Global CO_2 and Climate Change

A deeper look at the carbon dioxide cycle, greenhouse gases, and oceanic processes over the last 200 years

OCN 623 – Chemical Oceanography

Reading: Emerson & Hedges Ch. 11

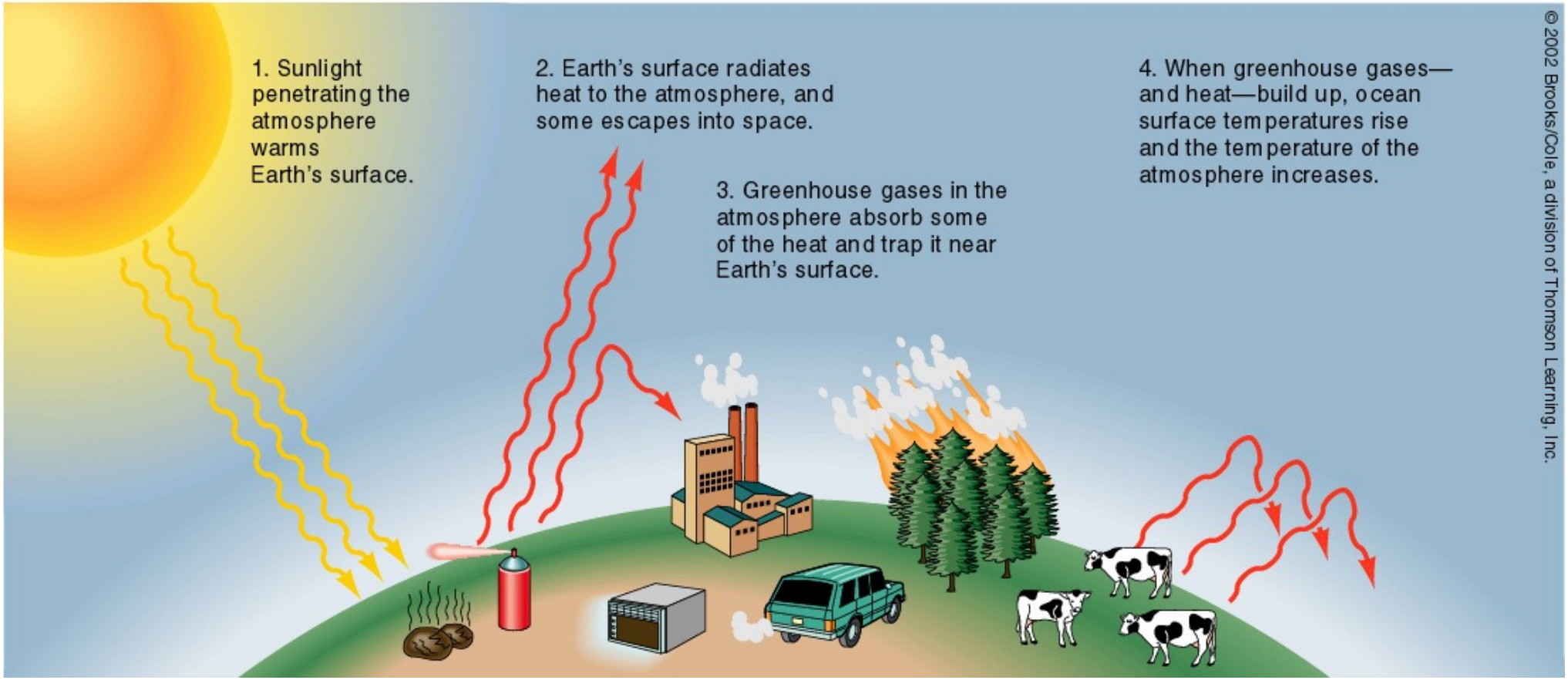
Student Learning Outcomes (SLOs)

At the completion of today's section, students should be able to:

1. Know what affects CO_2 variability in the atmosphere
2. Describe how has global carbon cycle changed over the past two centuries
3. Describe the long-term fate of anthropogenic carbon
4. Identify the role of the ocean in climate change
5. implications of climate change on society

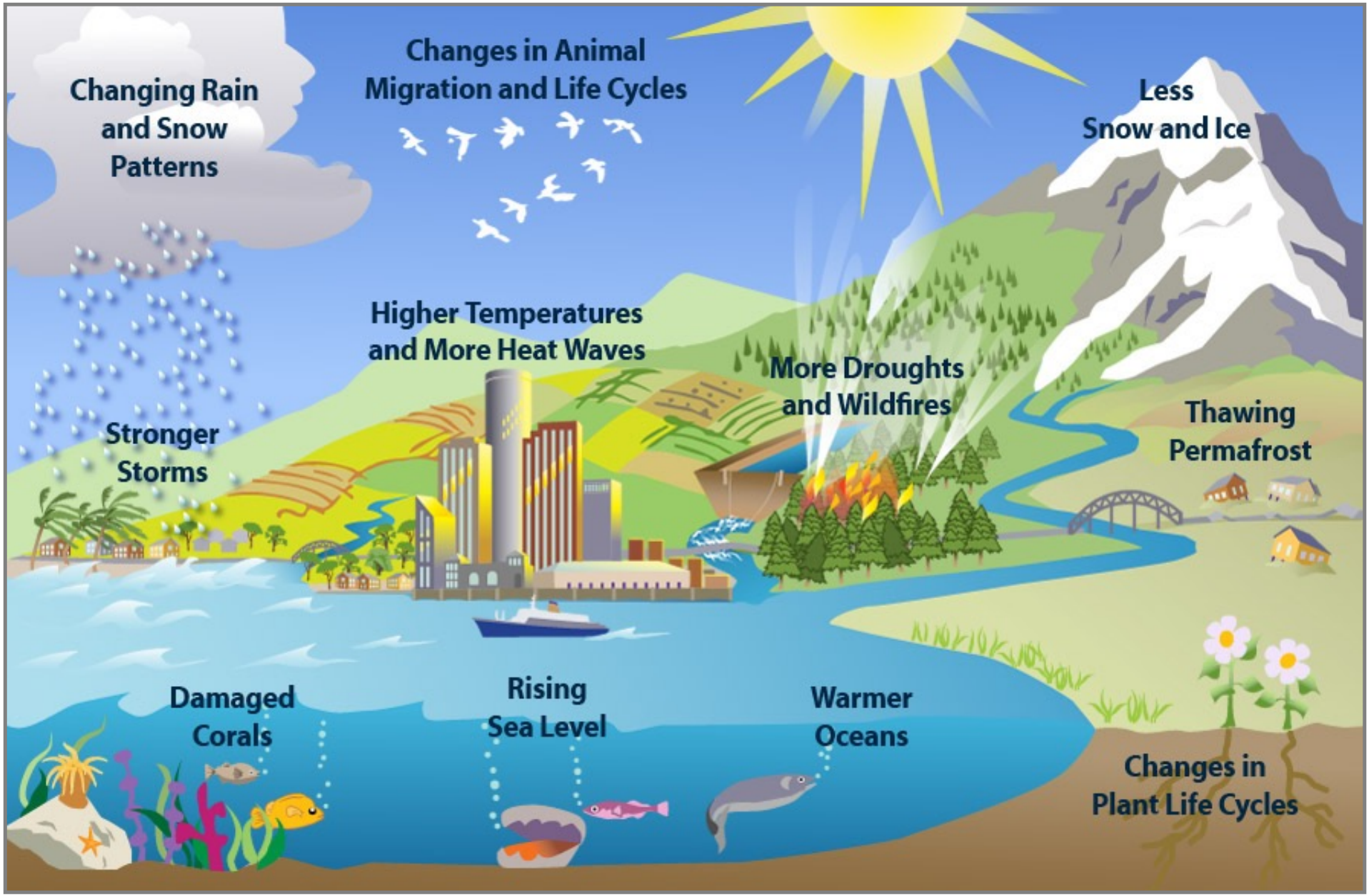
How does CO_2 affect climate?

The Earth's temperature is set by a *Radiation Balance*:
If more heat arrives from the sun than can escape as infrared (IR) rays, the Earth gets warmer.



CO_2 and other greenhouse gases absorb IR, so an increase in CO_2 causes an increase in temperature.

Climate Change versus Global Warming



Webster:

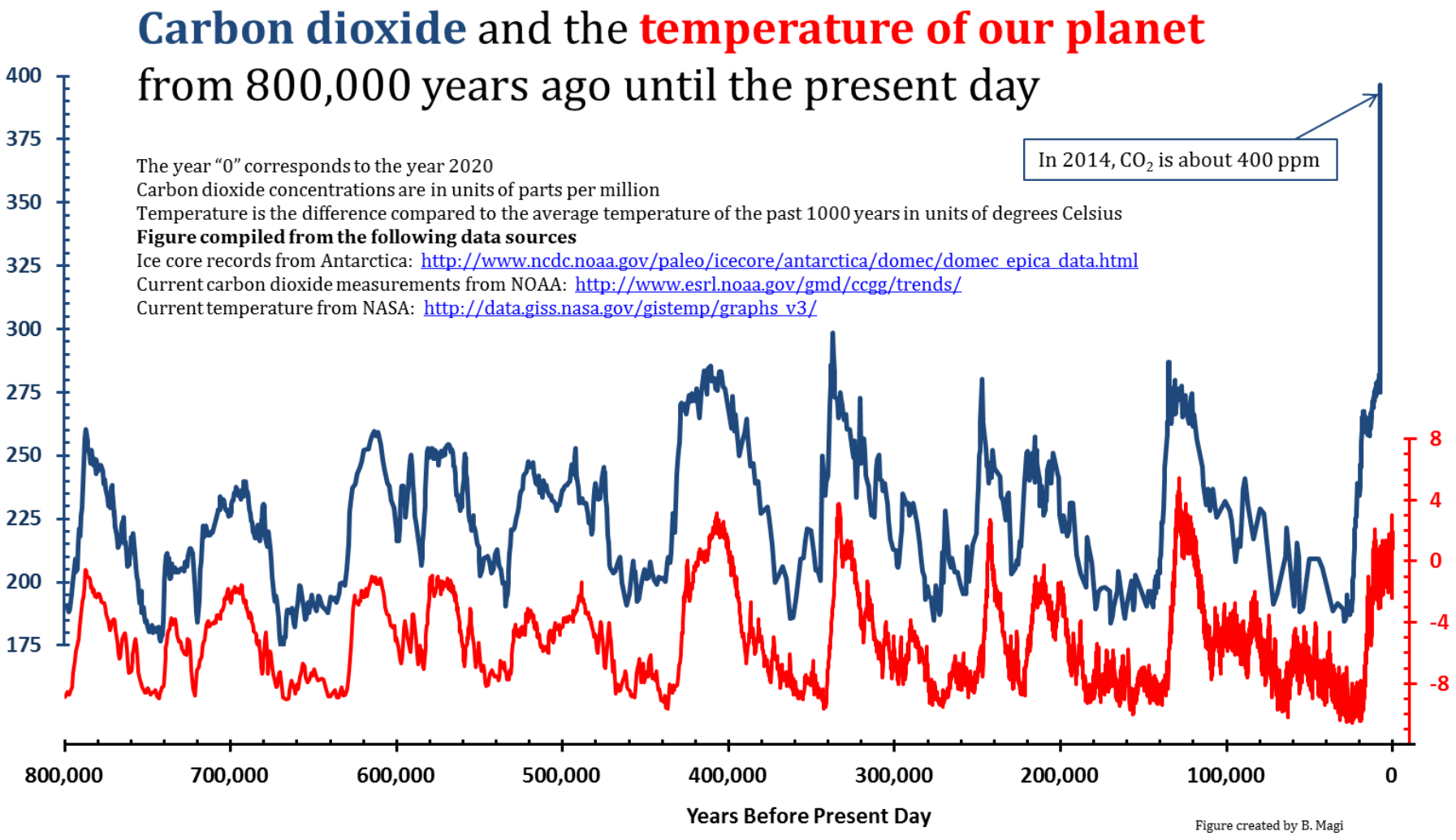
> "Climate: the average condition of the weather at a place over a period of years as exhibited by temperature, wind velocity, and precipitation"

So "climate" refers not to the weather today or this week or this year, but rather to the range of weather (including hot and cold years, wet and dry years) that is typical of each region.

- Climate change is a natural process that has happened for billions of years
- Human activities are changing the rate of climate change
- Climate change includes many more effects than warming

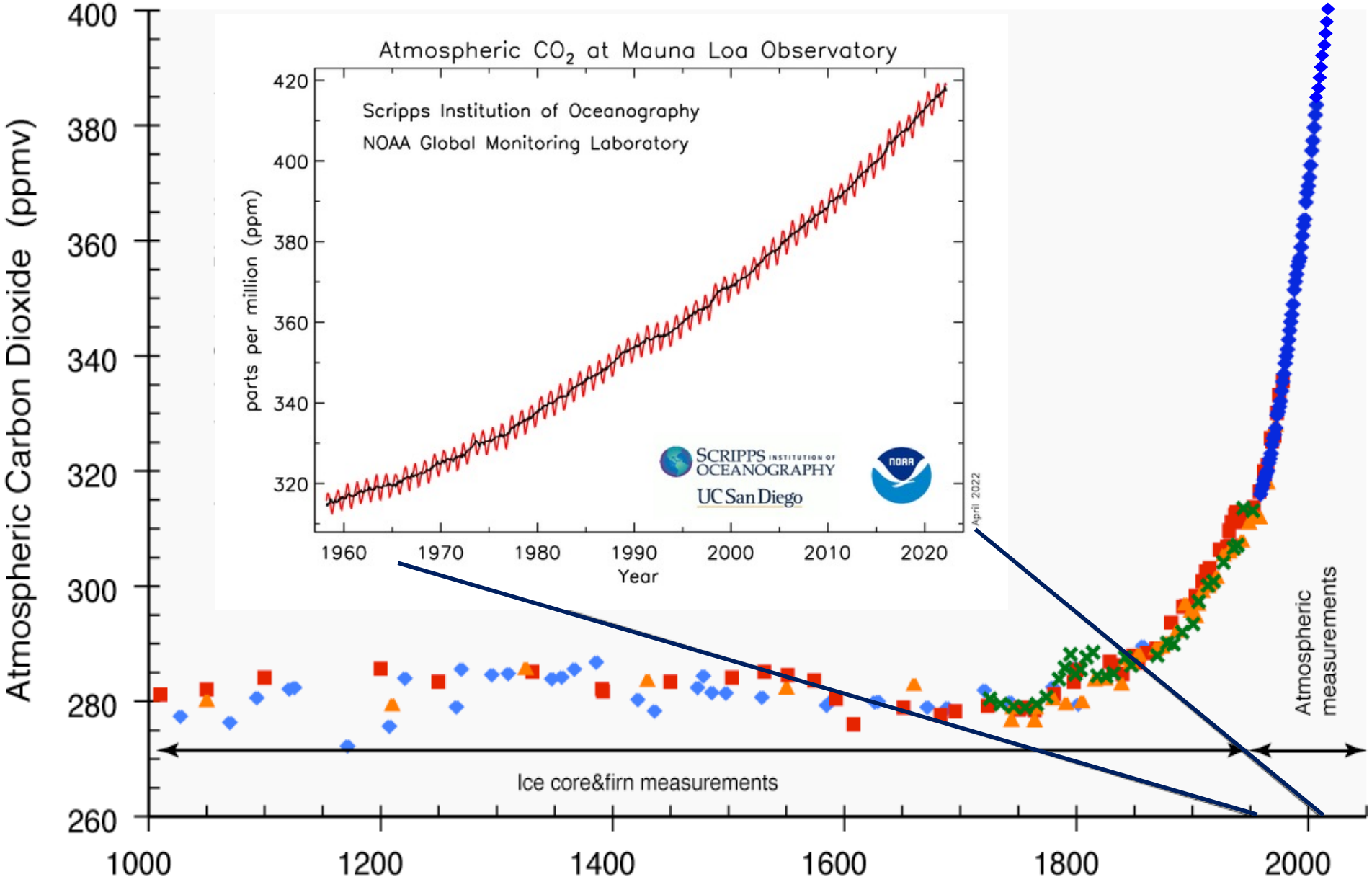
Are global temperatures linked to atmospheric CO_2 ?

Vostok Ice Core CO_2 Concentration and Temperature Variation Record



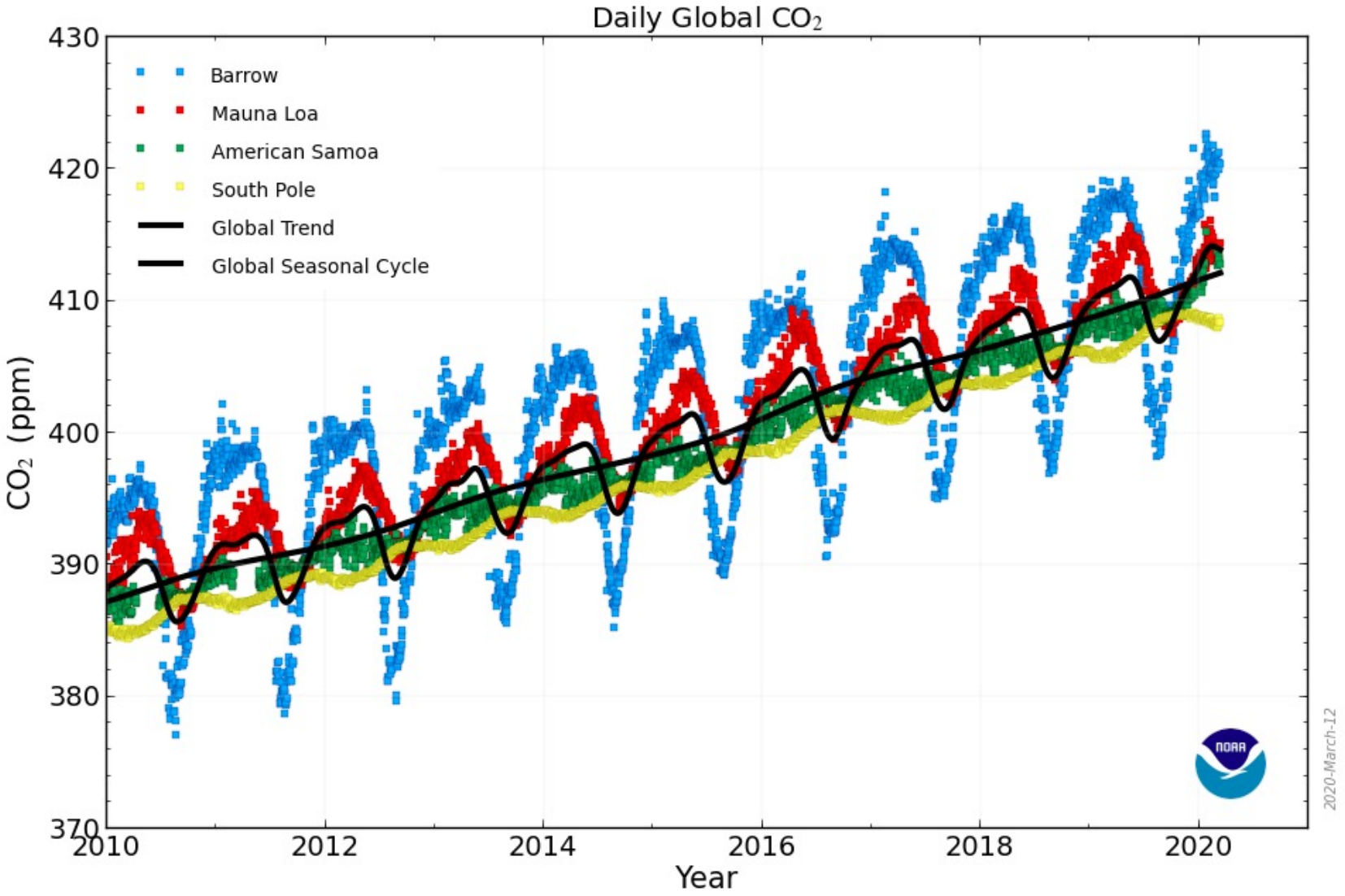
IPCC: "Global mean surface temperature has increased more than 0.5˚C since the beginning of the 20th century, with this warming likely being the largest during any century over the past 1,000 years for the Northern hemisphere."

Carbon Dioxide Levels Continue to Rise in the Atmosphere



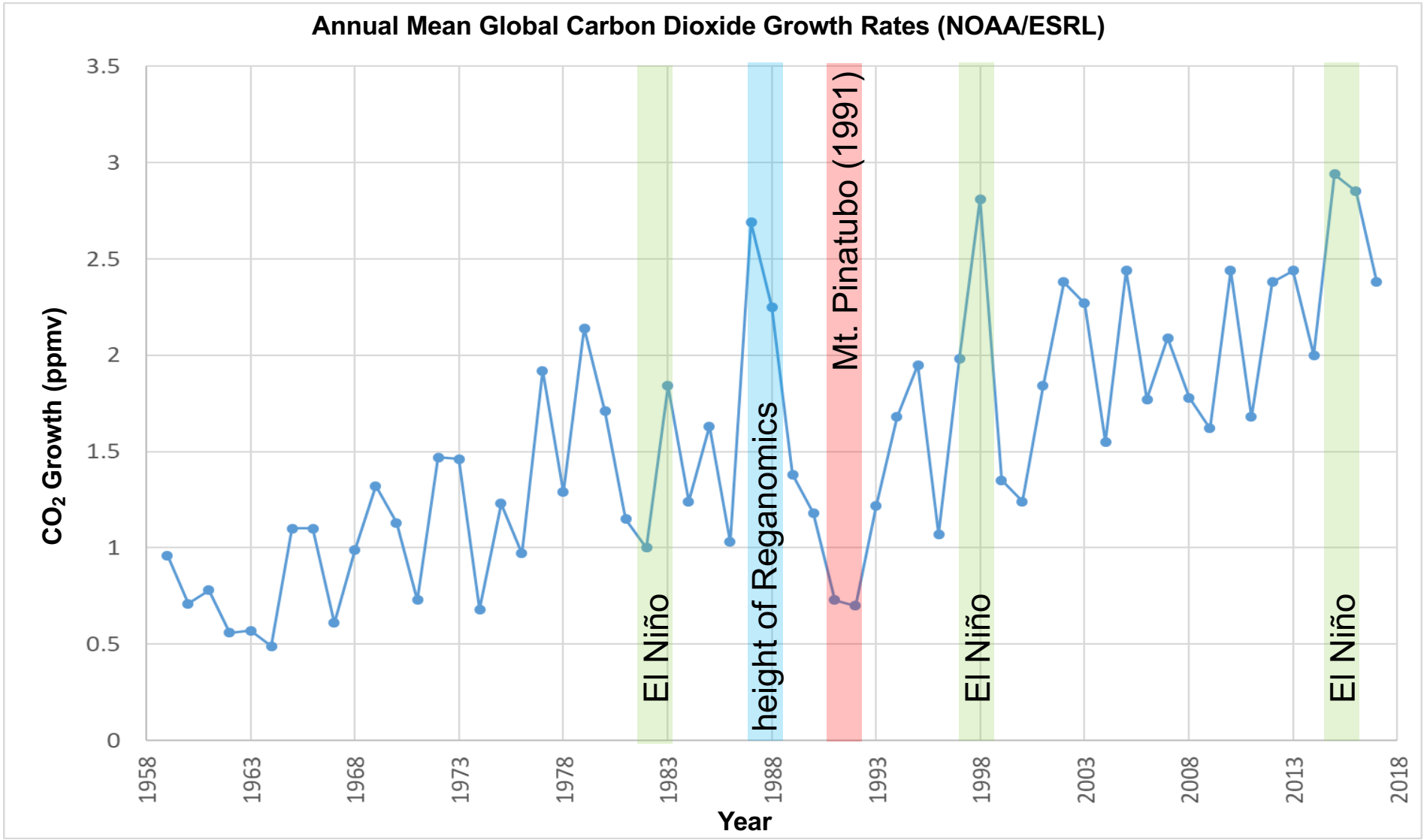
Adapted from Sarmiento and Gruber 2002 using Trends online data

Recent atmospheric carbon dioxide levels



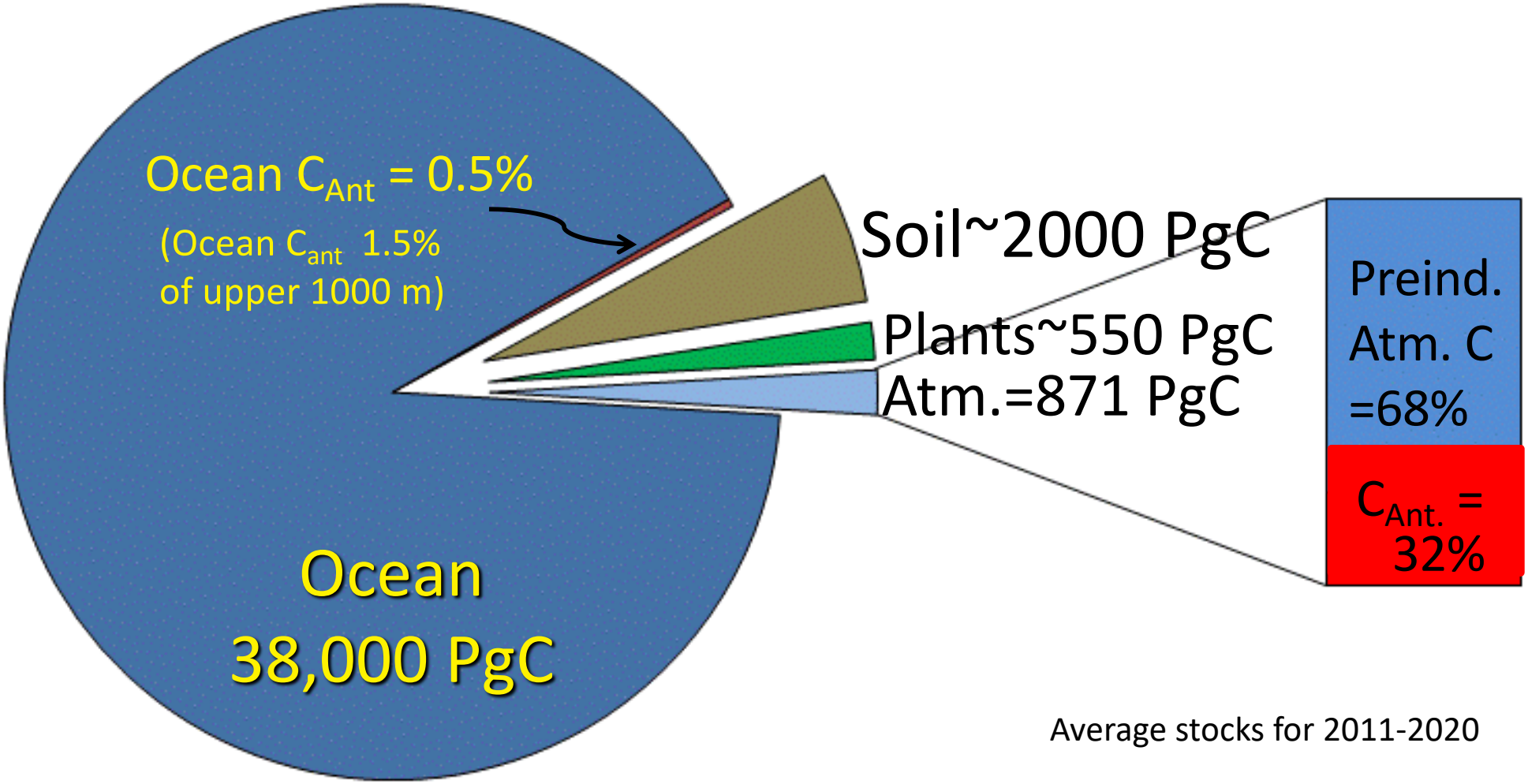
Atmospheric CO_2 levels have risen from ~315 ppmv in 1958 to 416 ppmv in 2021 (~24%)

Rate of increase of atmospheric CO_2 is not constant



Varies with: Economic activity and natural sinks/sources (El Nino, droughts, fires, Volcanic activity)

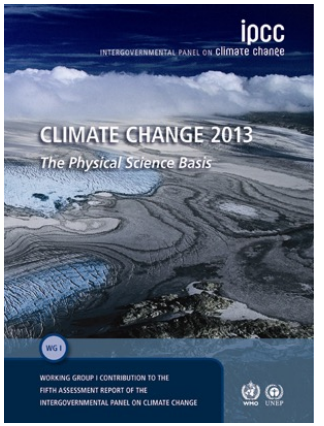
Carbon Inventories of Reservoirs that Naturally Exchange Carbon on Time Scales of Decades to Centuries



Average stocks for 2011-2020

- Oceans contain ~90% of carbon in this 4 component system
- anthropogenic component is difficult to detect in the ocean

IPCC global carbon cycle and the flows of carbon



Average stocks and flows for 2000-2009

Preindustrial C cycle was from the Ocean to the Land

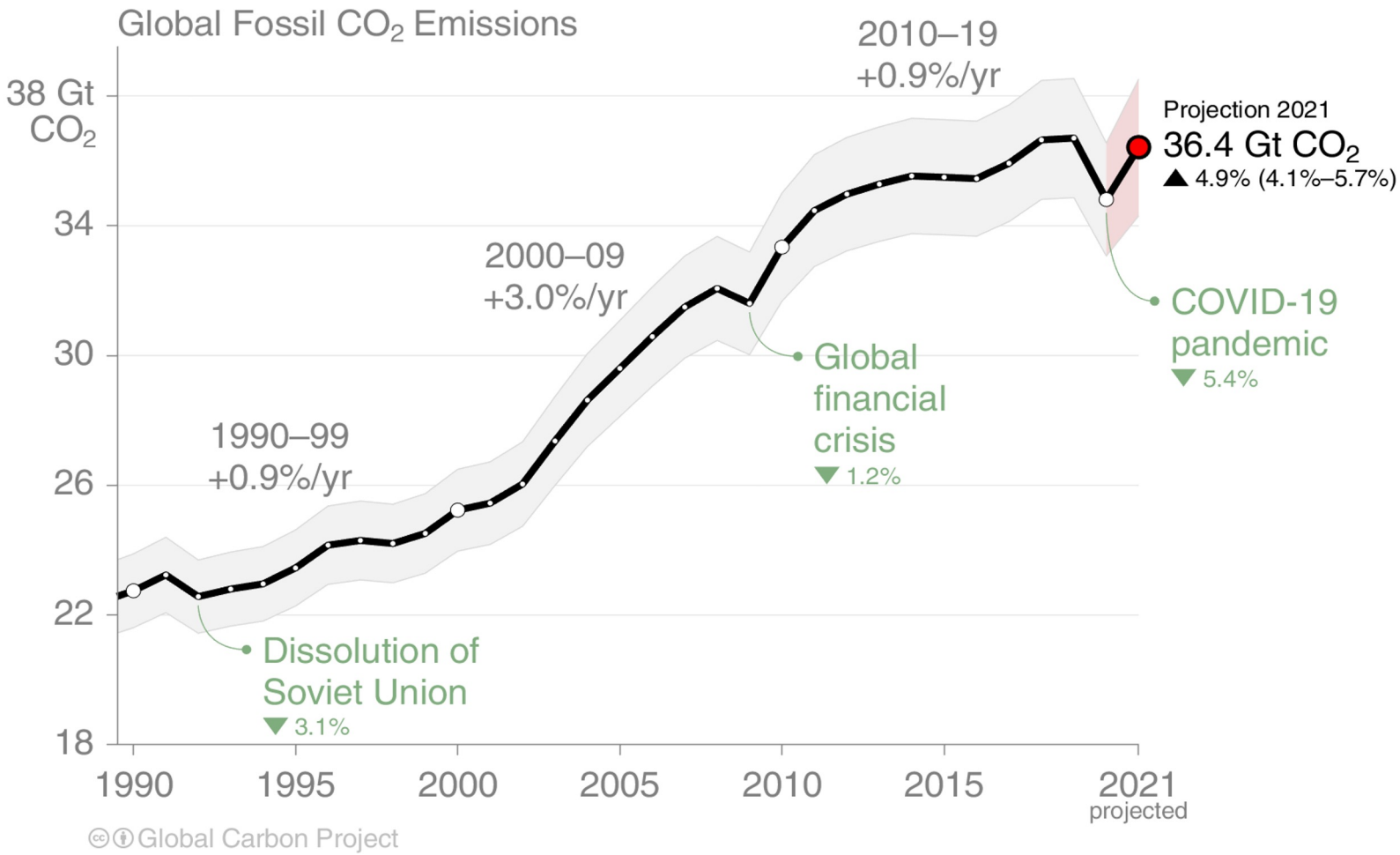
Average stocks and flows for 2000-2009

Today we have reversed that flow

Average stocks and flows for 2000-2009

Budget Changes Over Time Averages for last decade (2011-2020)

Global fossil CO_2 emissions: 34.8 ± 2 $GtCO_2$ in 2020, 53% over 1990
2021 emissions: 36.4 ± 2 $GtCO_2$ [9.9 PgC], 4.9% higher than 2020



Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2021

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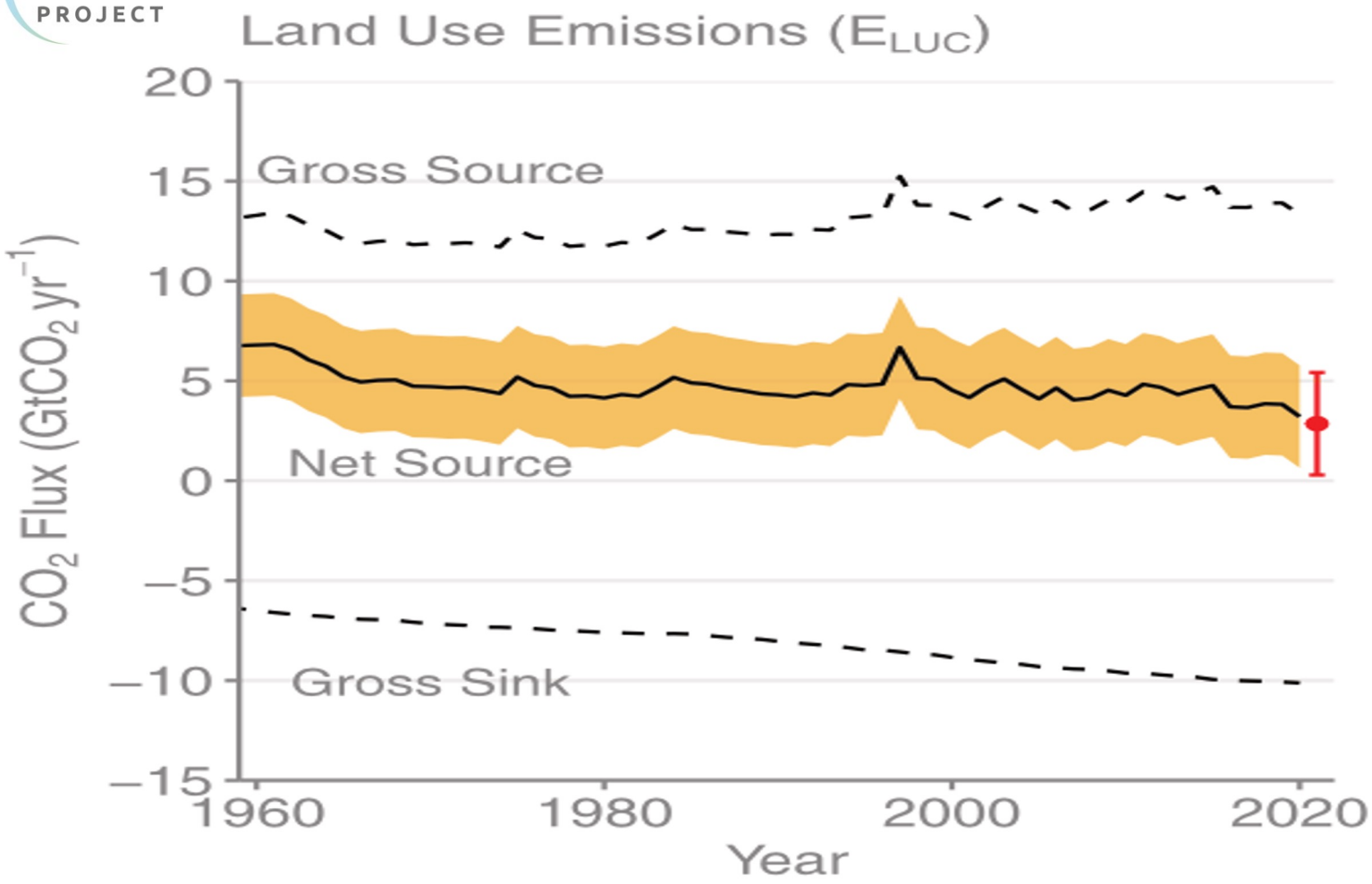

1.1±0.5 PgC/yr (4 $GtCO_2$)

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2021

Budget Changes Over Time Averages for last decade (2011-2020)

GLOBAL CARBON PROJECT

9.5 ±0.5 PgC/yr
(35 $GtCO_2$)

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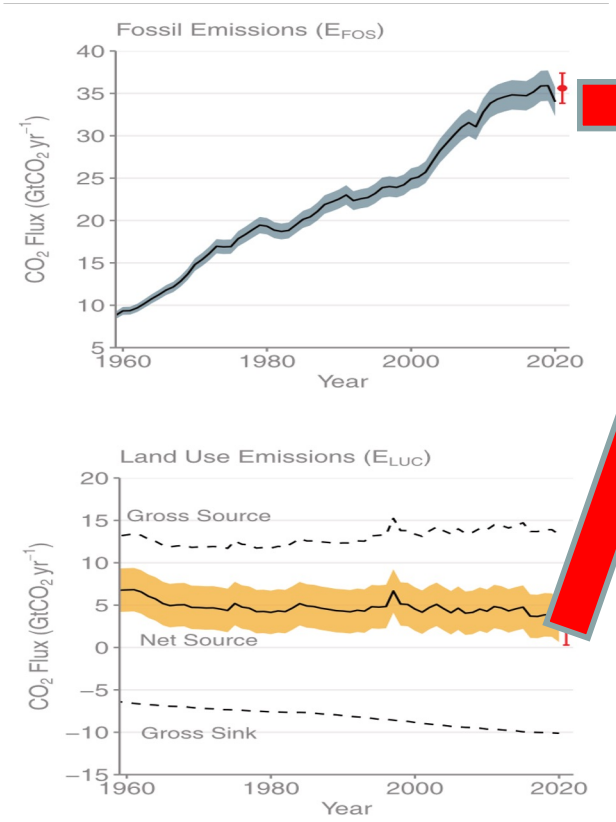

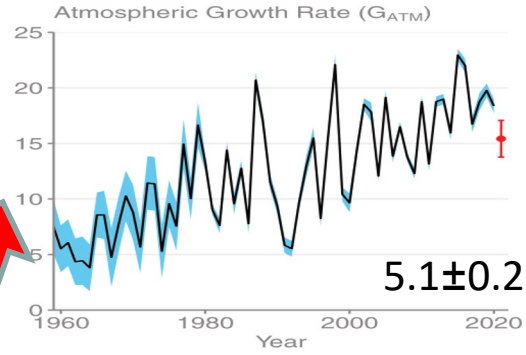

5.1±0.2 PgC/yr (18.5 $GtCO_2$)

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2021

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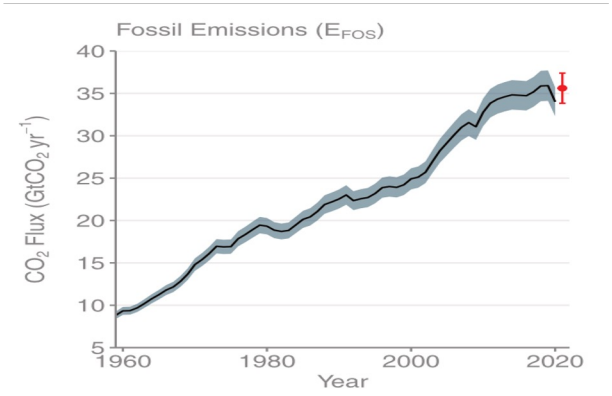

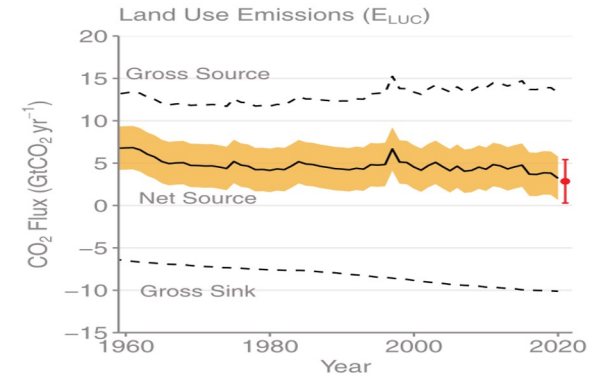

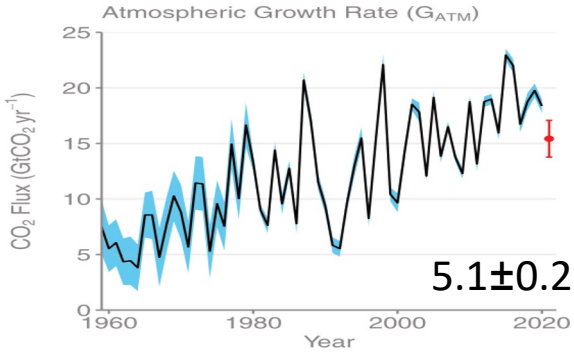

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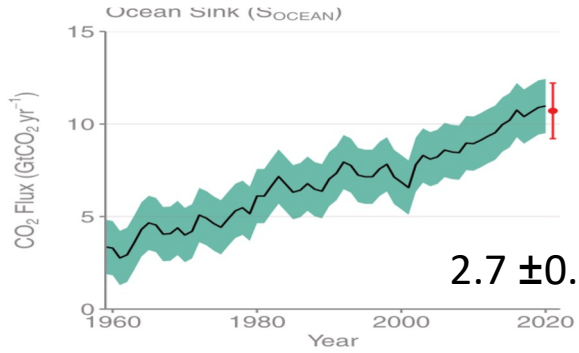
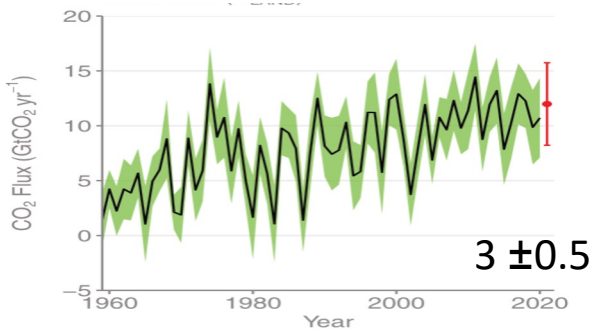


2.7 ±0.2 PgC/yr (10 $GtCO_2$)



3 ±0.5 PgC/yr (11 $GtCO_2$)

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2021

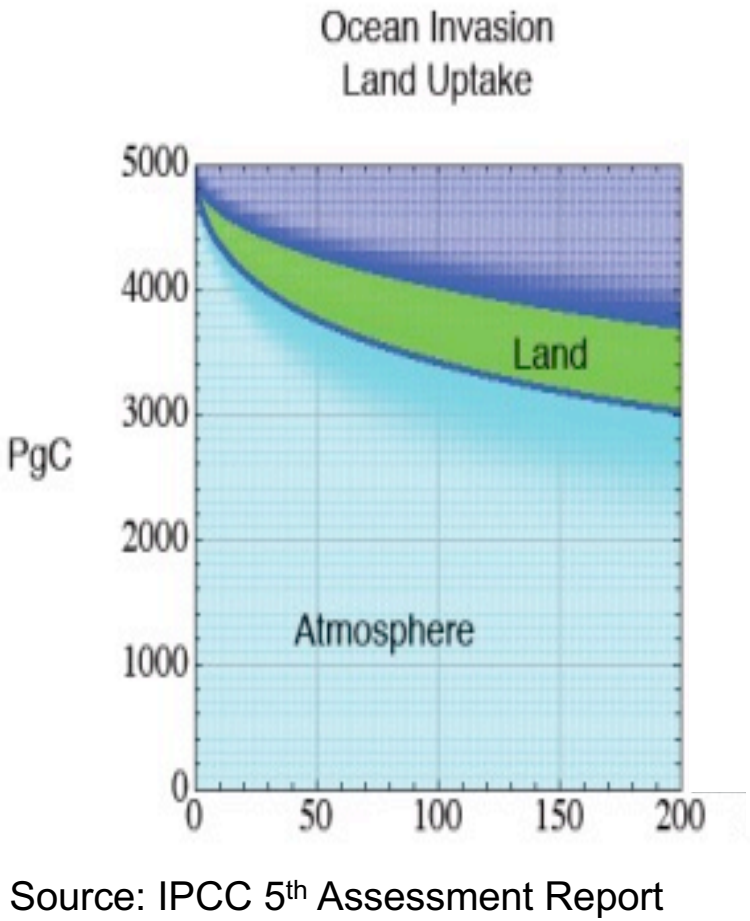
What are the long-term consequences of fossil fuel burning?

Hypothetical scenario: We instantly inject 5,000 Pg of carbon into the atmosphere

Time-scale of a few hundred years: primary storage is atmosphere with ocean and land absorption

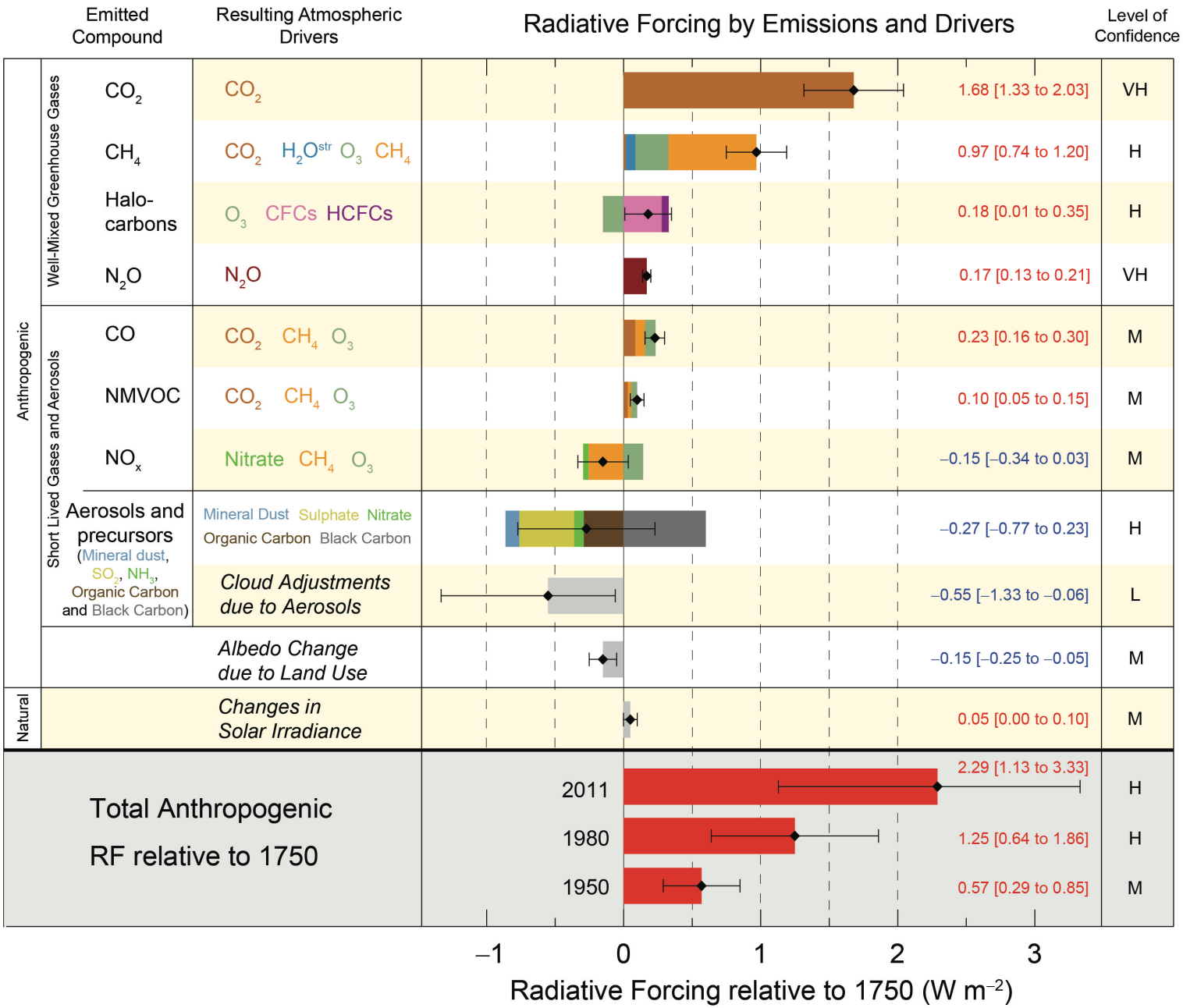
Time-scale of a few thousand years: land sink maxed out and ocean becomes primary storage location

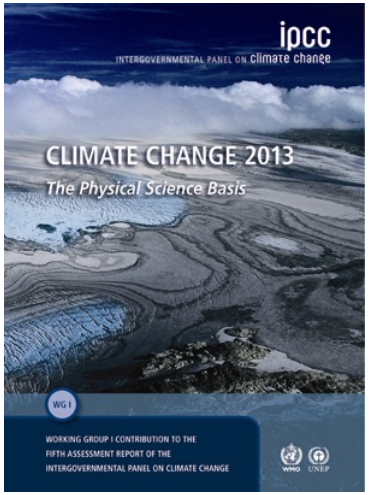
Time-scale of ten thousand years: ocean is primary storage location and mineral sink growing



Source: IPCC 5th Assessment Report

What causes climate change?



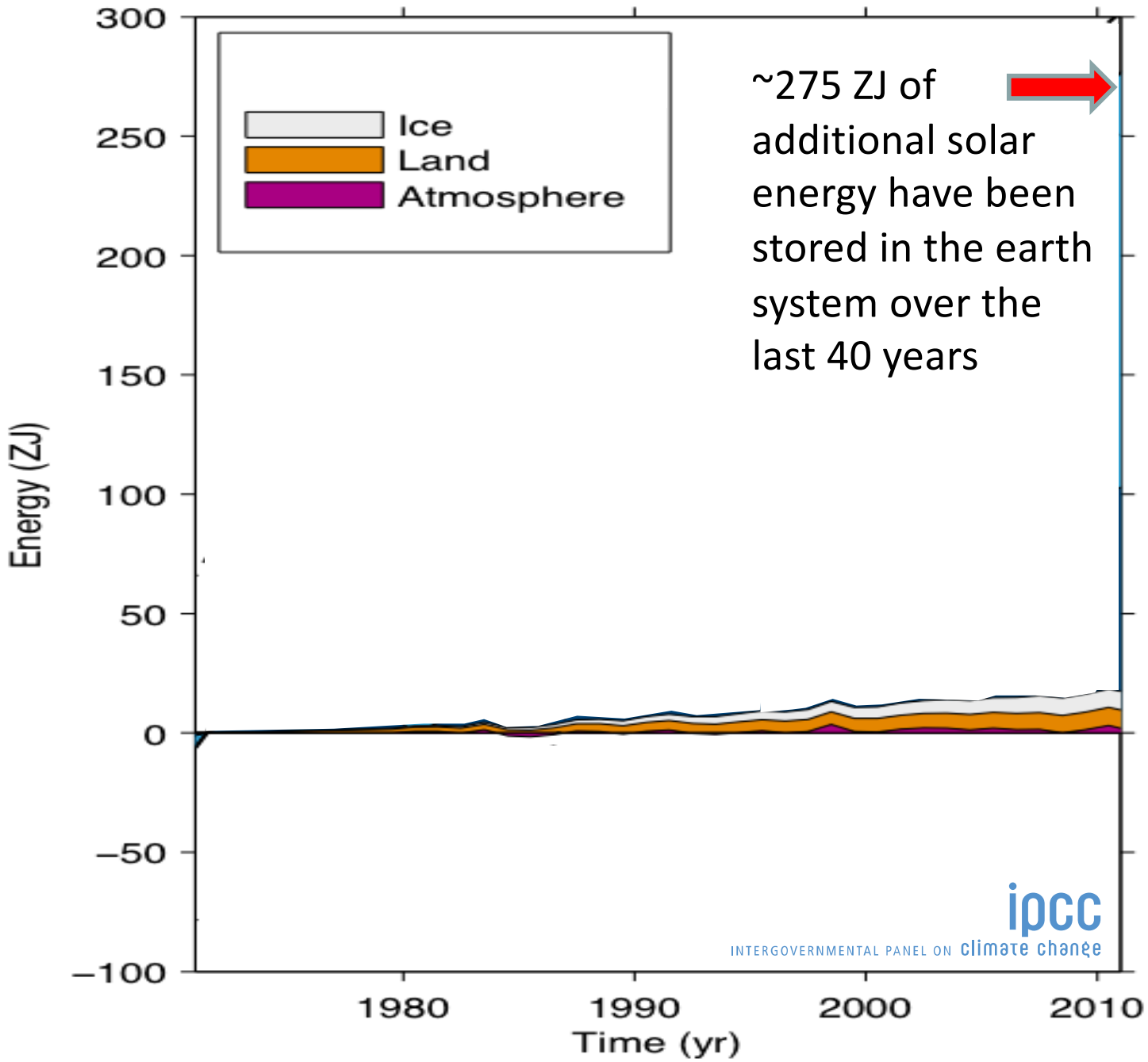


Global Energy Storage

Atmospheric warming accounts for about 1% of energy storage

Melting Ice (including Arctic sea ice) accounts for ~3% of energy storage

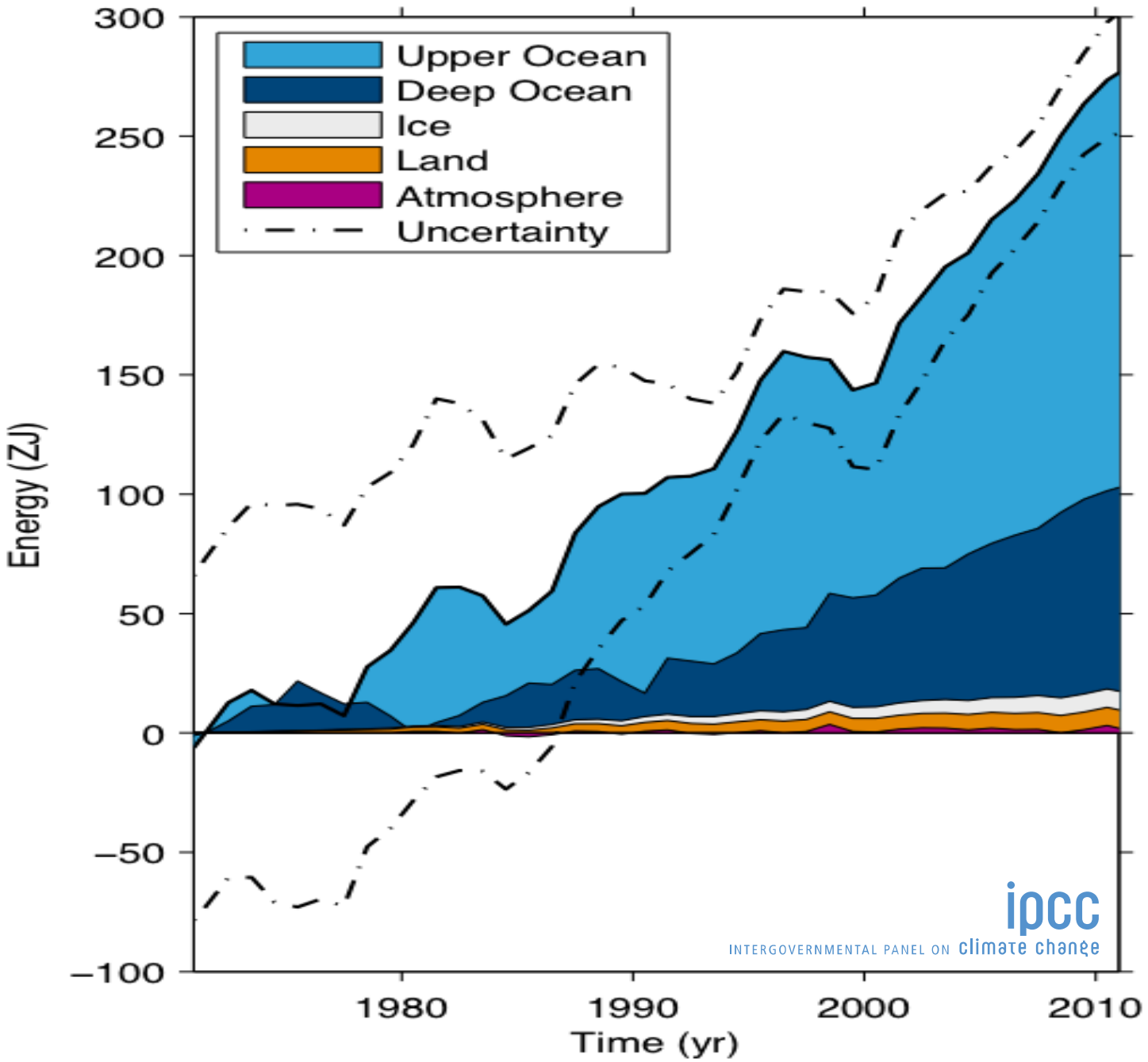
Warming Land accounts for ~3% of energy storage



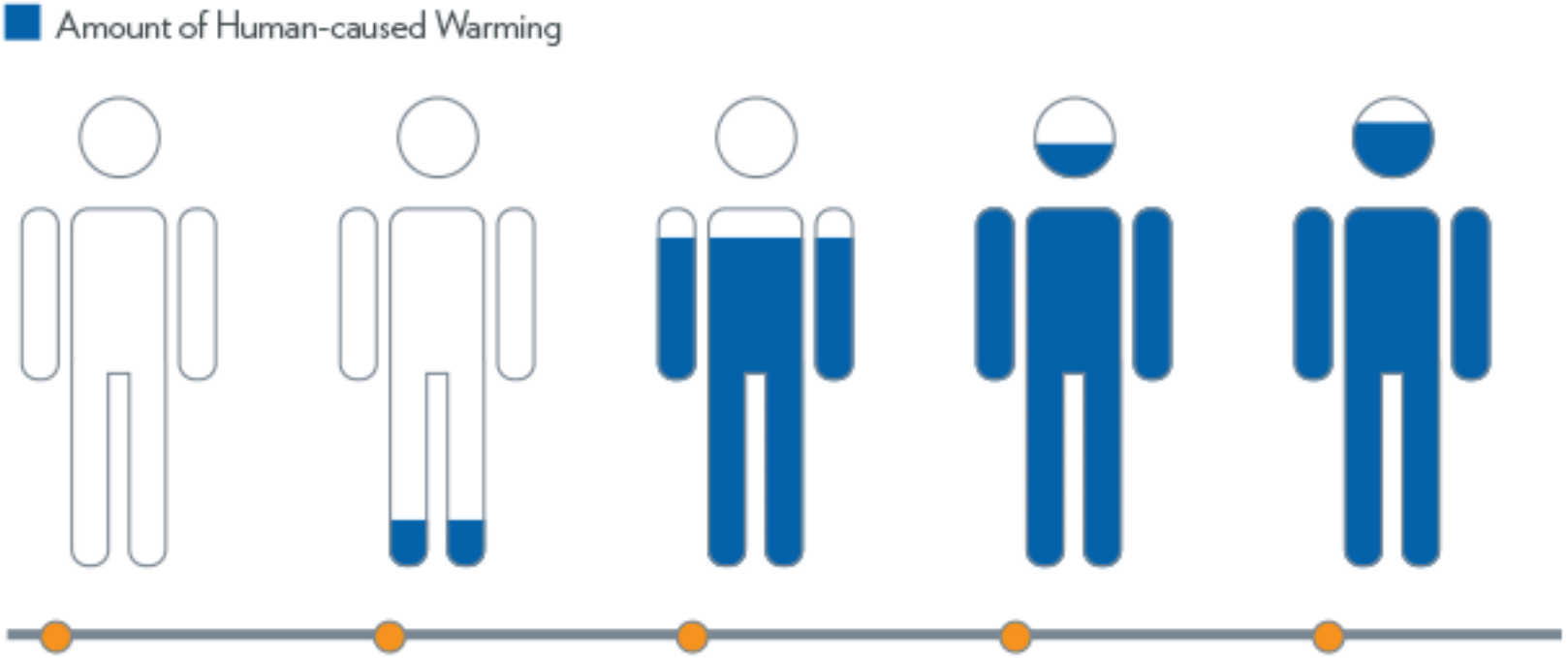
Global Energy Storage

Ocean warming accounts for about ~93% of total energy storage

The heat we are putting in the ocean will be trapped there for many thousands of years



Increasing Confidence With Each Assessment



1990
The report did not quantify the human contribution to global warming.

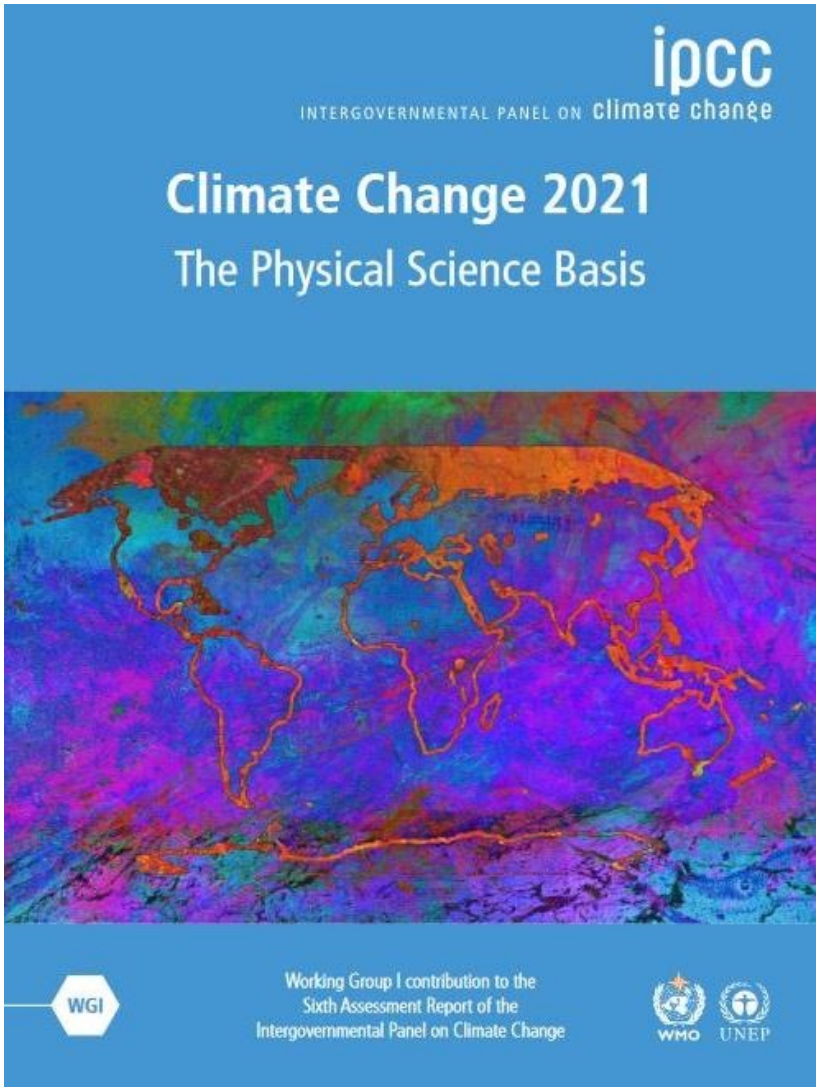
1995
"The balance of evidence suggests a **discernible** human influence on climate."

2001
Human-emitted greenhouse gases are **likely** (67-90% chance) responsible for more than half of Earth's temperature increase since 1951.

2007
Human-emitted greenhouse gases are **very likely** (at least 90% chance) responsible for more than half of Earth's temperature increase since 1951.

2013
Human-emitted greenhouse gases are **extremely likely** (at least 95% chance) responsible for more than half of Earth's temperature increase since 1951.

IPCC 6th Assessment Report



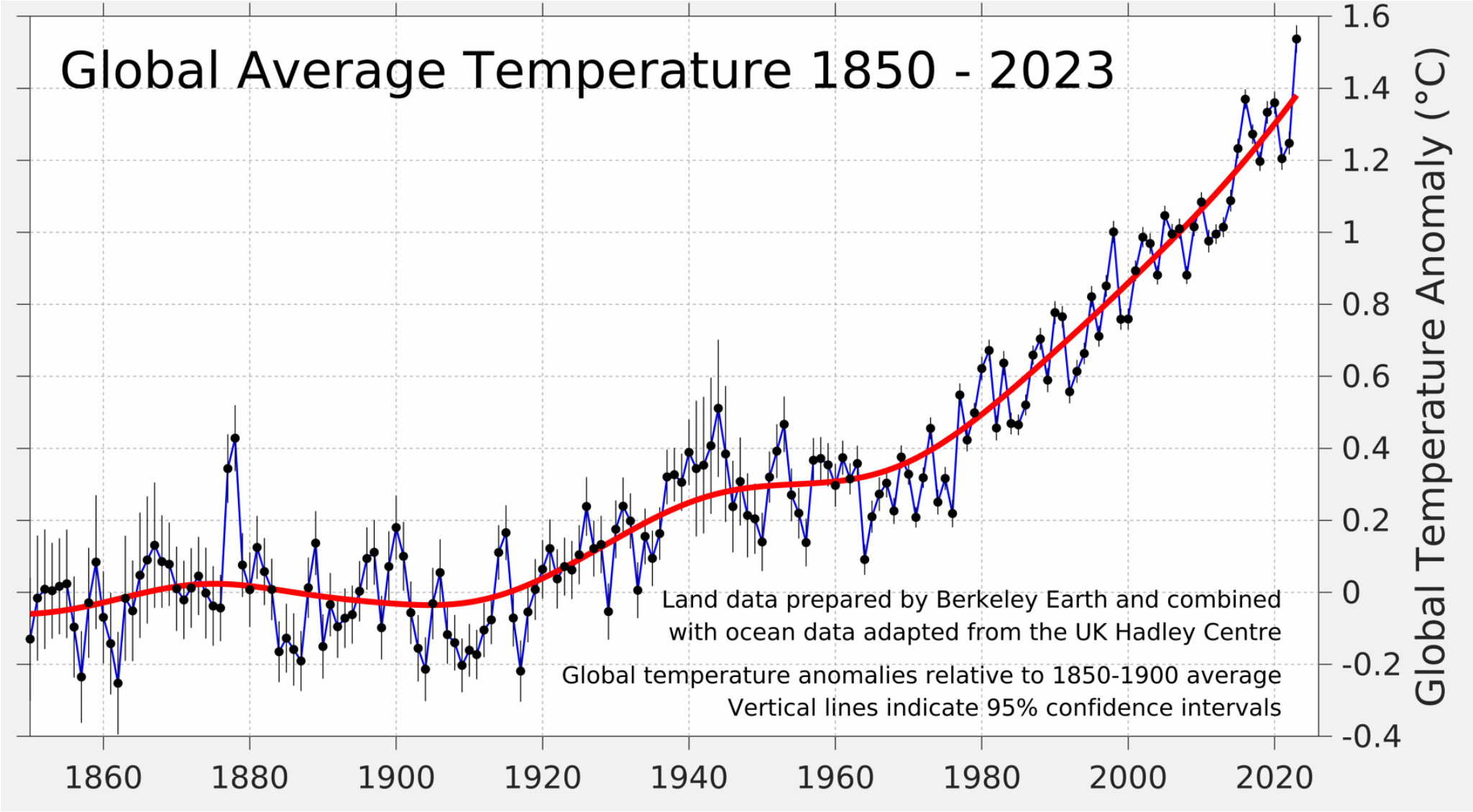
A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

A.2 The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.

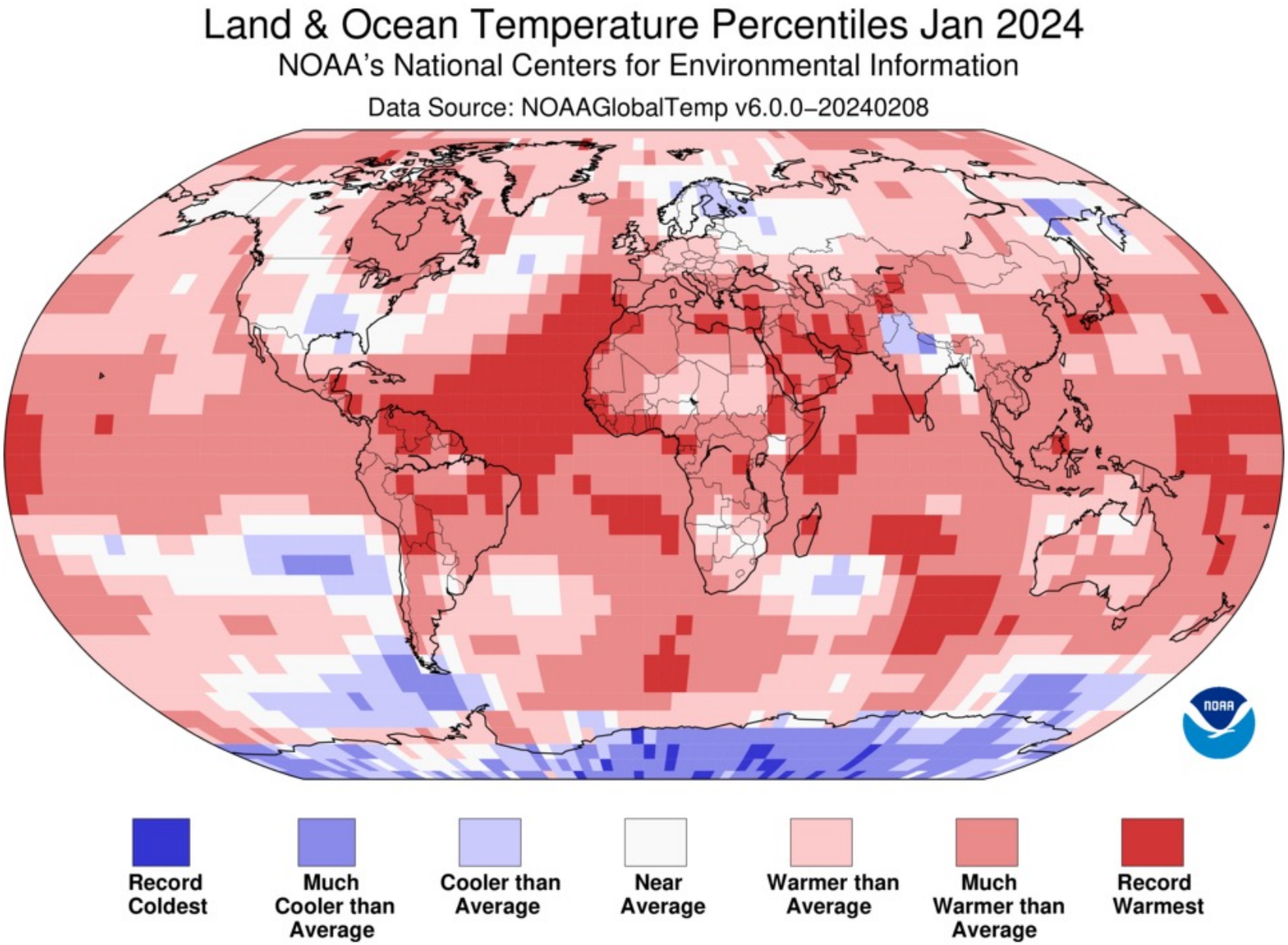
A.3 Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since the Fifth Assessment Report (AR5).

A.4 Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C, with a narrower range compared to AR5.

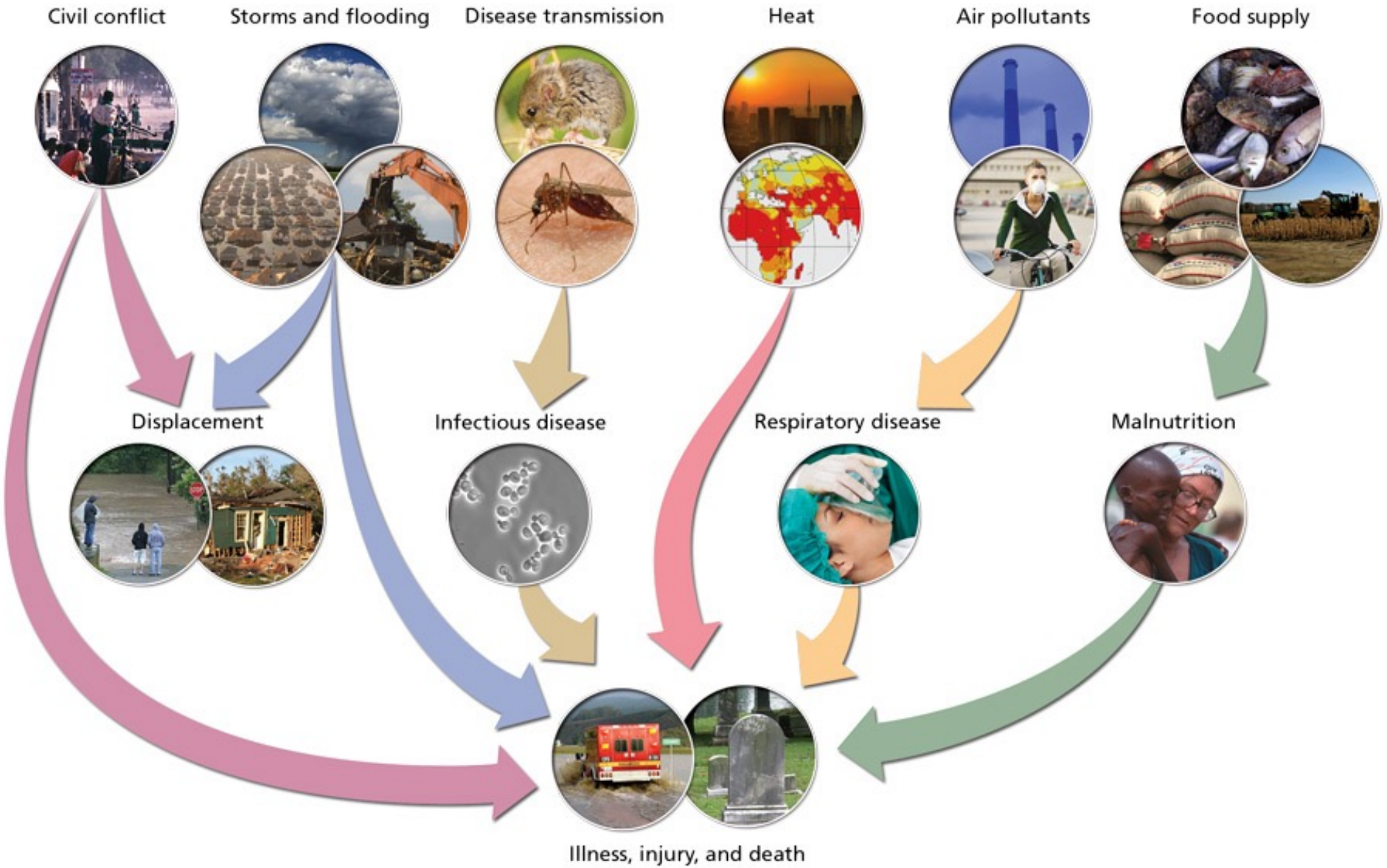
2016, 2019, and 2020 Were the 3 Warmest Years on Record



Earth had another record-warm month in January; it was also the second-wettest January on record



Climate Change Impacts on Human Health



The Impacts of Climate Change Show Up in Many Ways

The World Health Organization estimates that over the last two decades climate change has been responsible for an average of 150,000 deaths per year and they expect that rate to double over the next two decades!

	Climate Driver	Exposure	Health Outcome	Impact
Extreme Heat	More frequent, severe, prolonged heat events	Elevated temperatures	Heat-related death and illness	Rising temperatures will lead to an increase in heat-related deaths and illnesses.
Outdoor Air Quality	Increasing temperatures and changing precipitation patterns	Worsened air quality (ozone, particulate matter, and higher pollen counts)	Premature death, acute and chronic cardiovascular and respiratory illnesses	Rising temperatures and wildfires and decreasing precipitation will lead to increases in ozone and particulate matter, elevating the risks of cardiovascular and respiratory illnesses and death.
Flooding	Rising sea level and more frequent or intense extreme precipitation, hurricanes, and storm surge events	Contaminated water, debris, and disruptions to essential infrastructure	Drowning, injuries, mental health consequences, gastrointestinal and other illness	Increased coastal and inland flooding exposes populations to a range of negative health impacts before, during, and after events.
Vector-Borne Infection (Lyme Disease)	Changes in temperature extremes and seasonal weather patterns	Earlier and geographically expanded tick activity	Lyme disease	Ticks will show earlier seasonal activity and a generally northward range expansion, increasing risk of human exposure to Lyme disease-causing bacteria.
Water-Related Infection (*Vibrio vulnificus*)	Rising sea surface temperature, changes in precipitation and runoff affecting coastal salinity	Recreational water or shellfish contaminated with *Vibrio vulnificus*	*Vibrio vulnificus* induced diarrhea & intestinal illness, wound and bloodstream infections, death	Increases in water temperatures will alter timing and location of *Vibrio vulnificus* growth, increasing exposure and risk of waterborne illness.
Food-Related Infection (*Salmonella*)	Increases in temperature, humidity, and season length	Increased growth of pathogens, seasonal shifts in incidence of *Salmonella* exposure	*Salmonella* infection, gastrointestinal outbreaks	Rising temperatures increase *Salmonella* prevalence in food; longer seasons and warming winters increase risk of exposure and infection.
Mental Health and Well-Being	Climate change impacts, especially extreme weather	Level of exposure to traumatic events, like disasters	Distress, grief, behavioral health disorders, social impacts, resilience	Changes in exposure to climate- or weather-related disasters cause or exacerbate stress and mental health consequences, with greater risk for certain populations.