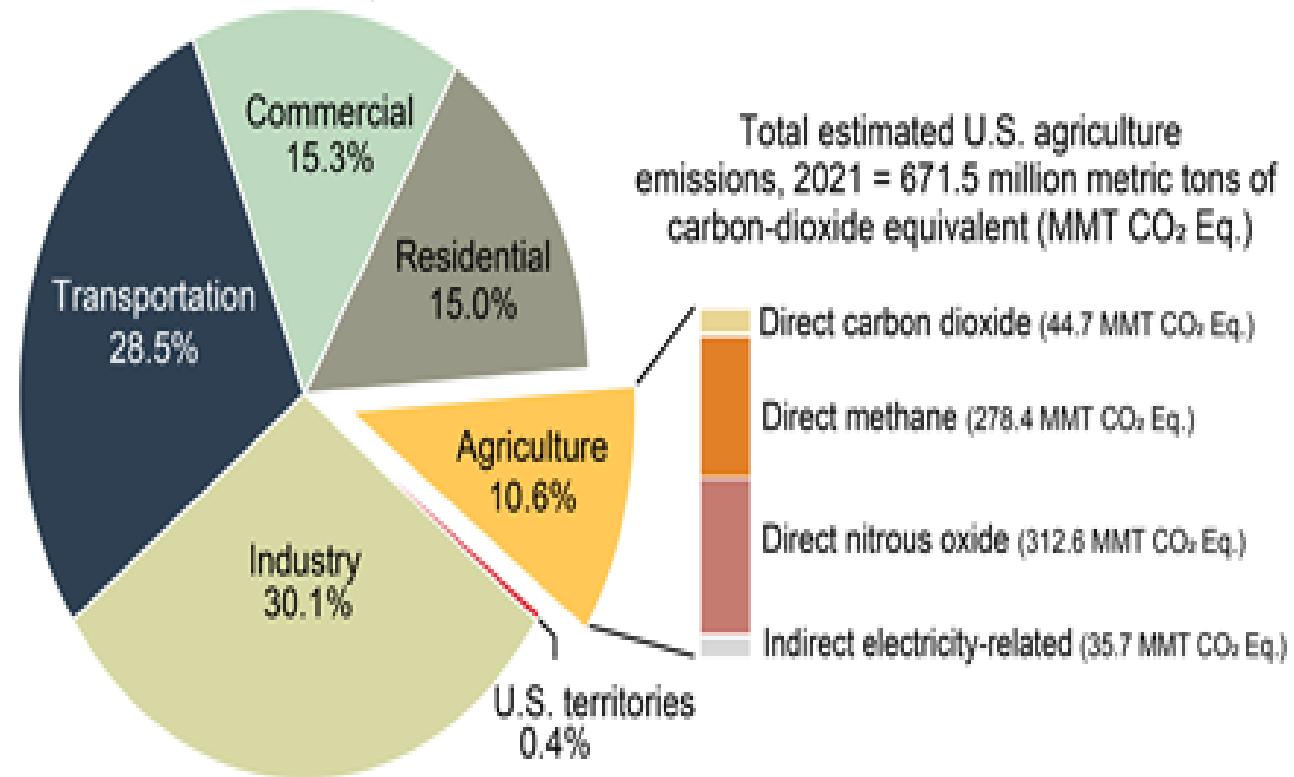


Global greenhouse gas emissions (2019) by sector.  
Source: IPCC

CLIMATE CENTRAL

## Estimated U.S. greenhouse gas emissions by economic sector, with electricity-related emissions distributed, 2021

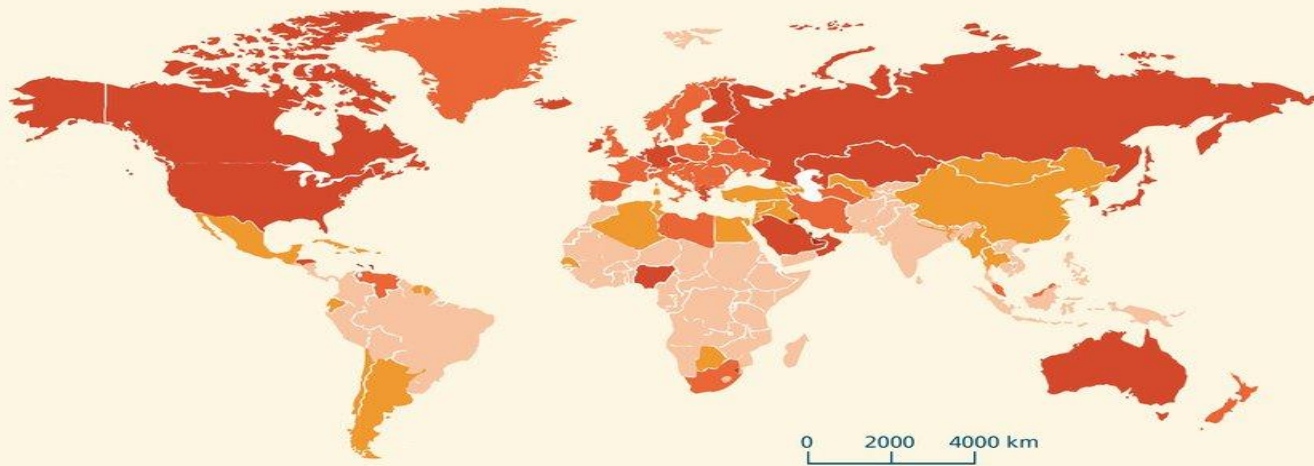
Total estimated U.S. emissions, 2021 = 6,340 million metric tons of carbon-dioxide equivalent



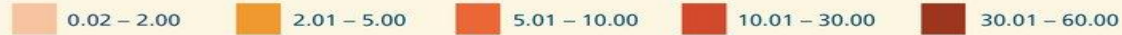
Note: Emissions from electric power are allocated based on aggregate electricity use in each end-use sector. Components may not sum to totals because of independent rounding. Source: USDA, Economic Research Service using data from U.S. Environmental Protection Agency, April 2023: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021*, table 2-12.

# World Greenhouse Gas Emissions

CO<sub>2</sub> emissions per capita in 2007



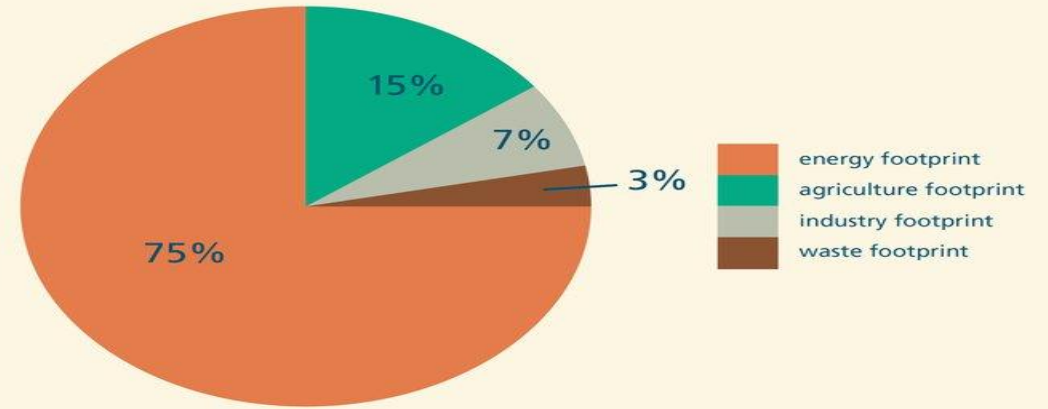
Unit tonnes of CO<sub>2</sub>



Highest carbon footprint per capita

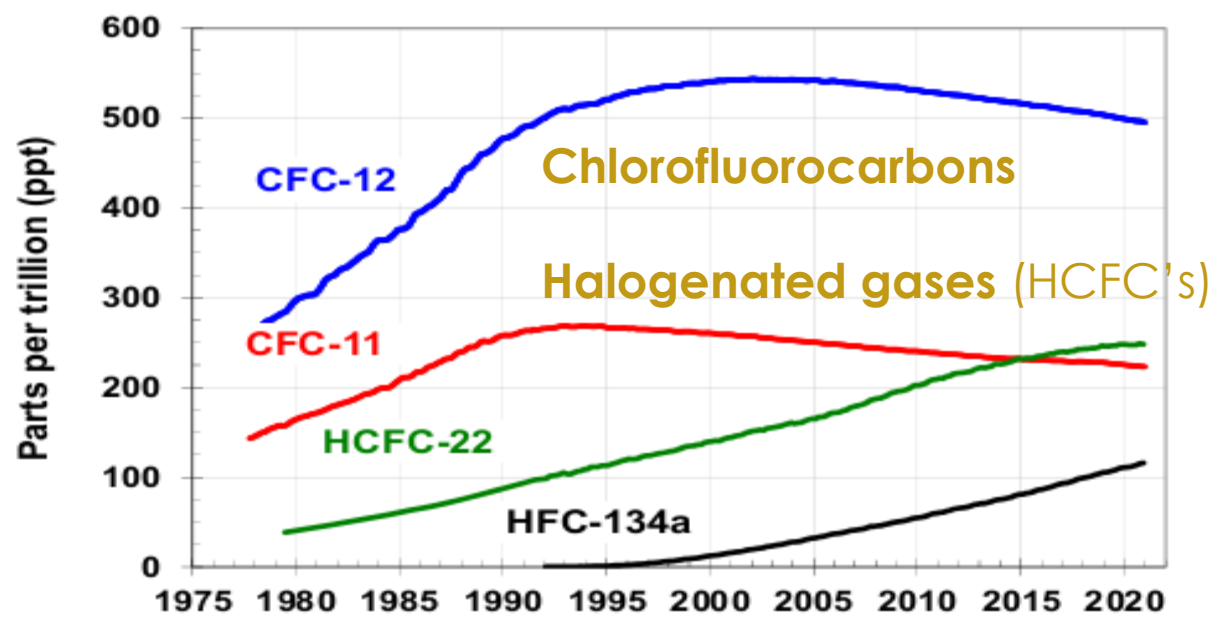
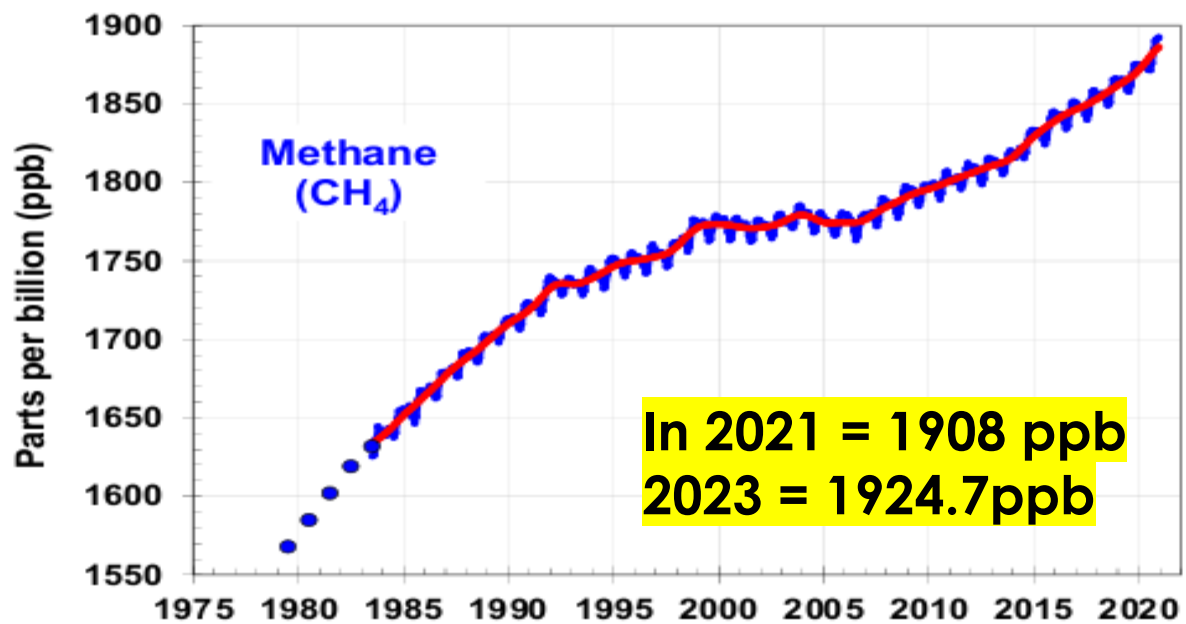
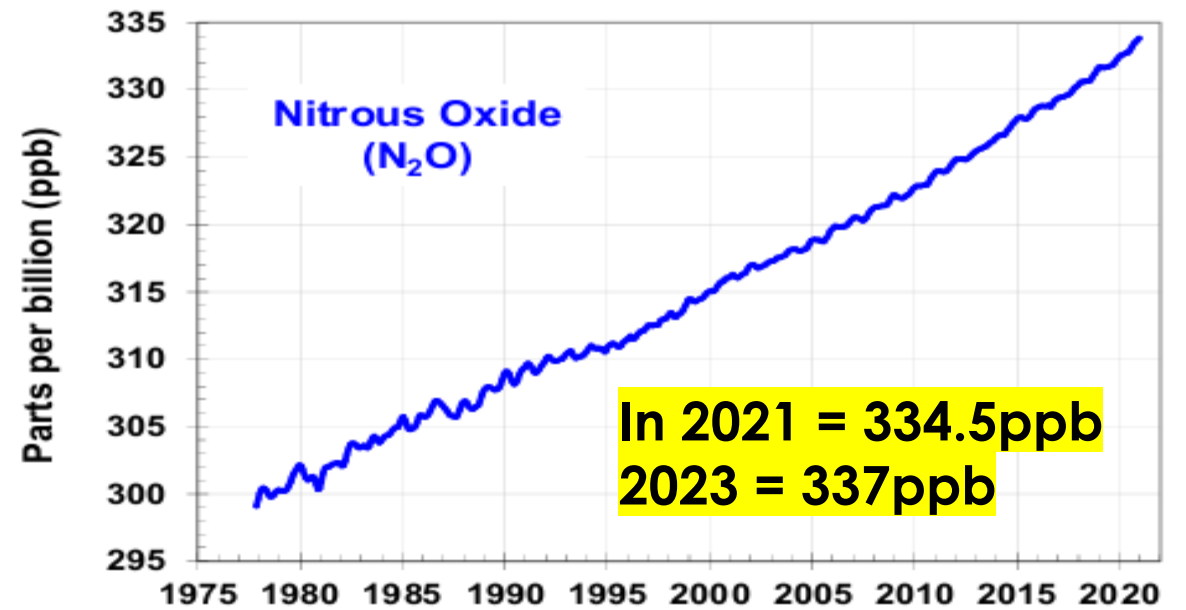
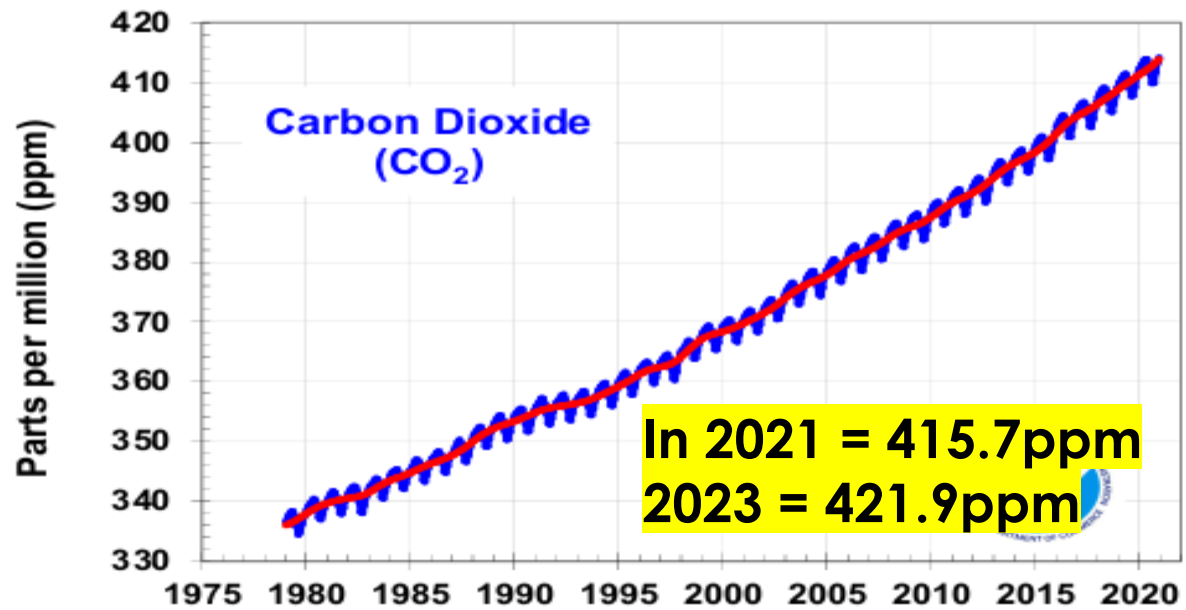


Breakdown of Australia's carbon footprint

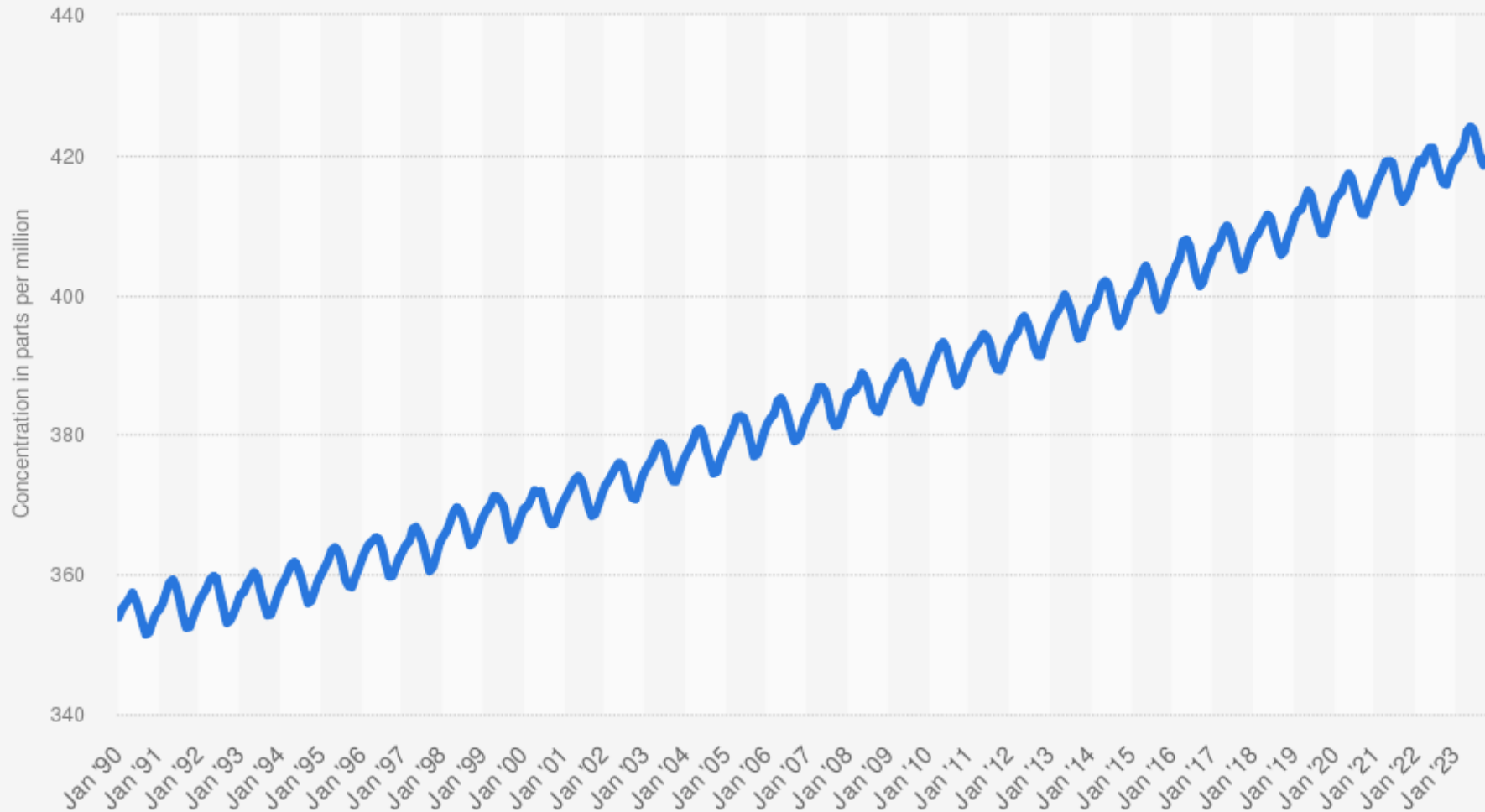


Carbon footprint of different foods





## Average monthly carbon dioxide (CO) levels in the atmosphere worldwide from 1990 to 2023 (in parts per million)

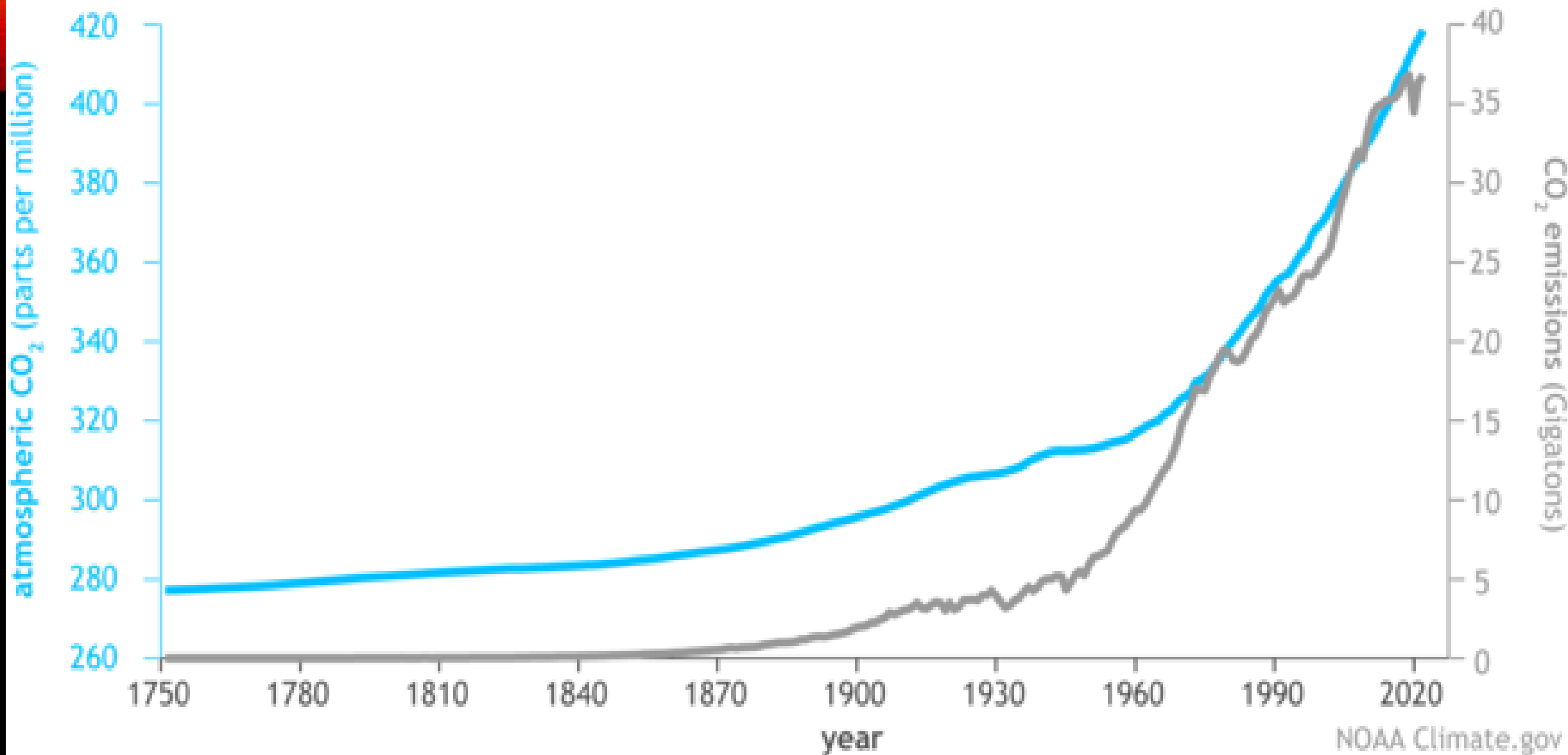


Source  
ESRL  
© Statista 2024

Additional Information:  
Worldwide

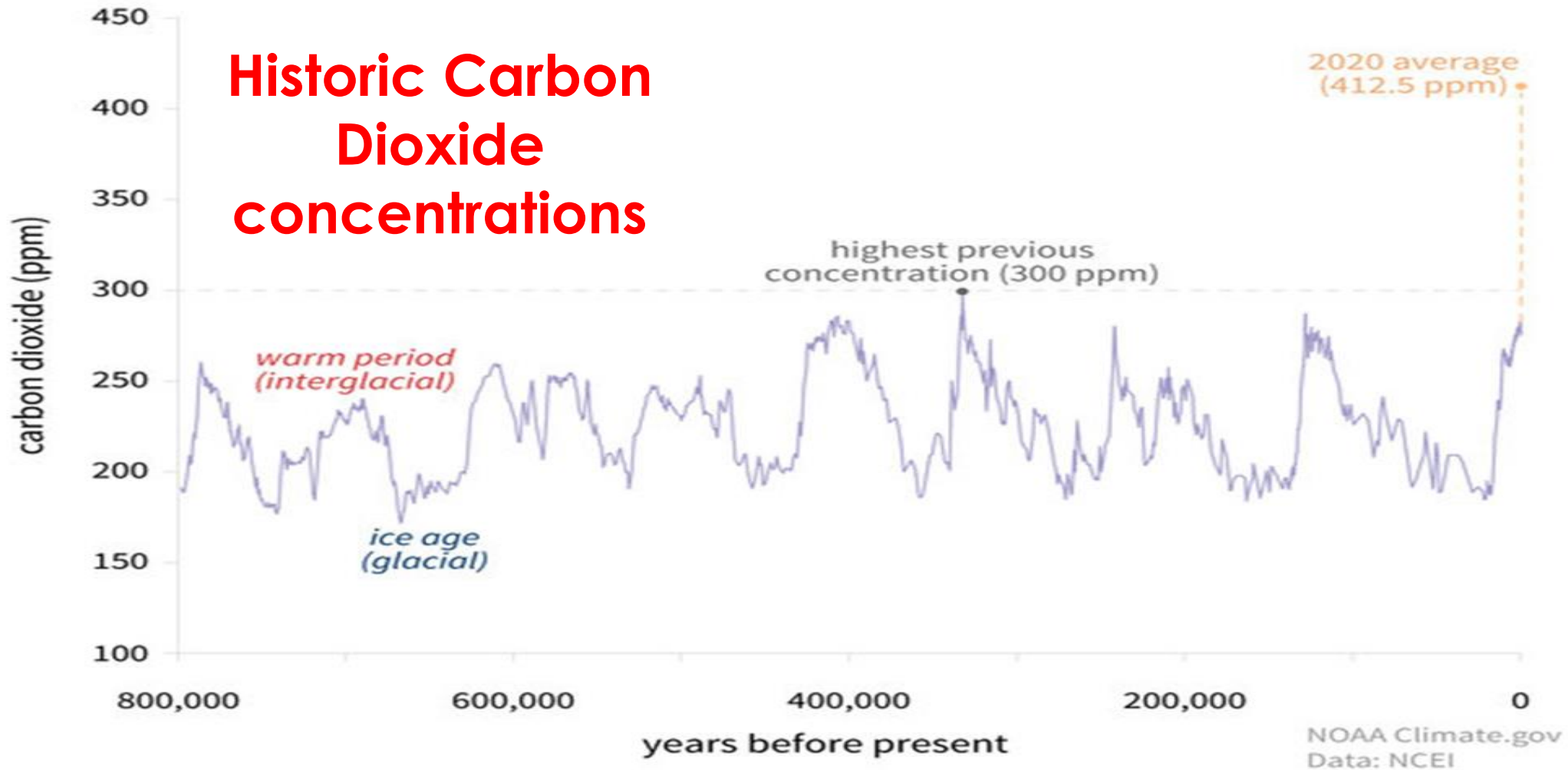
**ppm and ppb are actually fractions (parts PER)** when expressed as numbers, and the "million" and "billion" go in the denominator...  
**ppm is 1000x greater in concentration than ppb**

Global atmospheric carbon dioxide compared to annual emissions (1751-2022)



NOAA Climate.gov  
Data: NOAA, ETHZ, Our World in Data

# CARBON DIOXIDE OVER 800,000 YEARS



More than 400,000 years of Carbon Dioxide concentrations never exceeded 300ppm. After 1950, concentrations sharply increased to their current level (as of 12/23) is 421.9 ppm (2022 = 418.5ppm)



Ted Talk:  
Fast way to  
fix the  
Climate  
change

# METHANE CONCENTRATION



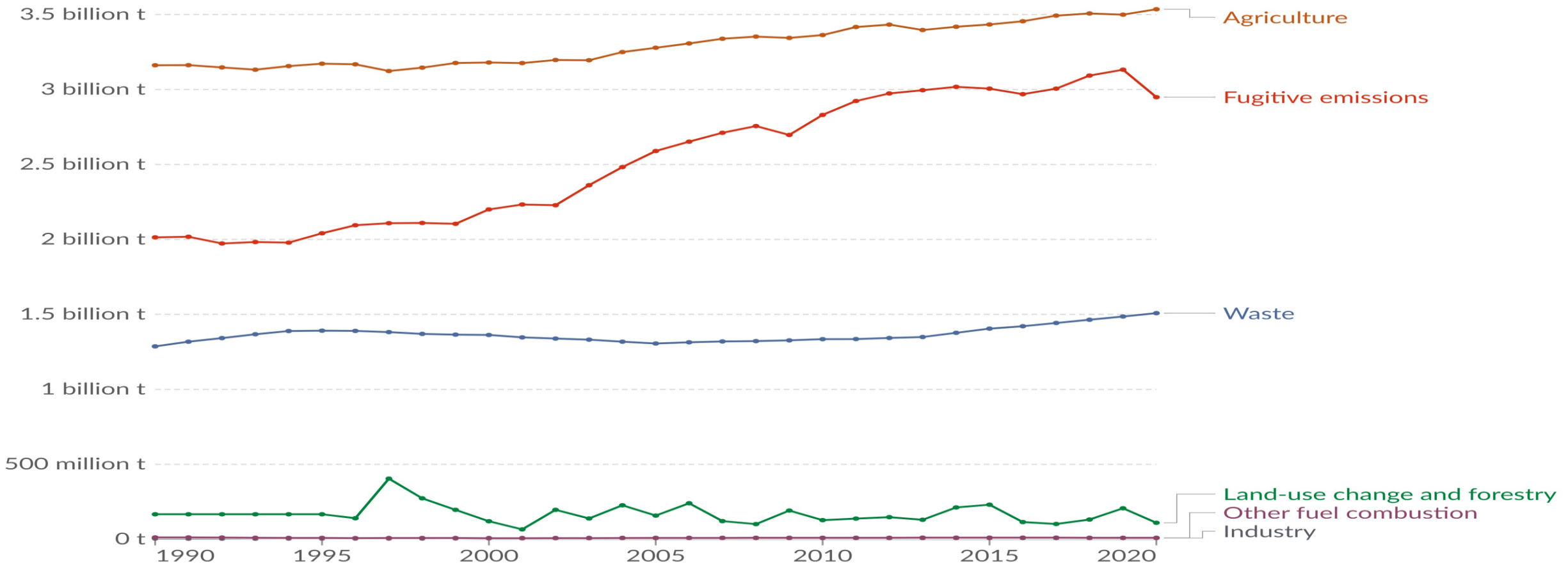
Atmpsheric methane concentration  
Source: US EPA

CLIMATE  CENTRAL

Methane concentrations reached 1908 parts per billion (ppb) in 2021, 17 ppb higher than last year...1925ppb in 2023, and 162% higher than pre-industrial methane levels. Methane traps heat 81 times more effectively and 25x more potent than CO2

# Methane emissions by sector, World

Methane (CH<sub>4</sub>) emissions are measured in tonnes of carbon dioxide-equivalents<sup>1</sup>.



Data source: Climate Watch (2023)

[OurWorldInData.org/co2-and-greenhouse-gas-emissions](https://OurWorldInData.org/co2-and-greenhouse-gas-emissions) | CC BY

**1. Carbon dioxide equivalents (CO<sub>2</sub>eq):** Carbon dioxide is the most important greenhouse gas, but not the only one. To capture all greenhouse gas emissions, researchers express them in “carbon dioxide equivalents” (CO<sub>2</sub>eq). This takes all greenhouse gases into account, not just CO<sub>2</sub>. To express all greenhouse gases in carbon dioxide equivalents (CO<sub>2</sub>eq), each one is weighted by its global warming potential (GWP) value. GWP measures the amount of warming a gas creates compared to CO<sub>2</sub>. CO<sub>2</sub> is given a GWP value of one. If a gas had a GWP of 10 then one kilogram of that gas would generate ten times the warming effect as one kilogram of CO<sub>2</sub>. Carbon dioxide equivalents are calculated for each gas by multiplying the mass of emissions of a specific greenhouse gas by its GWP factor. This warming can be stated over different timescales. To calculate CO<sub>2</sub>eq over 100 years, we’d multiply each gas by its GWP over a 100-year timescale (GWP100). Total greenhouse gas emissions – measured in CO<sub>2</sub>eq – are then calculated by summing each gas’ CO<sub>2</sub>eq value.

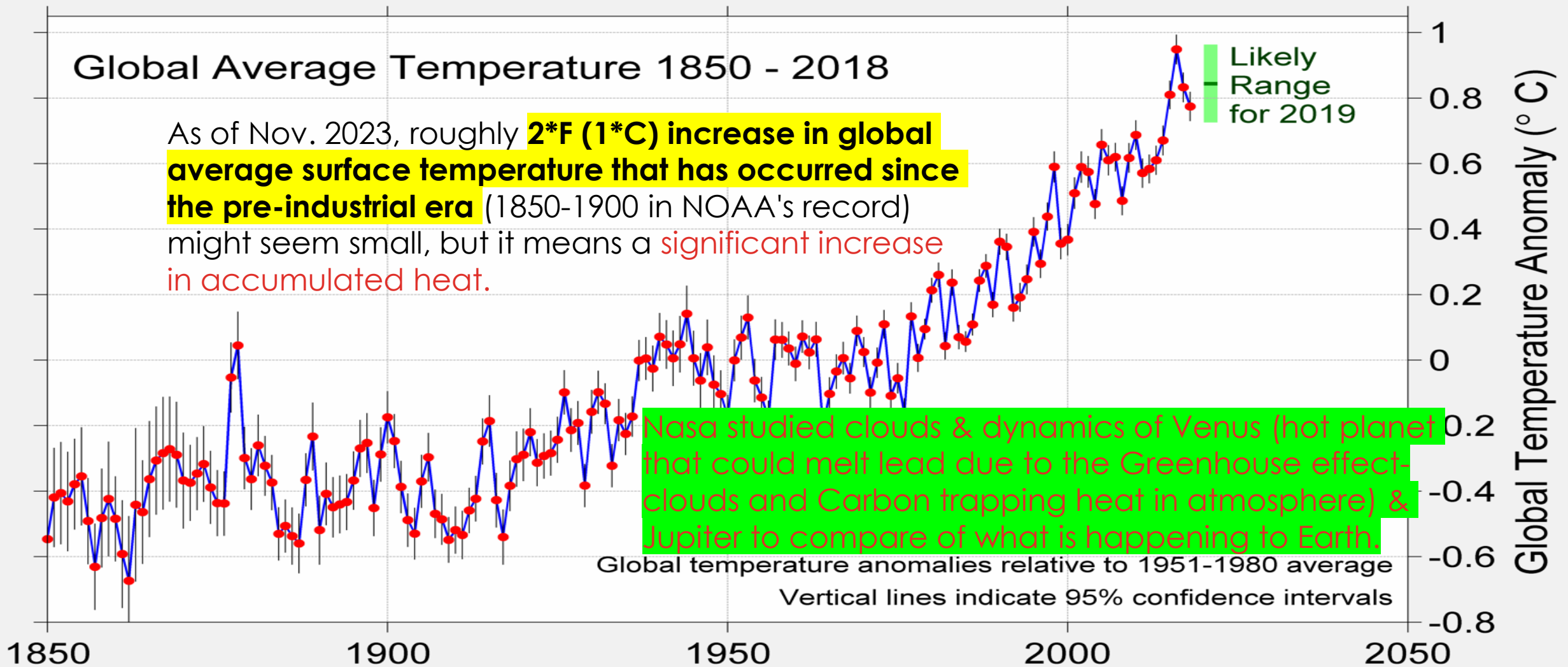
## Greenhouse gas levels reach new record

	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
2022 global mean abundance	417.9±0.2 ppm	1923±2 ppb	335.8±0.1 ppb
2022 abundance relative to 1750 <sup>a</sup>	150%	264%	124%
2021–2022 absolute increase	2.2 ppm	16 ppb	1.4 ppb
2021–2022 relative increase	0.53%	0.84%	0.42%
Mean annual absolute increase over the past 10 years	2.46 ppm yr <sup>-1</sup>	10.2 ppb yr <sup>-1</sup>	1.05 ppb yr <sup>-1</sup>

<sup>a</sup> Assuming a pre-industrial mole fraction of 278.3 ppm for CO<sub>2</sub>, 729.2 ppb for CH<sub>4</sub> and 270.1 ppb for N<sub>2</sub>O.

# History of Global Temperatures since 1850

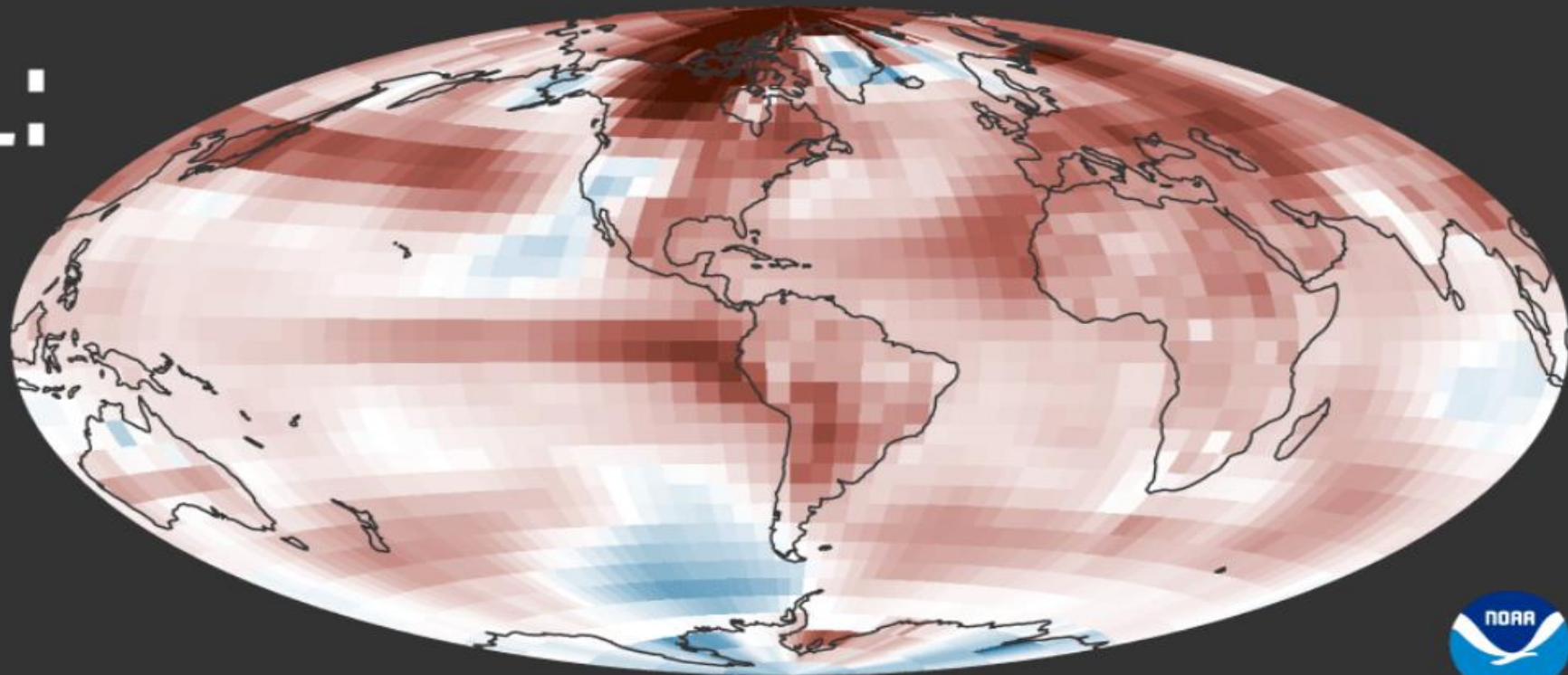
- Since 1880 temperatures have increased  $0.8^{\circ}\text{C}$  ( $1.4^{\circ}\text{F}$ ).



# IT'S OFFICIAL:

2023 was the world's warmest year on record (1850-2023)

(1850-2023)



Difference from 1991-2020 average (°F)



47 years since Earth's had a colder-than-average year



yearly temperature compared to 20<sup>th</sup>-century average

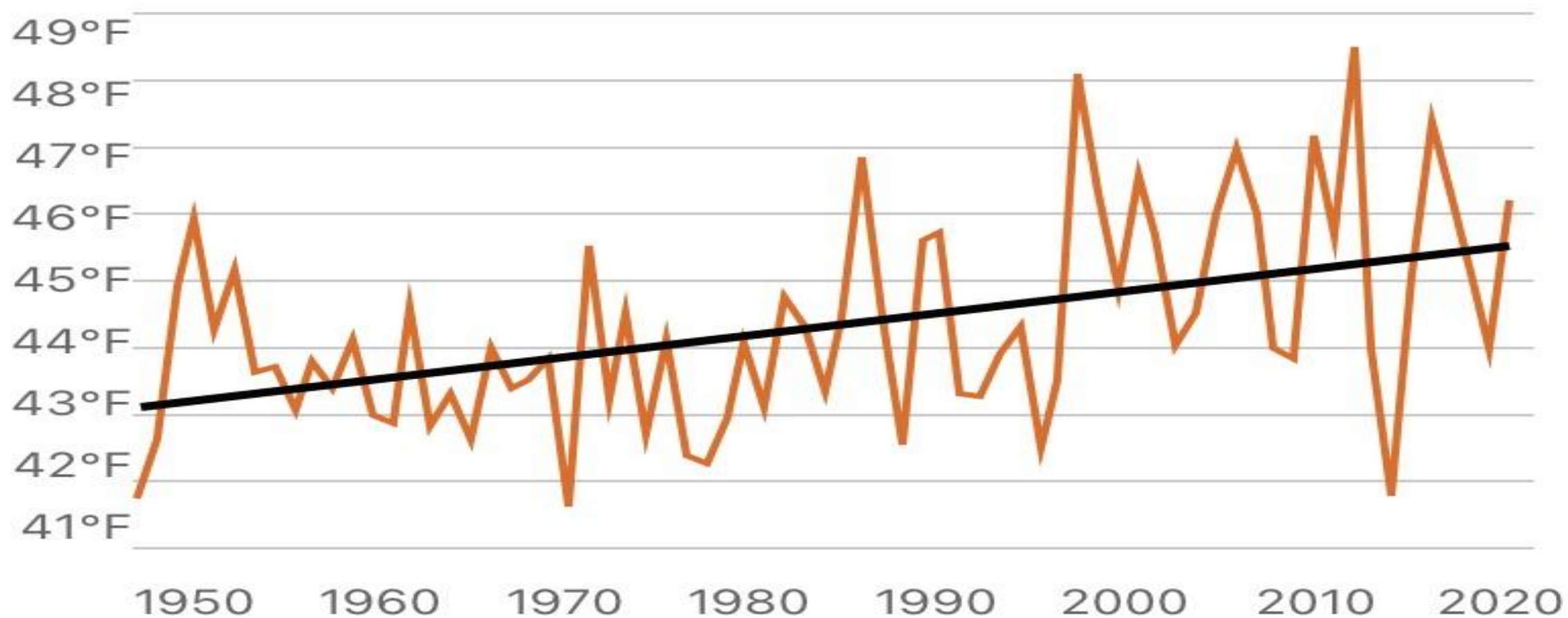
NOAA Climate.gov/NCEI

# Average temperature by year

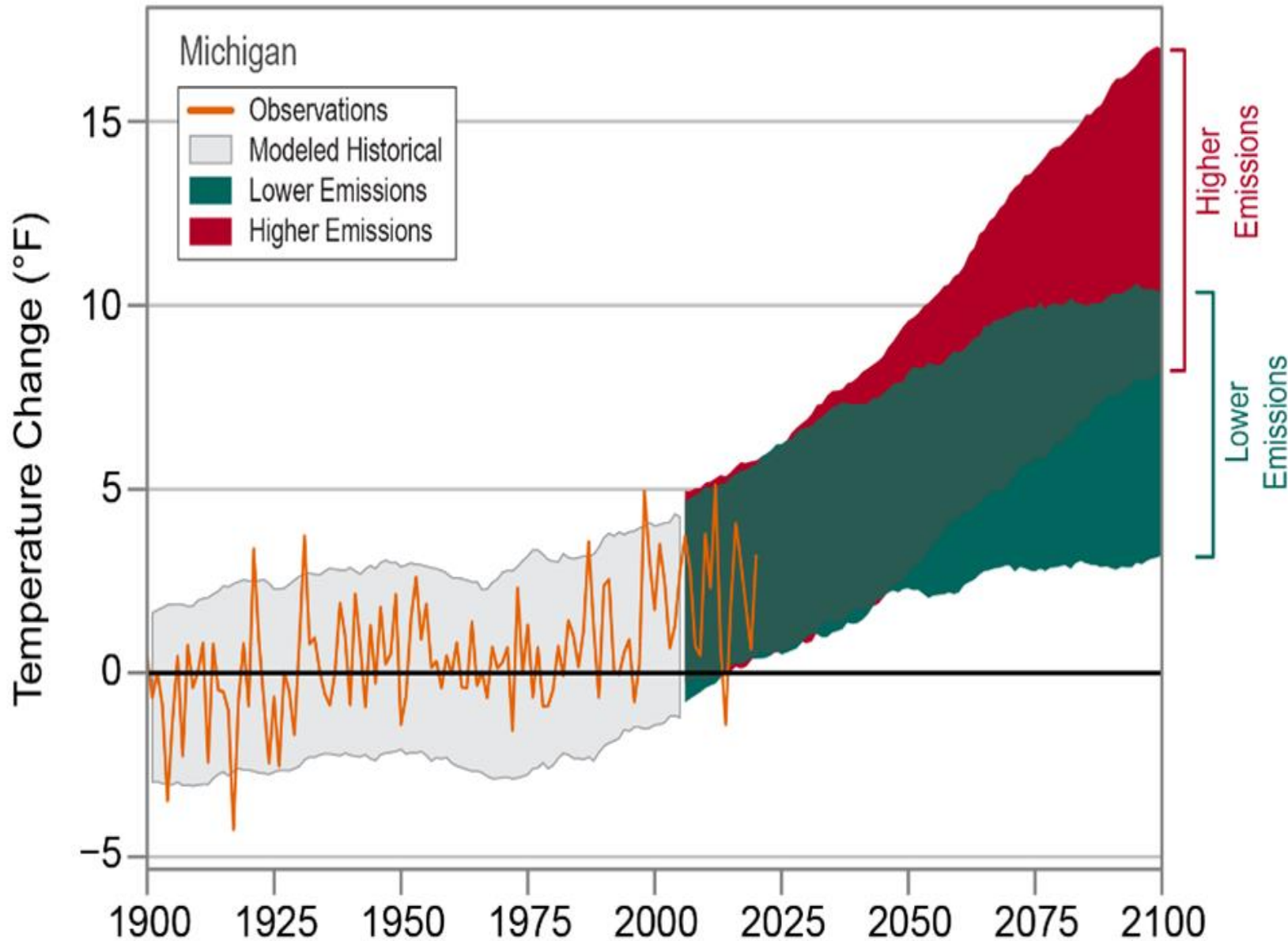


## Michigan ▾

The average annual temperature in Michigan has increased since 1950.



## Observed and Projected Temperature Change



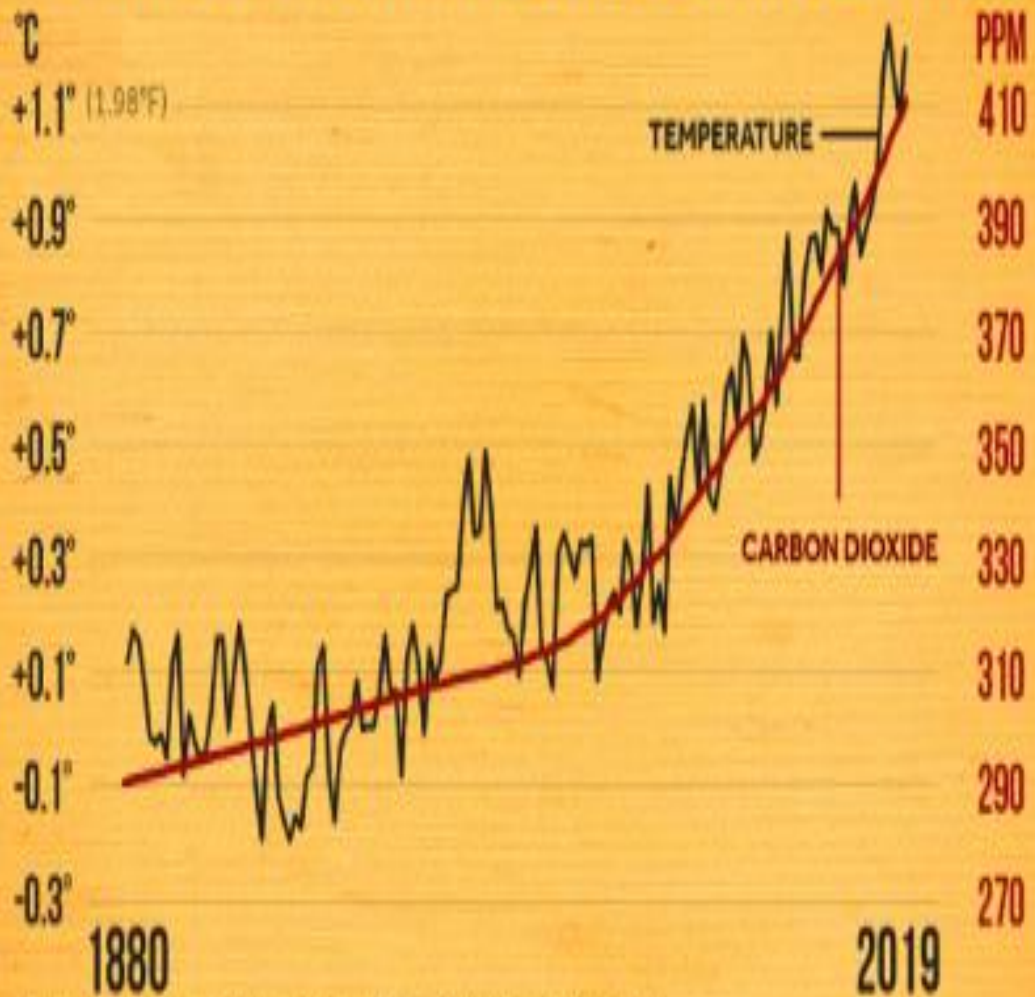
Precipitation is expected to increase in Southeastern Michigan and the middle of the state to about 2.25 inches between 2040 and 2059 with increased emissions.

While Southeastern Michigan will face continued potential flooding events, the data prediction also shows that the western side of the state will have a decrease in precipitation.

A **heat island**, is an area where heat is intensified due to structures, such as buildings and roads, that absorb and re-emit the sun's heat far more than natural landscapes, such as forests and bodies of water.

Temperatures in such heat islands can be 1 to 7 degrees higher than neighboring areas. The Detroit metropolitan area contains heat islands.

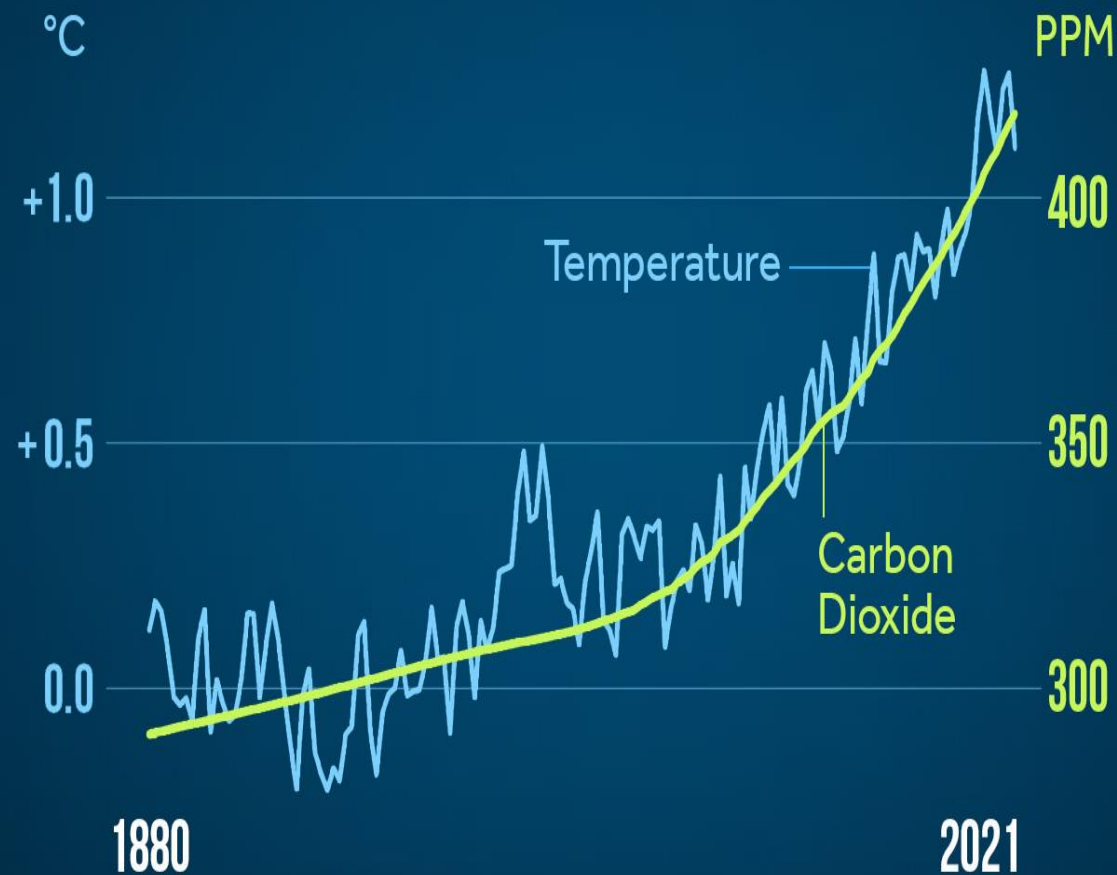
# GLOBAL TEMPERATURE & CARBON DIOXIDE



Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910)  
Global annual average carbon dioxide  
Source: NASA GISS, NOAA NCEI, ESRL

March 2022, average monthly carbon dioxide (CO<sub>2</sub>) levels reached 418 ppm and 422ppm in Dec. of 2023

# TEMPERATURE & CARBON DIOXIDE



Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910)  
Source: NASA GISS, NOAA NCEI, ESRL

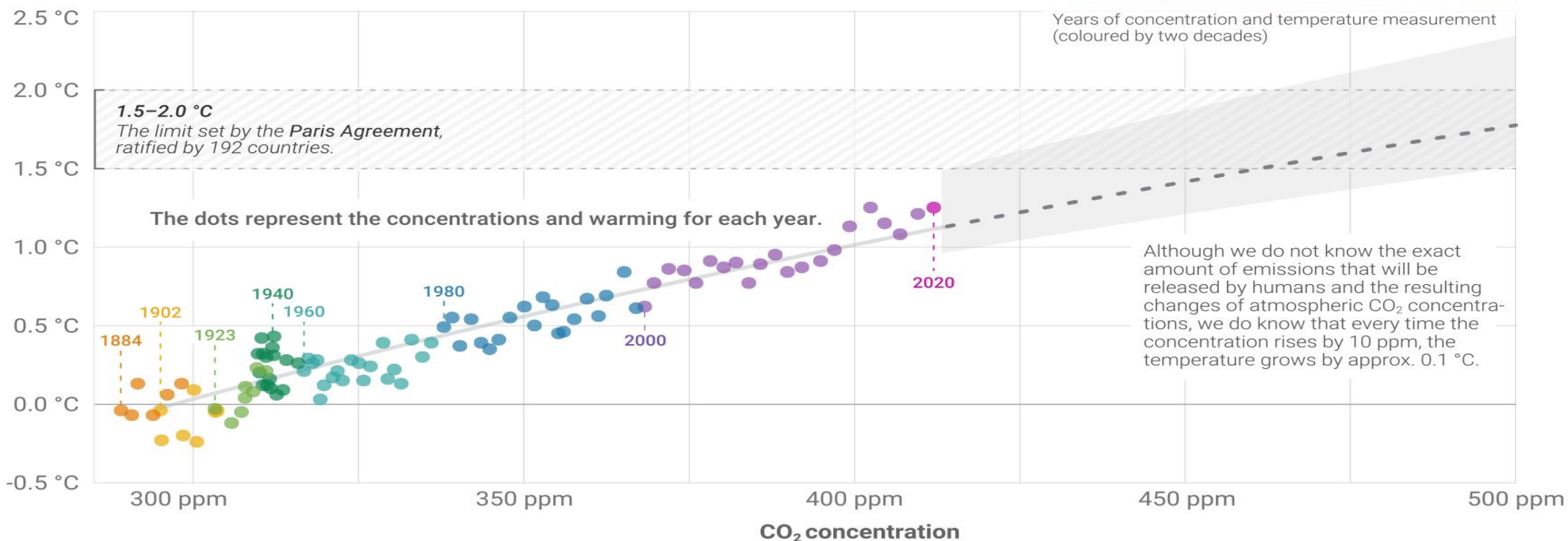


# HOW ARE CO<sub>2</sub> CONCENTRATIONS RELATED TO WARMING?

The higher the CO<sub>2</sub> concentration in the atmosphere, the higher the Earth's temperature. The levels of atmospheric CO<sub>2</sub> depend on the amount of emissions produced by humankind.

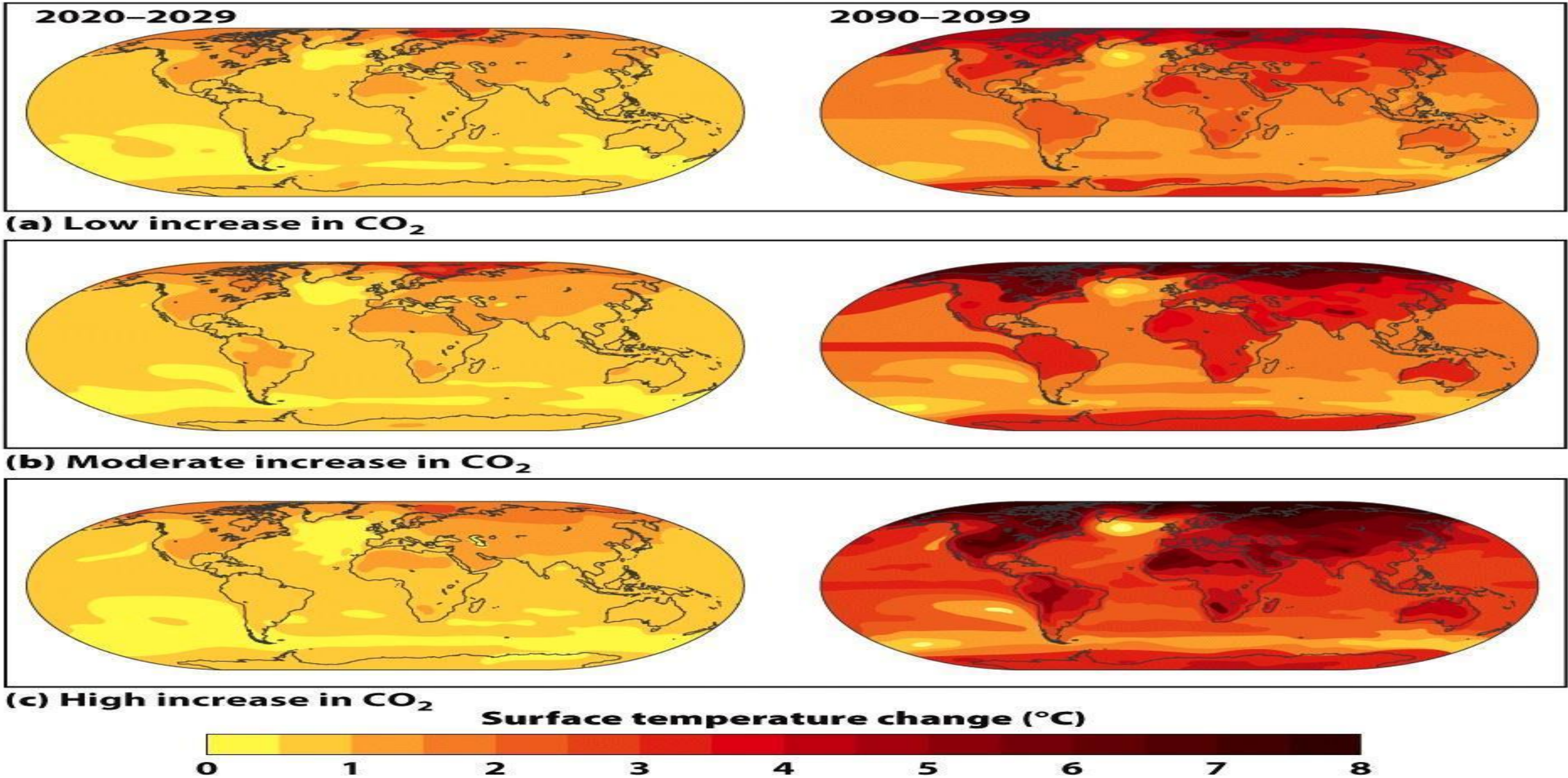
## Warming

relative to the 1850–1900 period



CO<sub>2</sub> concentration is measured in ppm (parts per million). The CO<sub>2</sub> concentration of 400 ppm means that one million of air molecules contains 400 molecules of CO<sub>2</sub>. Carbon dioxide (CO<sub>2</sub>) contributes to global warming more than any other greenhouse gas: the greenhouse effect is intensifying and 70% of this change is caused by CO<sub>2</sub>.

# Predictions of increase in global temps by 2100



**Figure 19.17**

*Environmental Science*

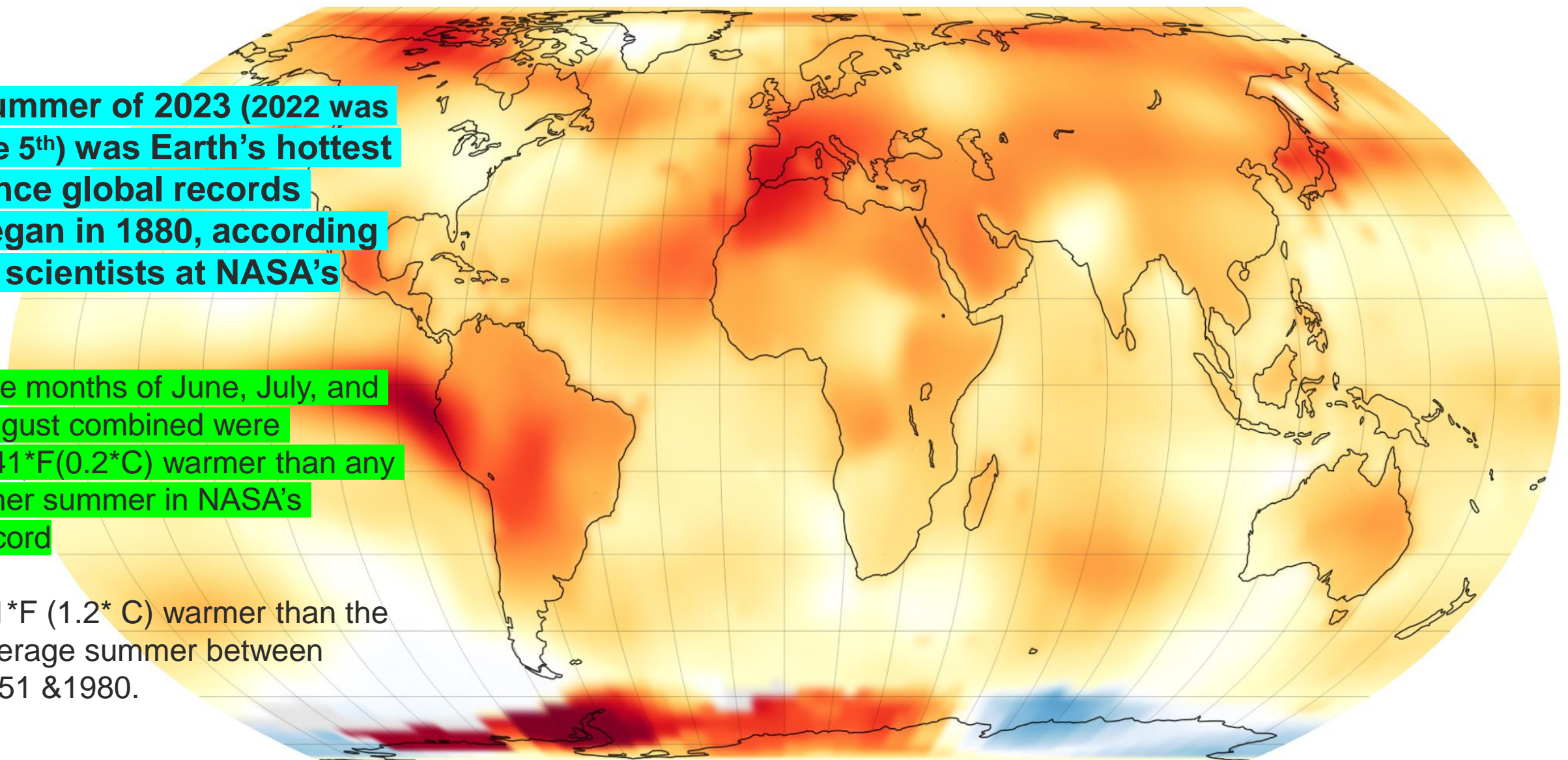
© 2012 W. H. Freeman and Company

Summer of 2023 (2022 was the 5<sup>th</sup>) was Earth's hottest since global records began in 1880, according to scientists at NASA's

The months of June, July, and August combined were 0.41°F (0.2°C) warmer than any other summer in NASA's record

2.1°F (1.2°C) warmer than the average summer between 1951 & 1980.

August alone was 2.2°F (1.2°C) warmer than the average.

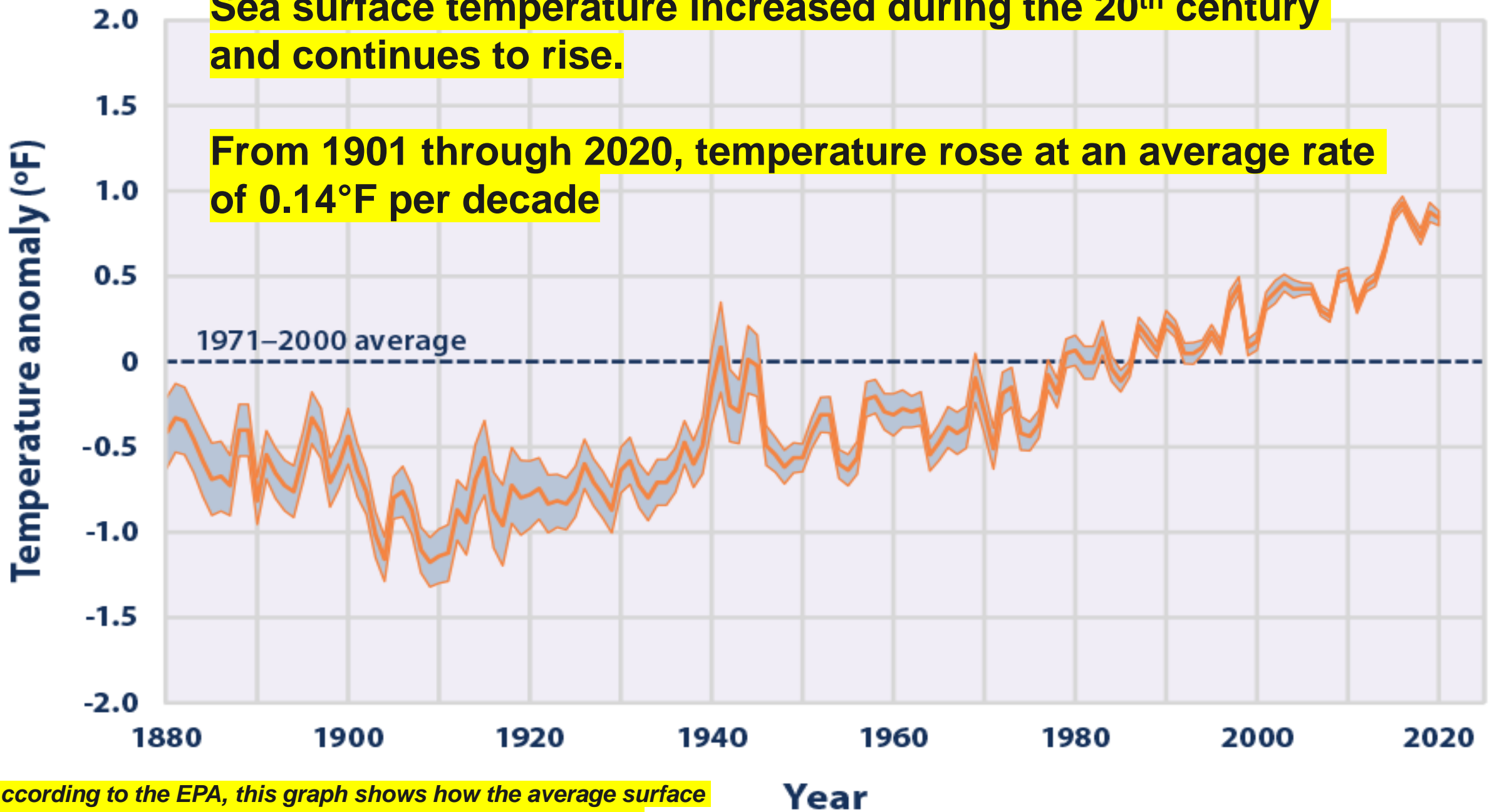


June, July, and August Global Temperature Anomaly (°C compared to 1951-1980 average)



**Sea surface temperature increased during the 20<sup>th</sup> century and continues to rise.**

**From 1901 through 2020, temperature rose at an average rate of 0.14°F per decade**



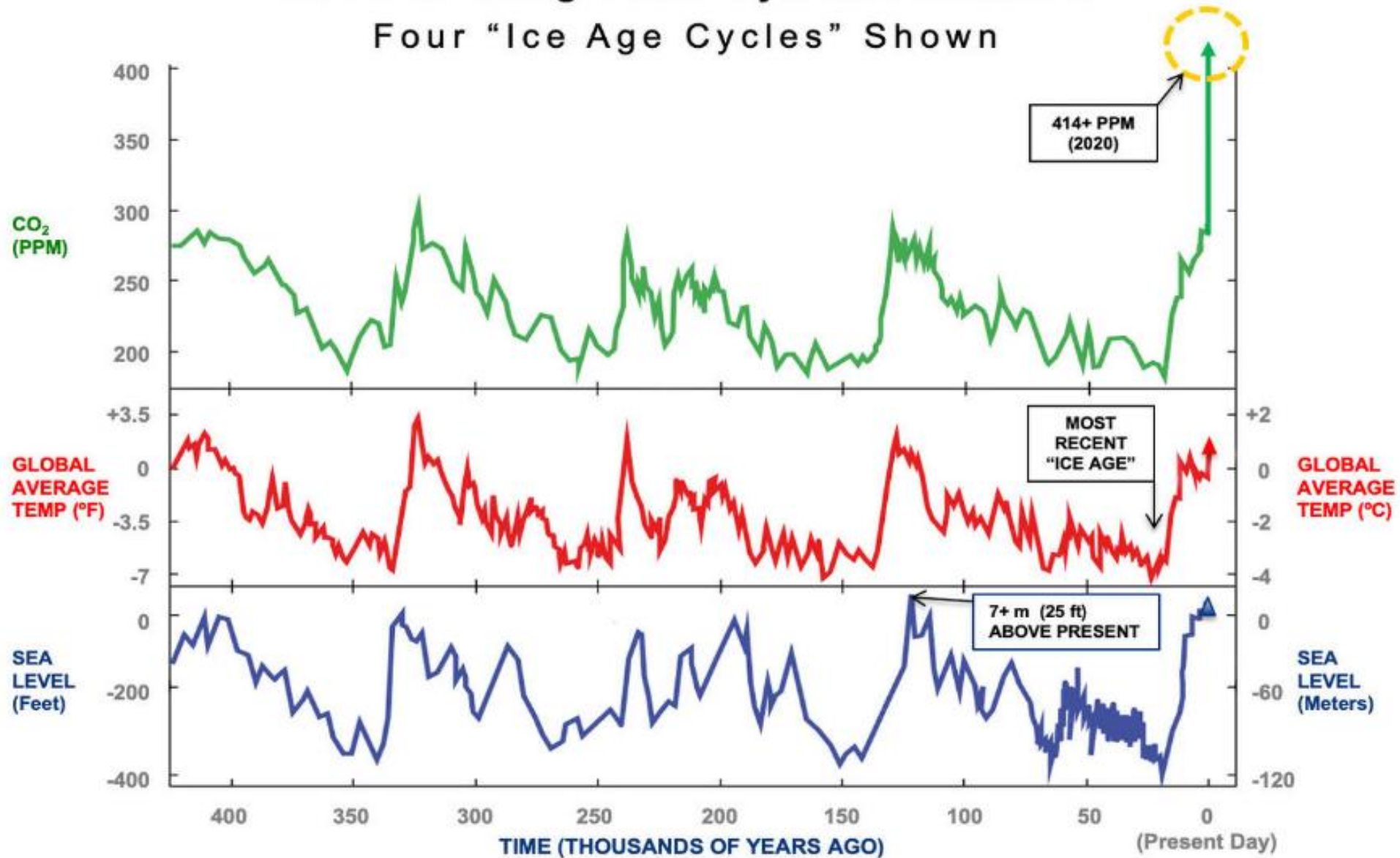
**According to the EPA, this graph shows how the average surface temperature of the world's oceans has changed since 1880.**

**Year**

# Carbon Dioxide (CO<sub>2</sub>), Temperature, & Sea Level

Move in Long-Term Synchronization

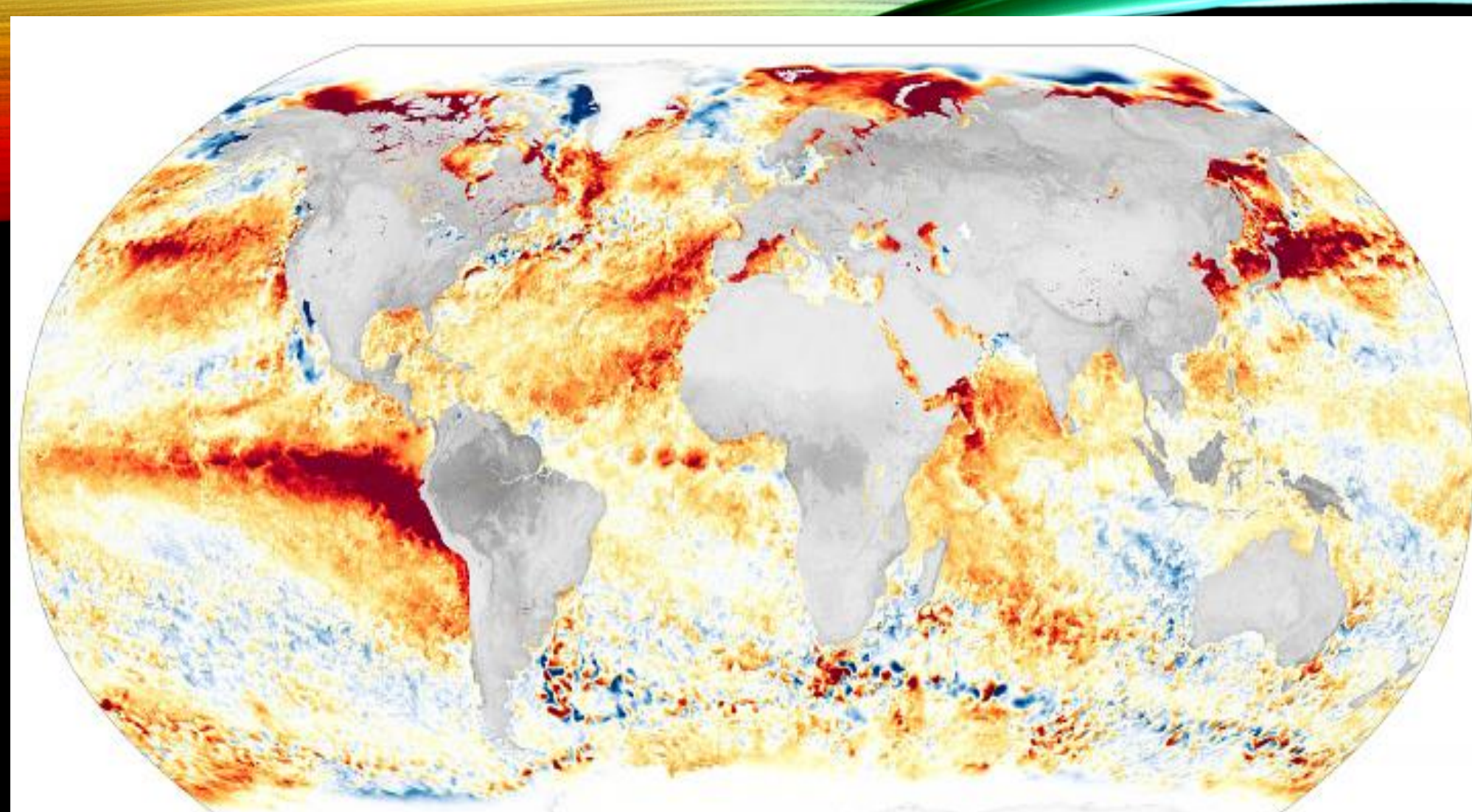
Four "Ice Age Cycles" Shown



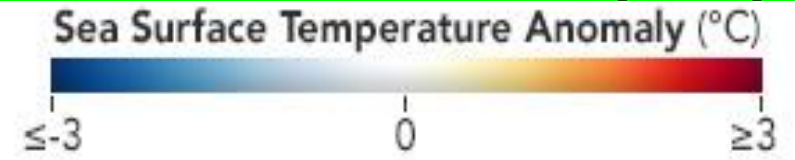
Adapted from Drs. James E. Hansen & Makiko H. Sato / csas.earth.columbia.edu

"Over the long term, we're seeing more warmer sea surface temperatures and heat islands pretty much everywhere," NASA's Goddard Institute for Space Studies.

"That long-term trend is almost entirely attributable to human forcing—the fact that we've put such a huge amount of greenhouse gas in the atmosphere since the start of the industrial era."



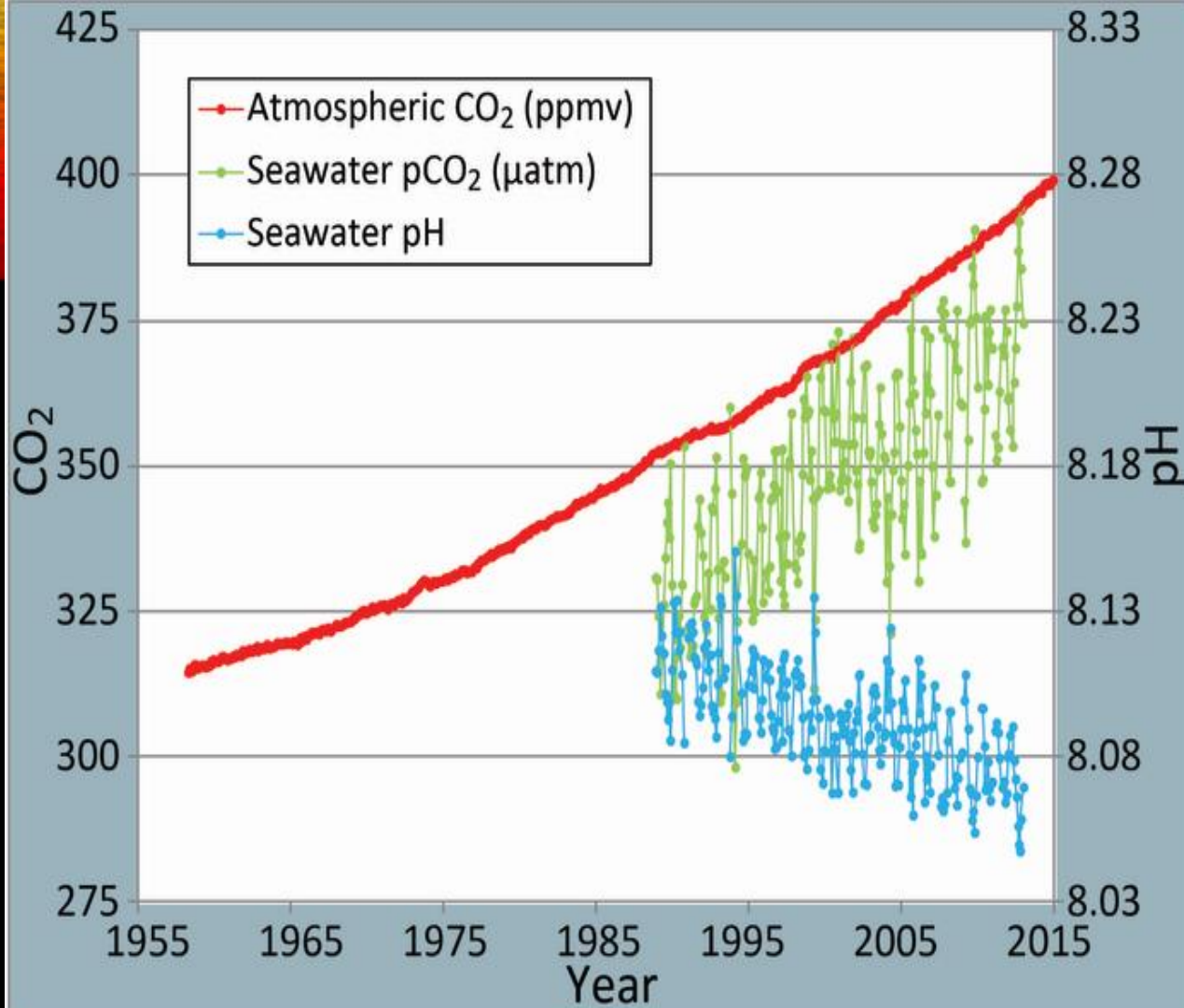
The map above shows sea surface temperature anomalies on August 21, 2023, when many areas were more than 3°C (5.4°F) warmer than normal.



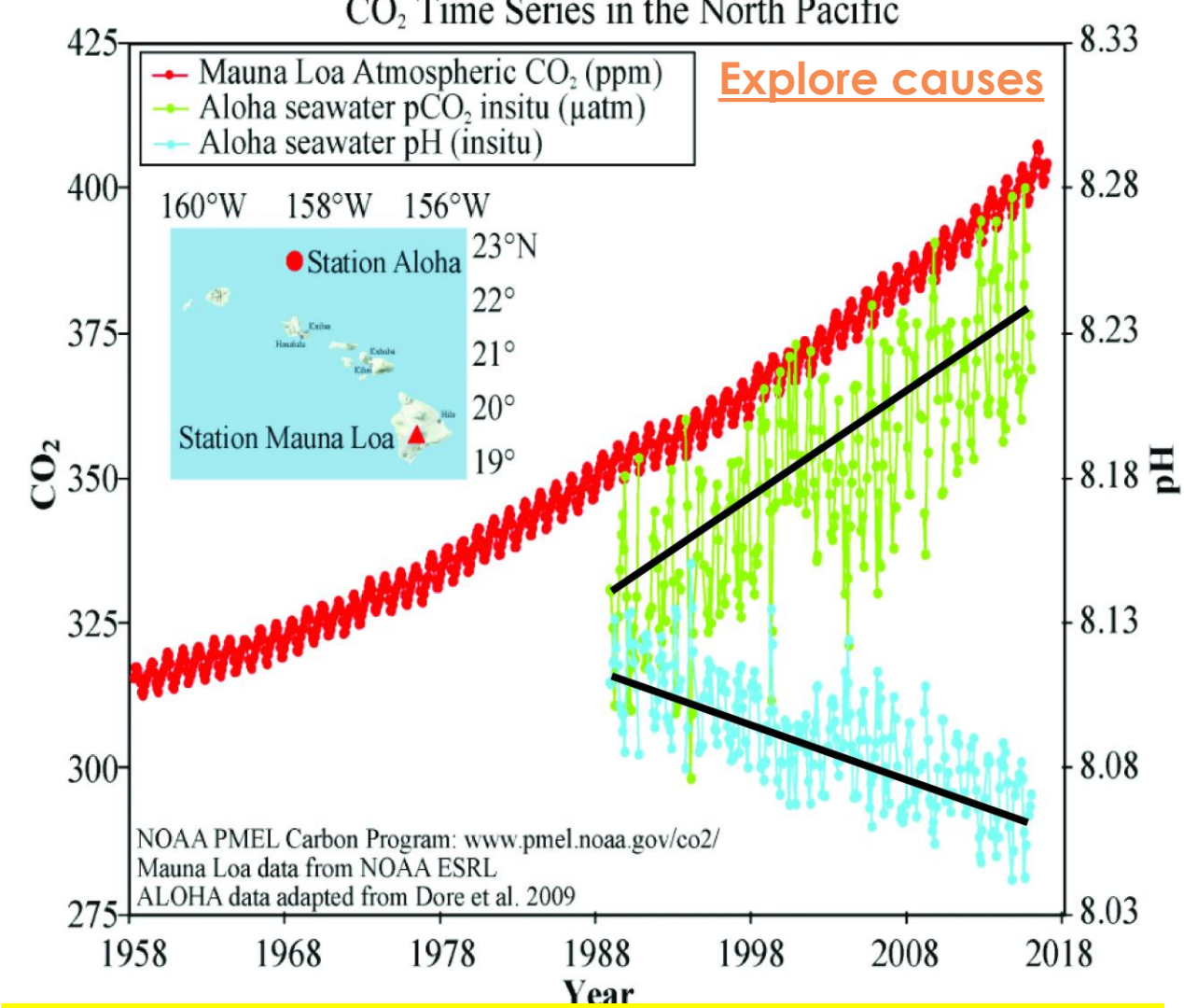
In March and April 2023, some earth scientists began to point out that average sea surface temperatures had surpassed the highest levels seen in a key data record maintained by NOAA.

Months later, they remain at record levels, with global sea surface temps 0.99°C (1.78°F) above average in July.

That was the fourth consecutive month they were at record levels.



This graph shows the correlation between rising levels of carbon dioxide (CO<sub>2</sub>) in the atmosphere at Mauna Loa with rising CO<sub>2</sub> levels in the nearby ocean at Station Aloha. As more CO<sub>2</sub> accumulates in the ocean, the pH of the ocean decreases. (modified after R. A. Feely, Bulletin of the American Meteorological Society, July 2008).



Scientists state that the **oceans have absorbed about 30% of all CO<sub>2</sub> that has been put into the atmosphere by humans since the Industrial Revolution.** Scientists have concluded that this has led to a **26% increase in the acidity of our oceans.** The rate at which the **oceans are becoming more acidic** is totally unprecedented, and research indicates that **ocean acidification (acid causes more stress to species making it harder to build their skeletons and shells)** is happening faster today than at any time in the last 300 million years!

# Global Warming Causes and Effects

**Gradual** (long term since pre-industrial period ~1850) heating of Earth's surface, oceans and atmosphere – climate system (primarily caused by human activities)

## Causes

- Rapid industrialization
- Energy use
- Agricultural practices
- Deforestation
- Consumer practices
- Livestock
- Transport
- Resource extraction
- Pollution



## Effects

- Rising temperatures
- Rising sea levels
- Unpredictable weather patterns
- Increase in extreme weather events
- Land degradation
- Loss of wildlife and biodiversity

## What are the Social Impacts of Global Warming



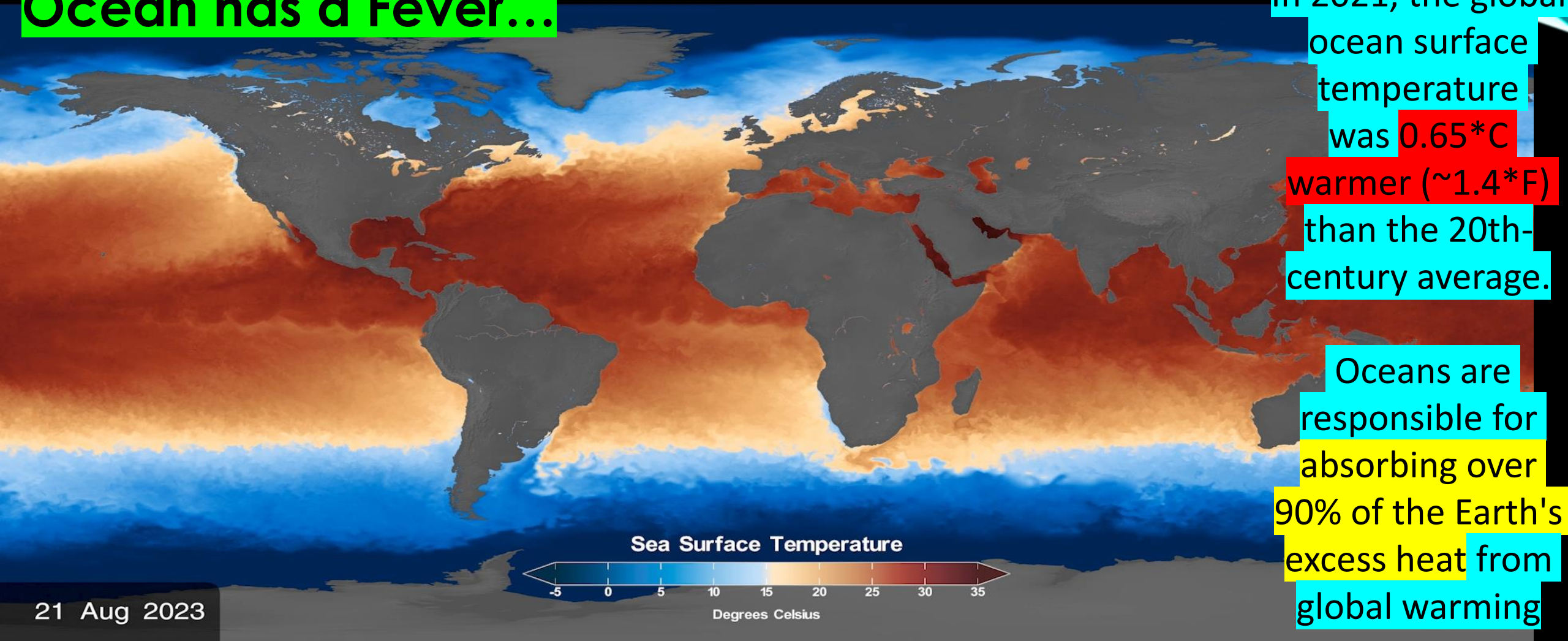
Displaced people. Poverty. Loss of livelihood. Hunger. Malnutrition. Increased risk of diseases. Global food and water shortages.



# Consequences to the Environment Because of Global Warming

- Melting
  - polar ice caps, Greenland and Antarctica
  - many glaciers around the world (*could reduce seasonal water drinking supplies*)
  - permafrost
- Rising of sea levels due to the melting of glaciers and ice sheets and as water warms it expands
- Heat waves and Cold spells
- Change in precipitation patterns
- Increase in storm intensity
- Shift in ocean currents

# Ocean has a Fever...



21 Aug 2023

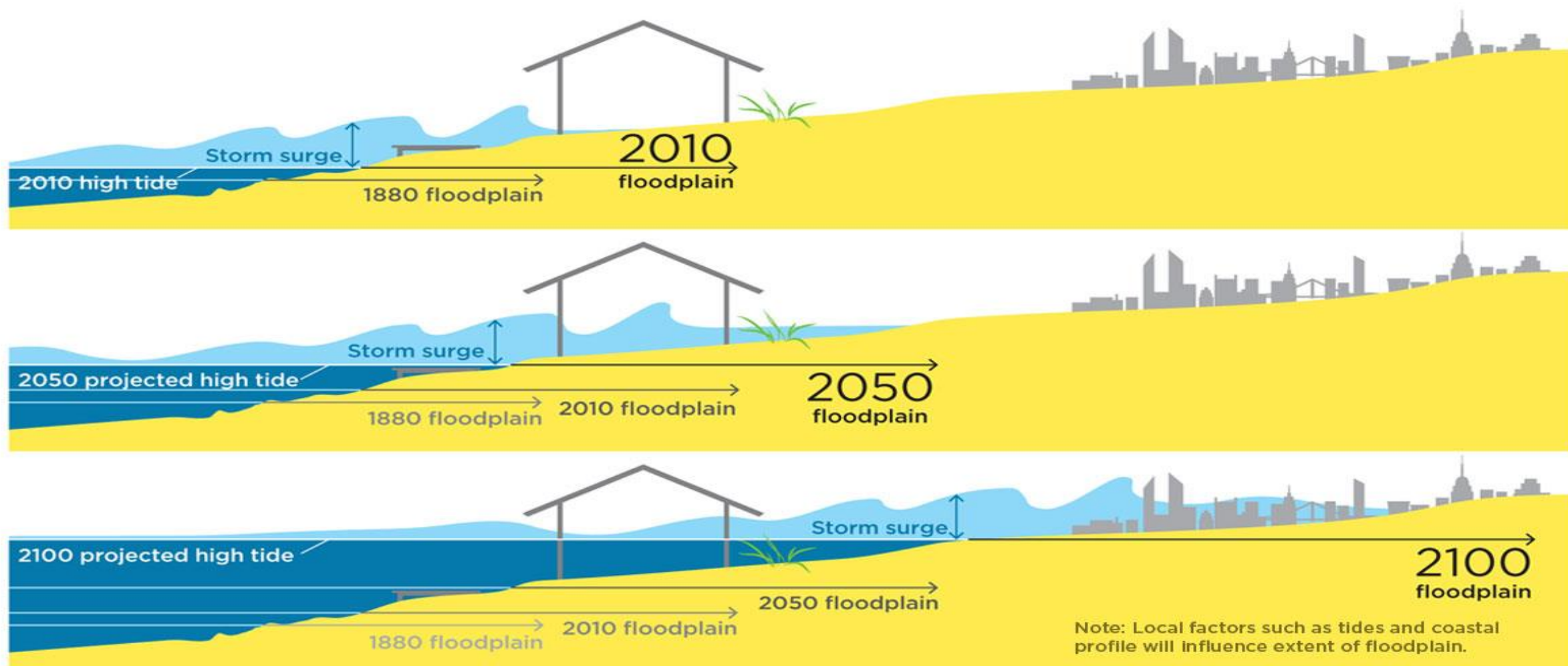
In 2021, the global ocean surface temperature was  $0.65^{\circ}\text{C}$  warmer ( $\sim 1.4^{\circ}\text{F}$ ) than the 20th-century average.

Oceans are responsible for absorbing over 90% of the Earth's excess heat from global warming

The unusually warm water in the equatorial Pacific associated with the developing El Niño after three consecutive years of La Niña is expected to weaken trade winds in ways that reinforce and amplify the warming of surface waters, **fueling the El Niño further.**

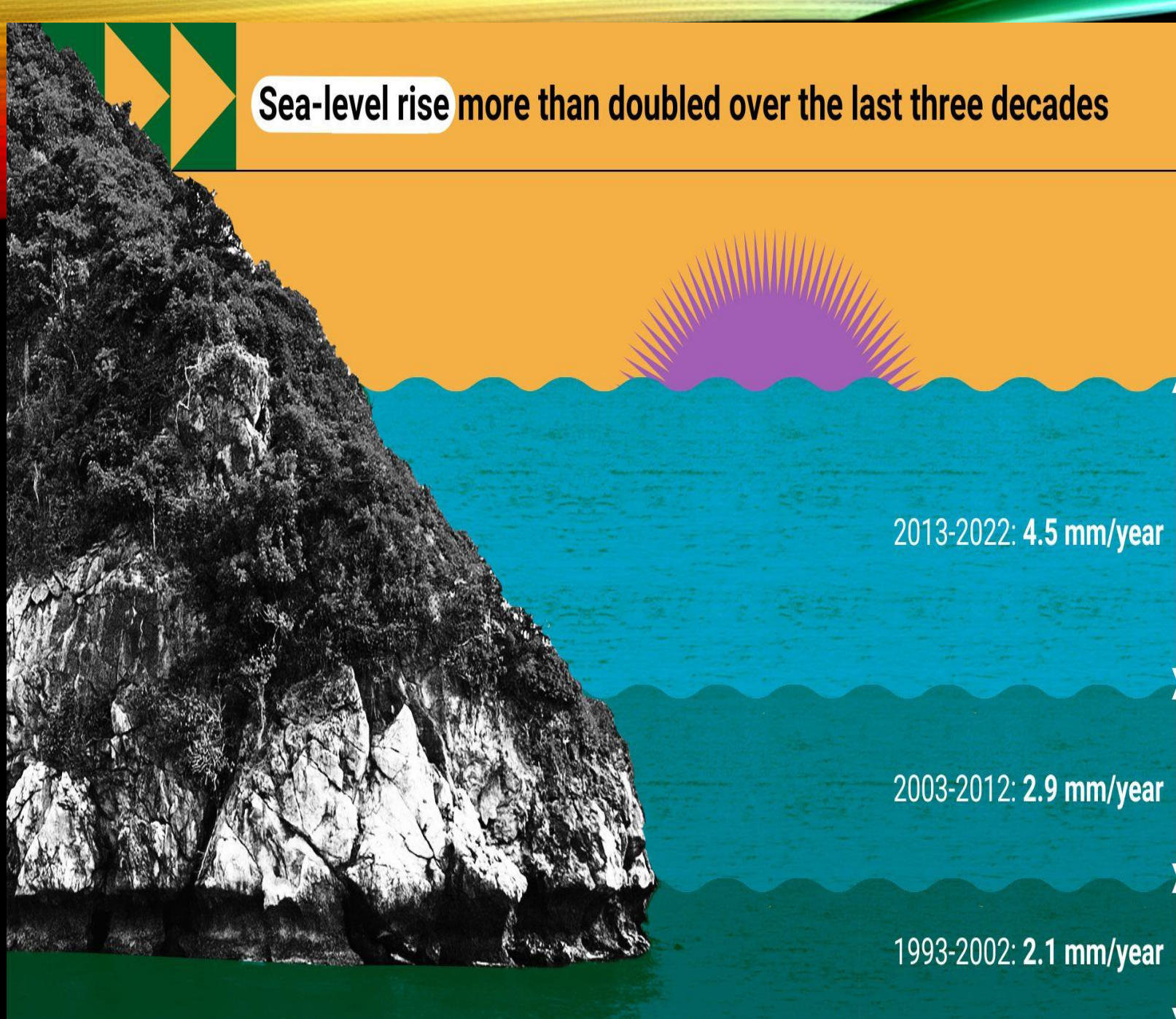
**Decades of gradual warming due to human-caused climate change and an El Niño in the Pacific Ocean nudged global sea surface temperatures to record levels in 2023.**

FIGURE 3. Storm Surge and High Tides Magnify the Risks of Local Sea Level Rise



Sea level sets a baseline for storm surge—the potentially destructive rise in sea height that occurs during a coastal storm. As local sea level rises, so does that baseline, allowing coastal storm surges to penetrate farther inland. With higher global sea levels in 2050 and 2100, areas much farther inland would be at risk of being flooded. The extent of local flooding also depends on factors like tides, natural and artificial barriers, and the contours of coastal land.

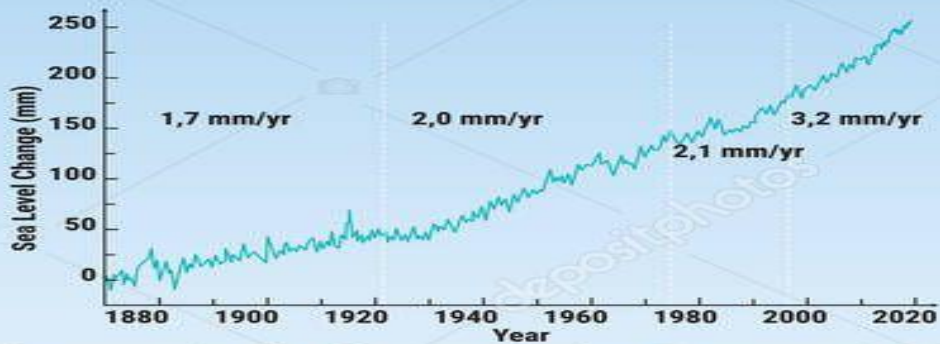
Sea-level rise more than doubled over the last three decades



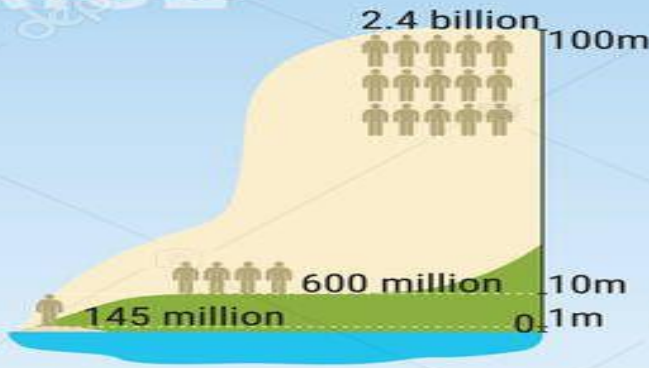
World Meteorological Organization shows that global mean sea-level reached a new record high in 2021, rising an average of 4.5 millimeter per year over the period 2013 to 2021.

NASA 101

# SEA LEVEL RISE



Globally averaged sea level has risen by about 25 cm since the 1800s. The annual rate increased to 3.3 millimeters per year



Nearly 145/600 million/2.4 billion people live within 1m/10m/100m of the coast

## CONSEQUENCES



The disappearance of some low-lying islands



Submergence and increases flooding of coastal land

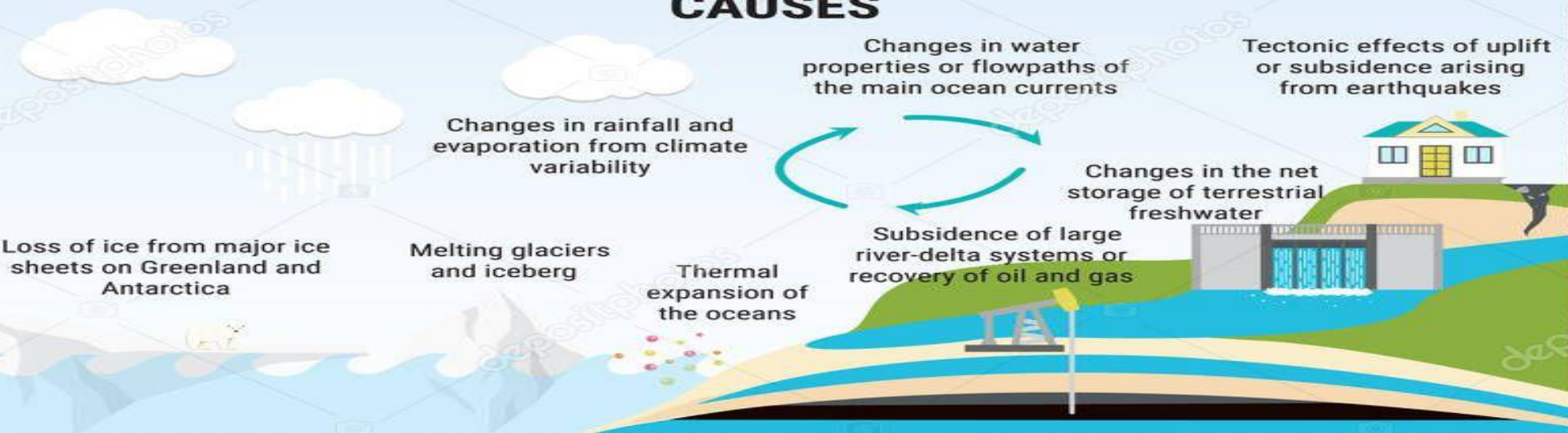


Increased erosion, and habitat destruction in coastal areas



Saltwater intrusion of surface and subsurface waters

## CAUSES



## ADAPTATION STRATEGIES

**AVOID**  
Restricting construction in at-risk areas

**ACCOMMODATION**  
Upgrading existing property

**PROTECTION**  
Improving flood defenses

**RETREAT**  
Preparing for planned relocations

# *MONTREAL PROTOCOL, 1987*

- Every country in the world eventually ratified the treaty, which required them to stop producing substances that damage the ozone layer, such as chlorofluorocarbons (CFCs)...not intended to stop climate change!
  - protocol has succeeded in eliminating nearly 99 percent of these ozone-depleting substances.
- In 2016, parties agreed via the **Kigali Amendment** to also **reduce their production of hydrofluorocarbons (HFCs)**, powerful greenhouse gases that contribute to climate change.

# The Kyoto Protocol 1997

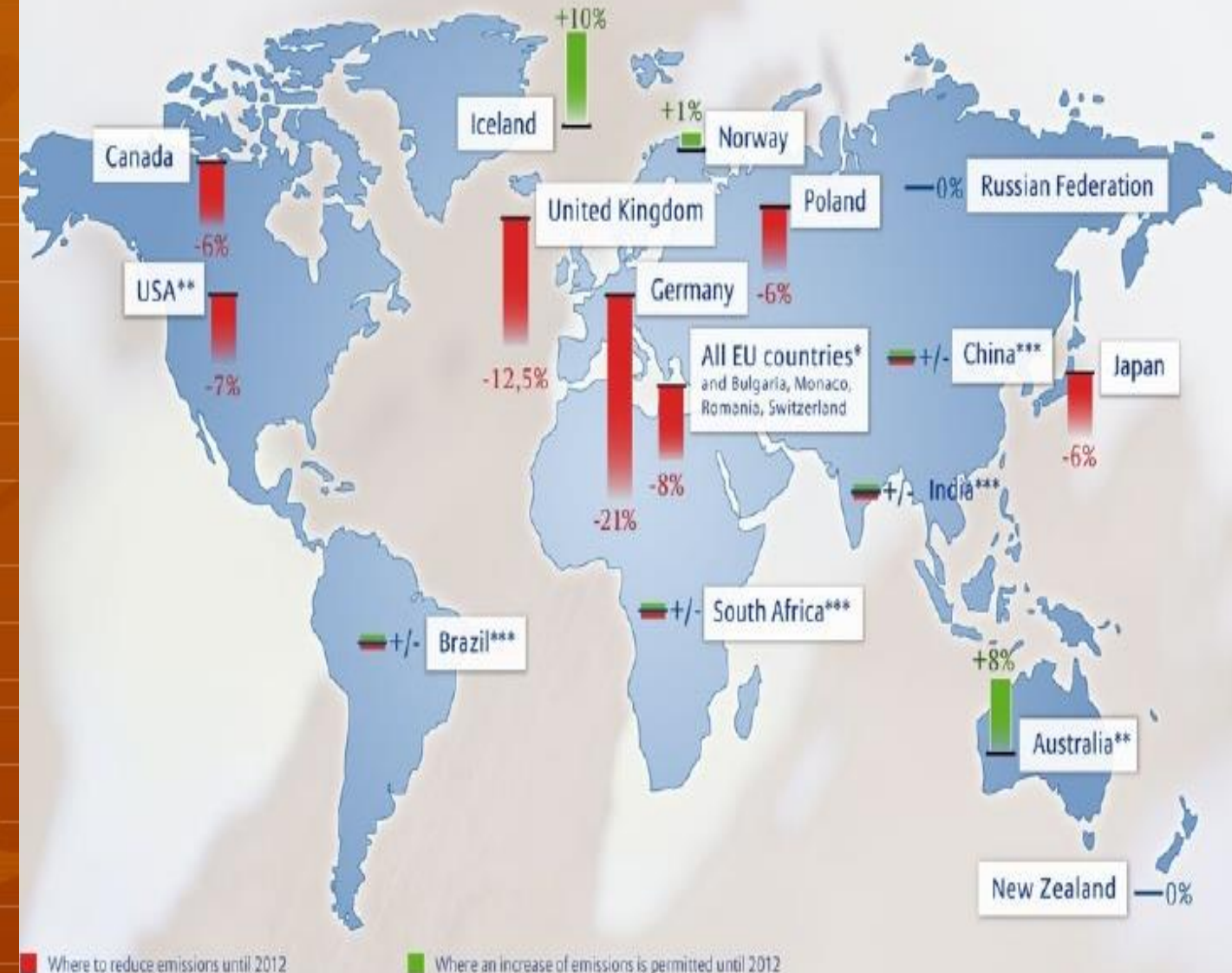
- was the first legally binding climate treaty... representatives of the nations of the world went to Kyoto, Japan to discuss how best to control the emissions contributing to global warming. Delegates from more than 150 countries signed.
- The agreement was that emissions of greenhouse gases from all industrialized countries will be reduced to 5.2% below their 1990 levels by 2012

# UK Government Response

- Set targets to reduce emissions by 30% by 2020 and 60% by 2050
- Pass laws on carbon reduction targets
- Invest in green technology creating 100,000 new jobs
- Create a \$20 billion World Bank Fund to help poorer countries

CO<sub>2</sub> Reduction

## Emission Targets for Selected Countries (Kyoto Protocol)



\* The EU countries have redistributed their reductions commitments in a so-called burden-sharing commitment.

\*\* The USA and Australia have not ratified the protocol.

\*\*\* No restrictions under the Kyoto Protocol



# Problems

- Some delayed in signing up to Kyoto such as Russia who signed in 2004
- Some still have not. Australia the world's 2<sup>nd</sup> largest polluter per capita.
- USA initially signed but then withdrew in 2001 following GW Bush's election (USA emit 25% of world emissions)

Treaty did not compel developing countries, including major carbon emitters China and India, to take action. The United States signed the agreement in 1998 but never ratified it and later withdrew its signature.

The United States hasn't become part of the agreement because it considers a problem the fact that several major developing nations, including India and China, are not required to reduce emissions under the agreement.

## AS OF JUNE OF 2020...

- The **Kyoto Protocol**, which took effect in 2005, **sets binding emission reduction targets for developed countries**. Its first commitment period ran from 2008-2012 and set an average reduction target of 5% compared to 1990 levels.
- During this time, the **emissions of the 37 developed countries that had reduction targets declined by more than 22%** compared to 1990, far exceeding the initial target of 5% compared to 1990 = **SUCCESSFUL!!**

The Kyoto Protocol showed that it was possible to strike a global agreement on climate and that the world community could build a consensus on climate goals and even fulfill them!!

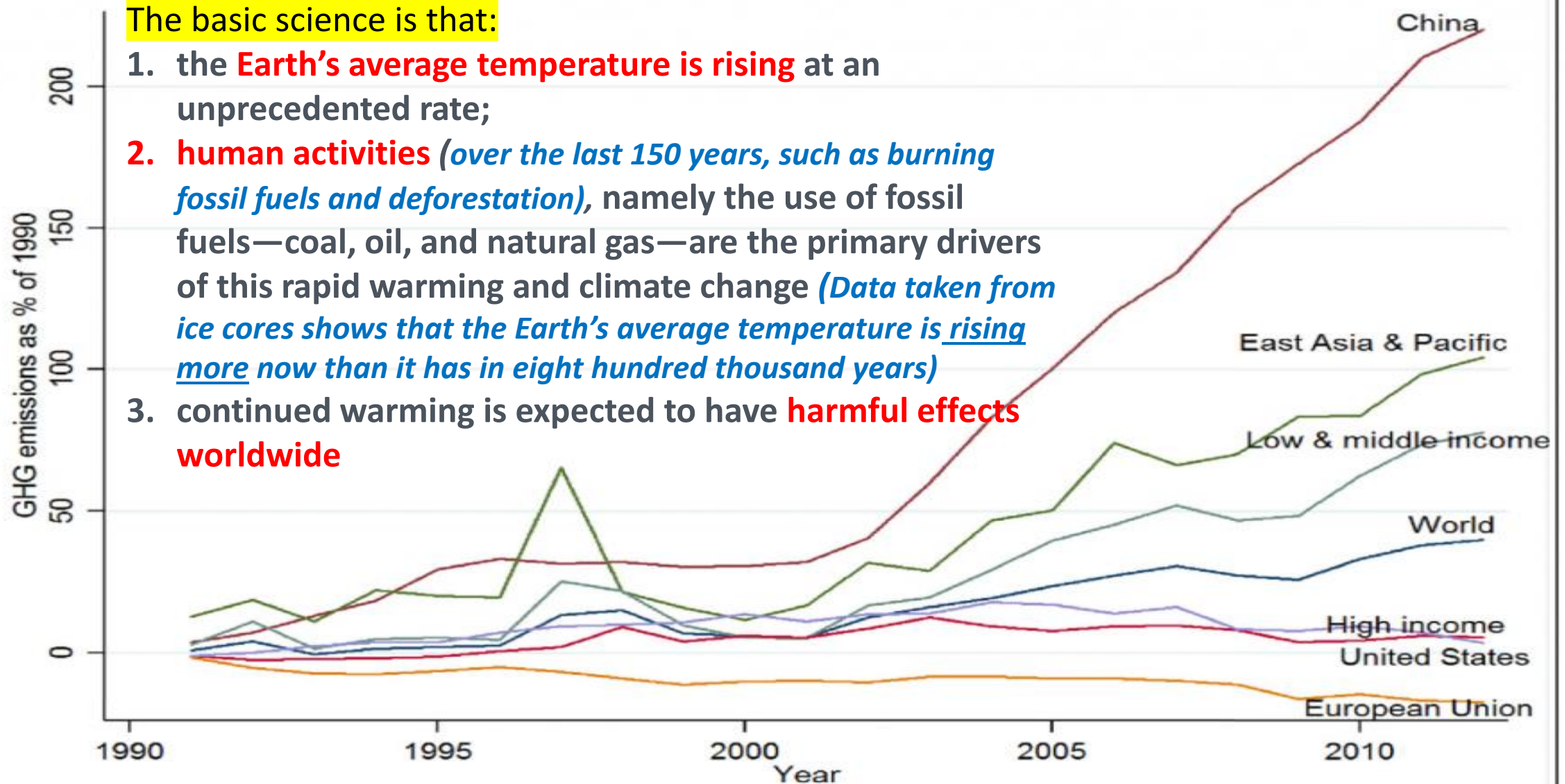
## 2022 SAW RECORD-HIGH GREENHOUSE GASES, SEA LEVELS AND OCEAN HEAT

- US is emitting fewer and fewer greenhouse gases every year while **India and China are doubling emissions** every couple of years.
- China produces 2x the greenhouse gases as the US now and it's steadily rising. India is right on the tails of the **US in 3rd place and producing more and more.**

GHG emissions as % change of 1990 emission levels. Source: 2019

The basic science is that:

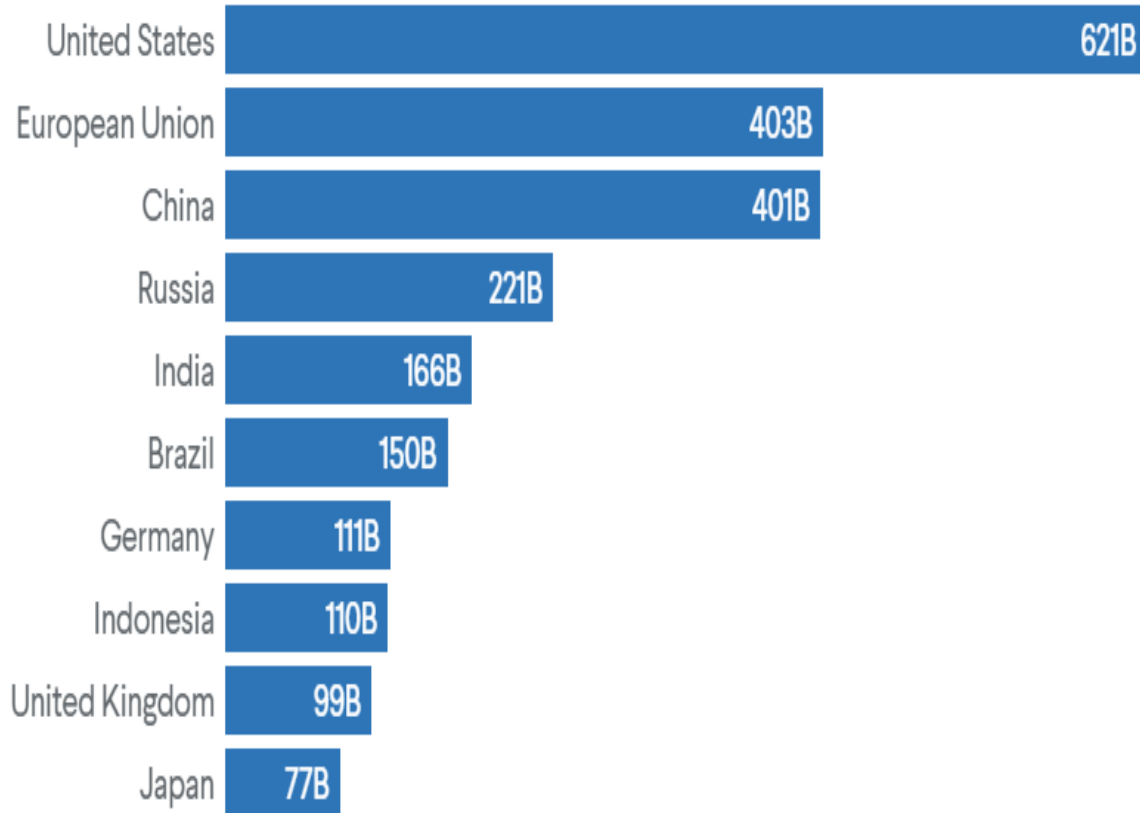
1. the **Earth's average temperature is rising** at an unprecedented rate;
2. **human activities** (*over the last 150 years, such as burning fossil fuels and deforestation*), namely the use of fossil fuels—coal, oil, and natural gas—are the primary drivers of this rapid warming and climate change (*Data taken from ice cores shows that the Earth's average temperature is rising more now than it has in eight hundred thousand years*)
3. continued warming is expected to have **harmful effects worldwide**



*Developing nations did not have emission limits imposed by the protocol.*

## Top Greenhouse Gas Emitters Since 1850

Emissions in metric tons of carbon dioxide equivalent, as of 2021

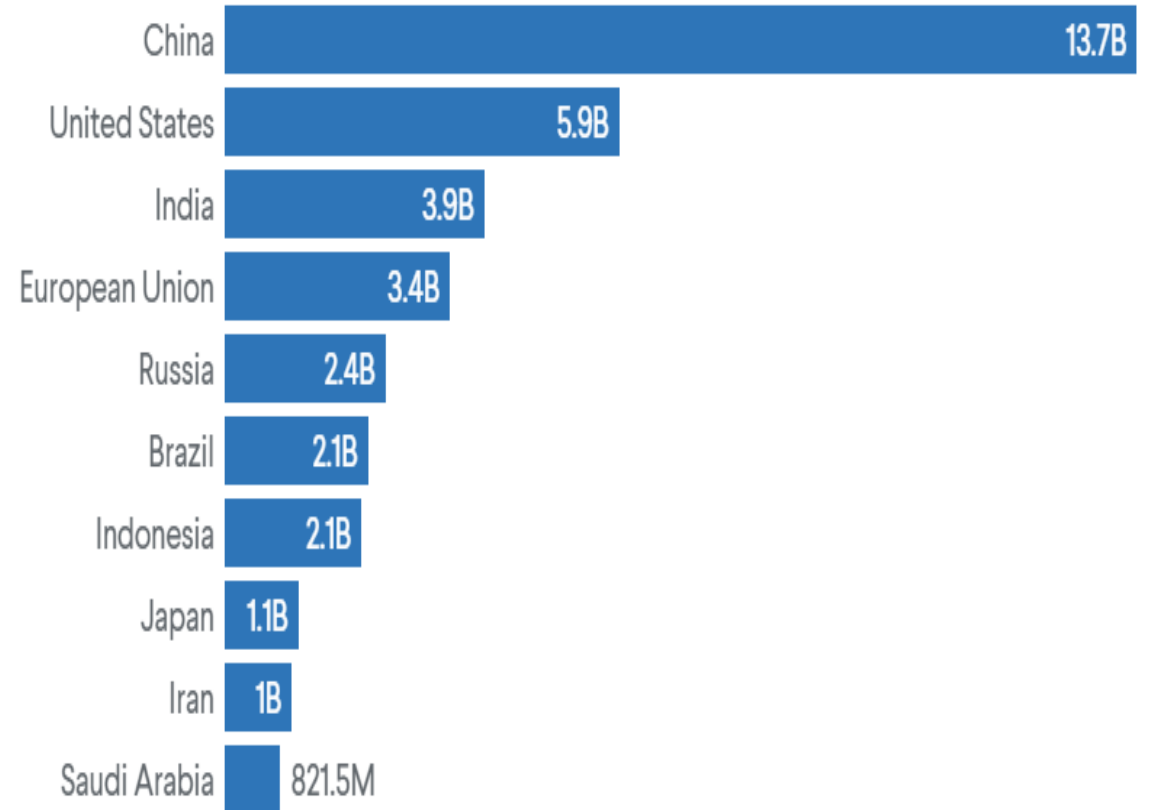


Note: EU data does not include the United Kingdom.

Source: Climate Watch.

## Top Greenhouse Gas Emitters in 2021

Emissions in metric tons of carbon dioxide equivalent



Note: EU data does not include the United Kingdom.

Source: Climate Watch.

China is one of the biggest producers—and biggest victims—of air pollution. (This smoggy skyline belongs to Shanghai.) One of the main contributors to China's emissions, factories, are vital to the nation's growth and one of the reasons the country did not sign the Kyoto Protocol.

PHOTOGRAPH BY  
NIGEL SWINN, MY  
SHOT



# PARIS AGREEMENT, 2015

- The **Kyoto protocol** focuses on **reducing emissions of greenhouse gases to 5.2% below** pre-1990 levels, whereas the **Paris agreement** focuses on preventing the global average temperature from **rising more than 2 °C (3.6°F) above pre-industrial levels and efforts to keep it below 1.5°C (2.8°F)**
  - Aims to reach global **net-zero emissions, where the amount of greenhouse gases emitted equals, the amount removed from the atmosphere**, in the second half of the century. (This is also known as being climate neutral or carbon neutral.)
- Unlike the **Kyoto Protocol**, which established top-down **legally binding emissions reduction targets** (as well as **penalties for noncompliance**) for developed nations only
- **The Paris Agreement requires that all countries—rich, poor, developed, and developing—do their part and slash greenhouse gas emissions** and has been signed by 195 countries and ratified by 190 as of January 2021.
- **Countries set their own targets, and there are no enforcement mechanisms to ensure they meet them.** Assess progress every 5 yrs, first assessment is 2023 (Carbon tax)
- The **United States**, withdrew, a move by former President Donald Trump, November 2020. However, Biden reentered the United States into the agreement during his first months in office.

## Air Quality Index



CBS NEWS

(AQI)



Live TV

WORLD >

### **Toxic smog turns India's capital "into a gas chamber"**

BY ARSHAD R. ZARGAR

UPDATED ON: NOVEMBER 4, 2022 / 9:00 AM / CBS NEWS



India's capital region of Delhi was a "gas chamber" with smog, haze and an Air Quality Index over 600, indicating a severe health risk, in many places on November 4, 2022.

In 2021, China has now officially confirmed that its commitment to tackle climate change under the terms of the Paris Agreement will see it peak its carbon dioxide (CO<sub>2</sub>) emissions before 2030 and achieve net-zero emissions before 2060.

In 2022, China would not abandon coal-fired power plants before renewables could substitute for the lost fossil fuel. But this substitution will not occur because fossil fuels generate substantially more energy than renewables.

China has repeatedly stated that it has no intention of going along with the Western push to net-zero.

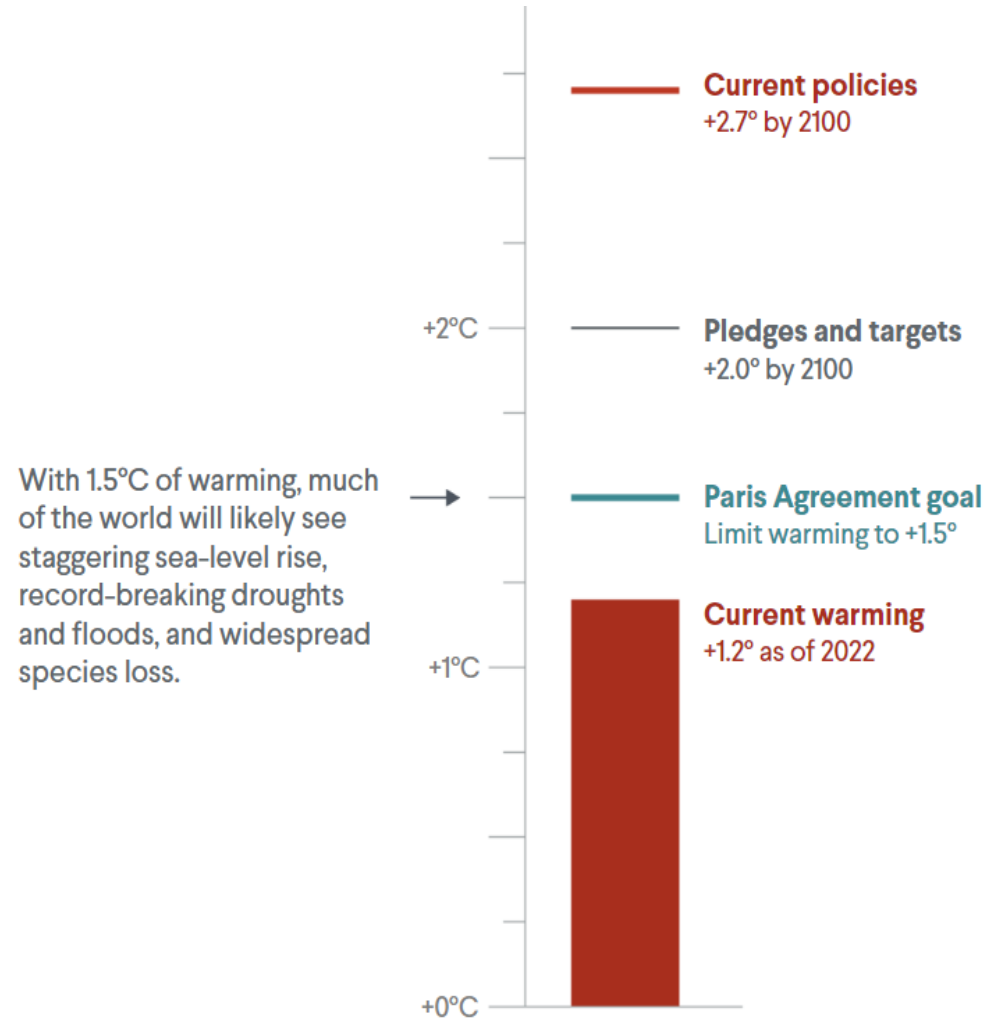


# PARIS AGREEMENT

- Since negotiating the Paris accord in 2015, many of the 195 countries that are party to the agreement have strengthened their climate commitments, including through pledges on curbing emissions and supporting countries in adapting to the effects of extreme weather, during the annual UN climate conferences known as the Conference of the Parties (COP).
- As of 2023, the absence of U.S. President Joe Biden and Chinese President Xi Jinping from this year's COP28 summit in Dubai, United Arab Emirates (UAE) have raised concerns about future climate commitments from the world's two largest greenhouse gas emitters.
- Three countries have not formally approved the agreement: Iran, Libya, and Yemen.

# Even With Pledges, World Is Not on Track to Meet Paris Agreement's Goal

Global temperature rise over preindustrial average



Note: Current policies and pledges and targets are projections. In each scenario, the temperature shown is the most likely of a range of possible outcomes. Pledges and targets include submitted and binding commitments for 2030 and beyond.

- The Intergovernmental Panel on Climate Change (IPCC), a UN body established in 1988, regularly assesses the latest climate science and produces consensus-based reports for countries.
- The Earth's average temperature has already increased approximately 1.1°C above preindustrial levels, according to a 2021 assessment... IPCC (over 200 scientists & 60 countries) predicts our Earth will reach or exceed 1.5°C (~2.8°F) of warming within the next two decade
- The first of these reports, released in September 2023, warned governments that "the world is not on track to meet the long-term goals of the Paris Agreement.

- Climate tracker

As of 2015, **U.S. energy-related carbon dioxide emissions were about 12% below 2005 levels**, according to the Department of Energy.

### Carbon emissions fell for two reasons

1. utilities began **using more Natural Gas**, which is cleaner than coal, because hydraulic fracturing increased the supply of natural gas dramatically, driving down prices.
2. **renewable energy use grew**. The Department of Energy notes all renewable energy sources – hydropower, wind, solar, biomass and geothermal – now comprise **14.9 % of total U.S. electricity generation**. Ford Motor Company...2035 electric cars
3. The best way to cut global emissions, he says, would be to have governments negotiate a universal carbon price rather than focus on country emissions limits.