Topic 6 Atmosphere

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Topic 6 Content

If we do not act soon, anthropogenic environmental changes will bring serious harms to the future. We have a moral obligation to avert harms to the future, so as to leave a world as rich in life and possibility as the world we inherited. Therefore, we have a moral obligation to act, and act now.

By whom?

6.2 Causes and Effects of Climate Change

Abstract

Climate is shaped by atmospheric physical processes, yet anthropogenic carbon dioxide emissions have driven a significant rise in atmospheric concentrations, with emission rates accelerating notably since 1950. Proxy records such as ice cores, tree rings, and sediments demonstrate a positive correlation between CO_2 levels and global temperatures, evidencing the enhanced greenhouse effect caused by human activities. This intensification has led to global warming and subsequent climate change, which undermines the resilience of ecosystems, drives biome shifts, and affects human societies across multiple scales and socio-economic contexts. Systems models and diagrams help illustrate the causal relationships, feedback loops, and shifts in the global energy balance associated with these processes. Current evidence suggests that the Earth has already surpassed the planetary boundary for climate change, and perspectives on its causes and consequences are shaped by a range of individual and societal factors.

6.2 Overview

[PSA]

- Individual actions are essential in addressing climate change alongside government efforts.
- Collective action has already produced positive change, including:
  - Reduction of single-use plastics.
  - Increased energy efficiency and renewable energy adoption.
  - Conservation initiatives and clean-up activities.
  - Greater accountability for corporate pollution.
- Personal choices have a measurable impact:
  - Avoid fast fashion and unnecessary travel.
  - Reduce reliance on disposable plastics.
  - Make sustainable energy and dietary choices.
- Core strategies: **reduce, reuse, repurpose, recycle.**
- Widespread adoption of low-carbon lifestyles can help prevent the most severe IPCC climate projections.

6.2.1 Learning Objectives

- Define weather, climate and climate change
- Explain the correlation between CO_2 and the change in atmospheric temperature
- Describe the climate change models
- Explain different perspectives on climate change

- [AHL] Describe further evidences of climate change

Perspectives

What people think about climate change?

- **Psychological responses to climate change:**
  - Some individuals use denial as a defense mechanism because the issue is perceived as too large or frightening.
  - Responses vary:
    - Some reject human-caused climate change entirely.
    - Others acknowledge it but question the magnitude or human contribution.
- **Public concern and perception:**
  - Survey across UK, Ireland, Norway, Poland, Italy, and Germany:
    - 81% worried about impacts on future generations.
    - 80% worried about impacts on humanity in general.
    - Most believe climate change is currently harmful or will be harmful within 10 years.

Misconceptions about scientific consensus:

- Public estimates of scientific agreement: 68%
- Actual scientific consensus: ~99.9%
- Beliefs about human causes of climate change:
  - Average 74% say mainly caused by human activities.
  - Country variation: 82% in Italy, 61% in Norway.
- Many believe oil companies suppress technologies for non-fossil-fuel vehicles.

Rationale for proactive mitigation

- Multiple factors influence societal and individual perspectives, creating debate on responses.
- Preventing climate change is more cost-effective than responding after impacts:
  - Example: improving energy efficiency and reducing emissions is cheaper than abandoning/rebuilding coastal cities.
  - Historical anti-pollution programs show prevention is consistently less expensive than repairing damage.

Climate Change – causes

Definitions

Weather

- Daily outcome of interactions among temperature, air pressure, wind speed, precipitation, and humidity.

Climate

- The average weather pattern over approximately 30 years in a specific location.

Climate Change

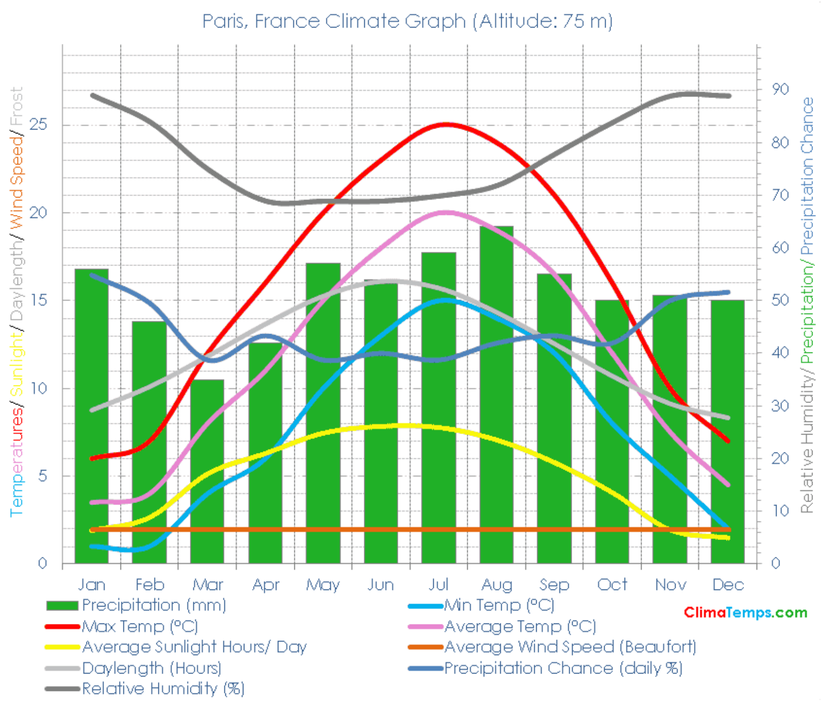
- Long-term shifts in global or regional climate patterns.

Weather

- Varies greatly between places, sometimes over very short distances.
- Forecasts are only reliable for about five days due to the complexity of interacting variables.
- Extreme single events (e.g., a hot day, cold day, or one unusual season) do not indicate long-term climate change.

Climate

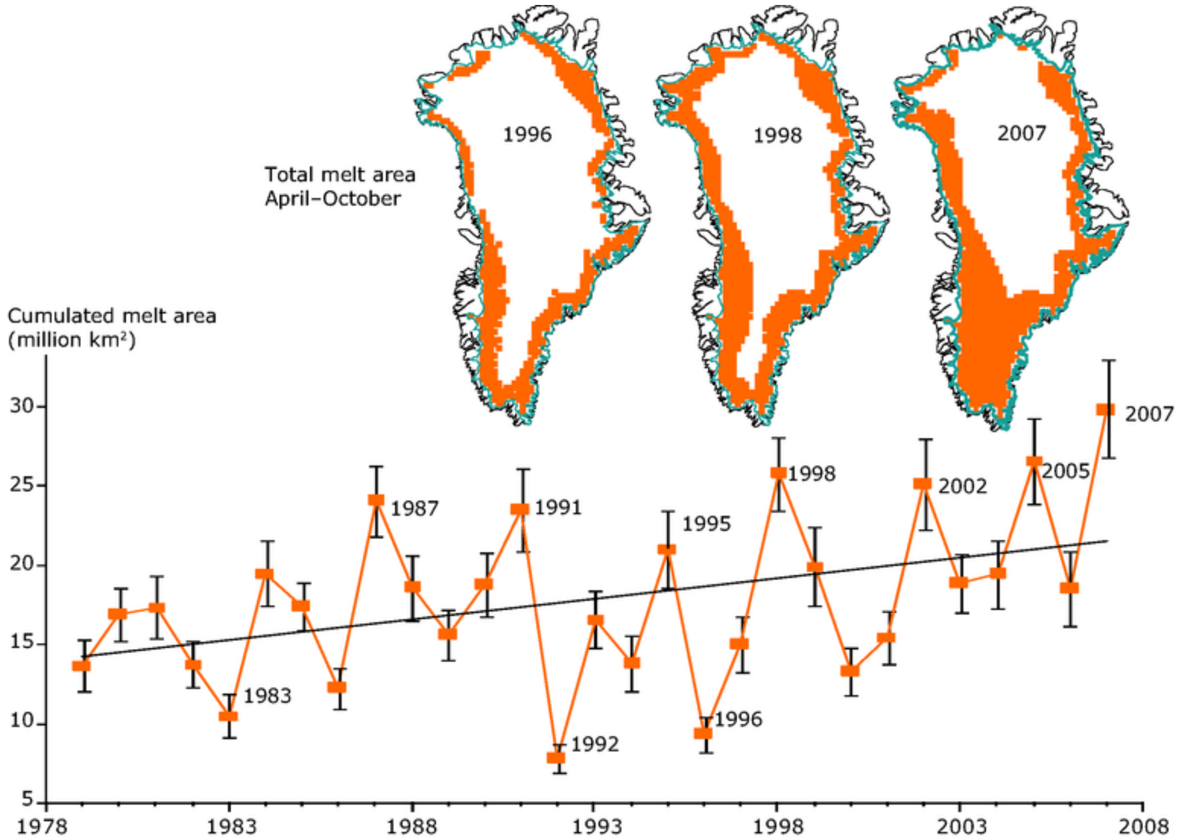
- Long-term records reveal climate trends and shifts.
- Operates on different timescales from weather but both are influenced by ocean and atmospheric circulation.
- Additional influencing factors include:
  - Clouds: can trap heat or reflect sunlight away.
  - Forest fires: emit CO_2 but regrowth can recapture it in carbon stores.
  - Volcanic eruptions: release ash that cools the Earth temporarily (e.g., Mt. Pinatubo, 1990).
  - Human activity: burning fossil fuels and livestock farming release greenhouse gases.



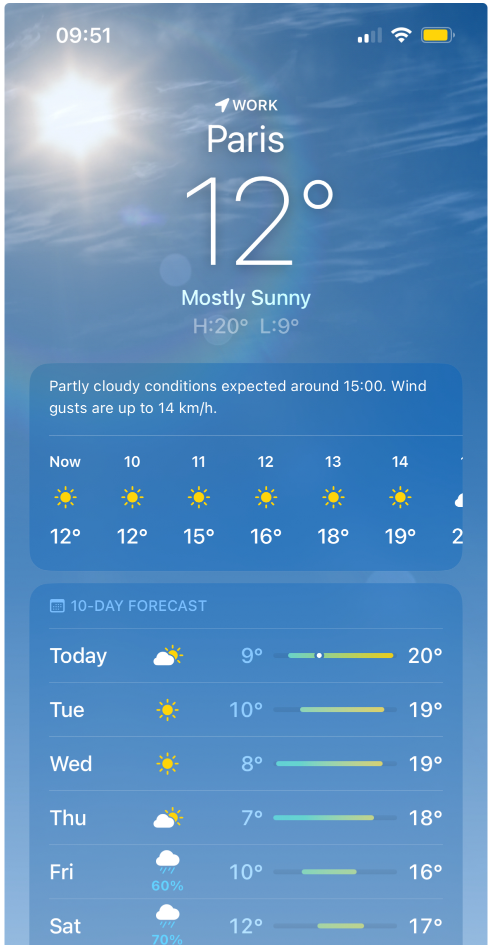
Paris Climate
Source: https://www.climate.top/france/paris/

Climate Change

- Naturally influenced by:
  - Fluctuations in solar insolation.
  - Milankovitch cycles.
  - Changes in atmospheric gas composition from biological activity.



Greenland melt 2007
Source: eea.europa.eu

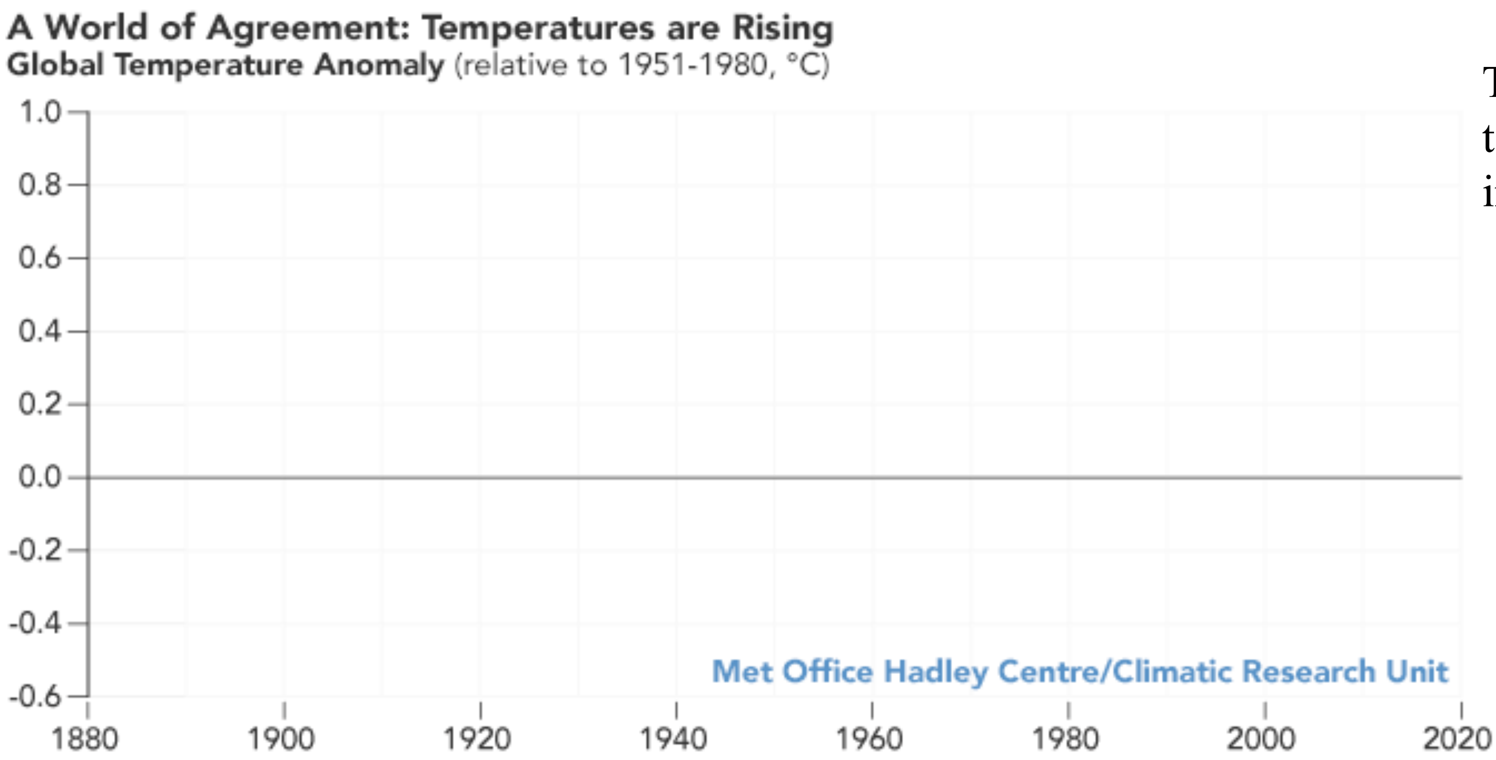


Weather in Paris

Correlation Between CO_2 and Atmospheric Temperautre

Temperature Rising

Multiple independent datasets (NASA, NOAA, Berkeley Earth, and meteorological agencies in the UK and Japan) confirm the trend and magnitude of global warming.



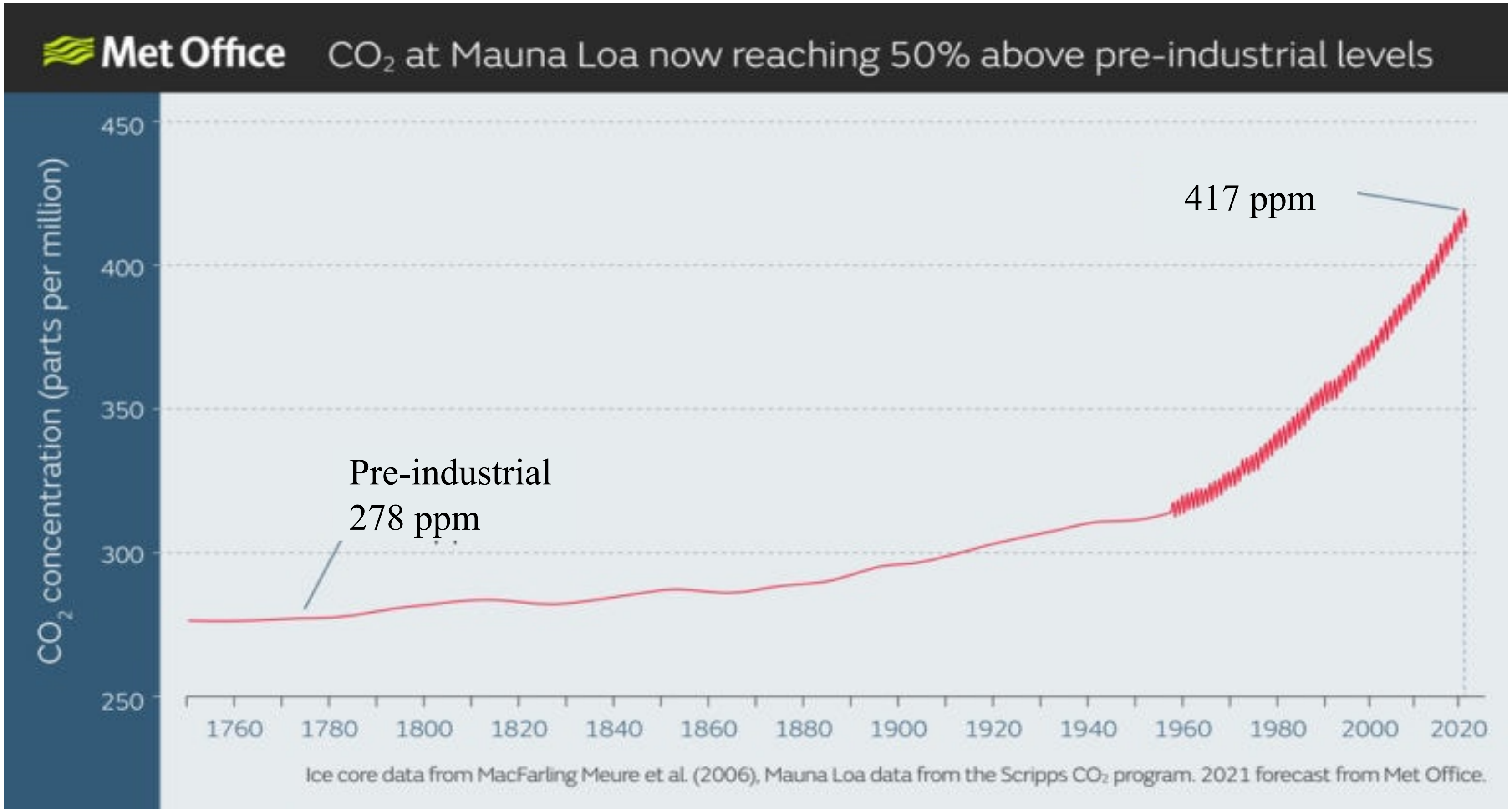
The global average temperature increase = _____ ^{o}C

Source: Earthobservatory.nasa.gov

Temperature and carbon dioxide levels

- For global climate change to occur, the balance of energy inputs and outputs must shift (e.g., increased heat input, reduced heat output, or both).
- Greenhouse gases (GHGs) limit heat loss from the atmosphere; higher concentrations result in greater heat retention.
- The climate system operates in a state of dynamic equilibrium, which can stabilize or shift to a new equilibrium if tipping points are exceeded.
- Long-term data show a consistent rise in the Earth’s average surface temperature, despite annual fluctuations.

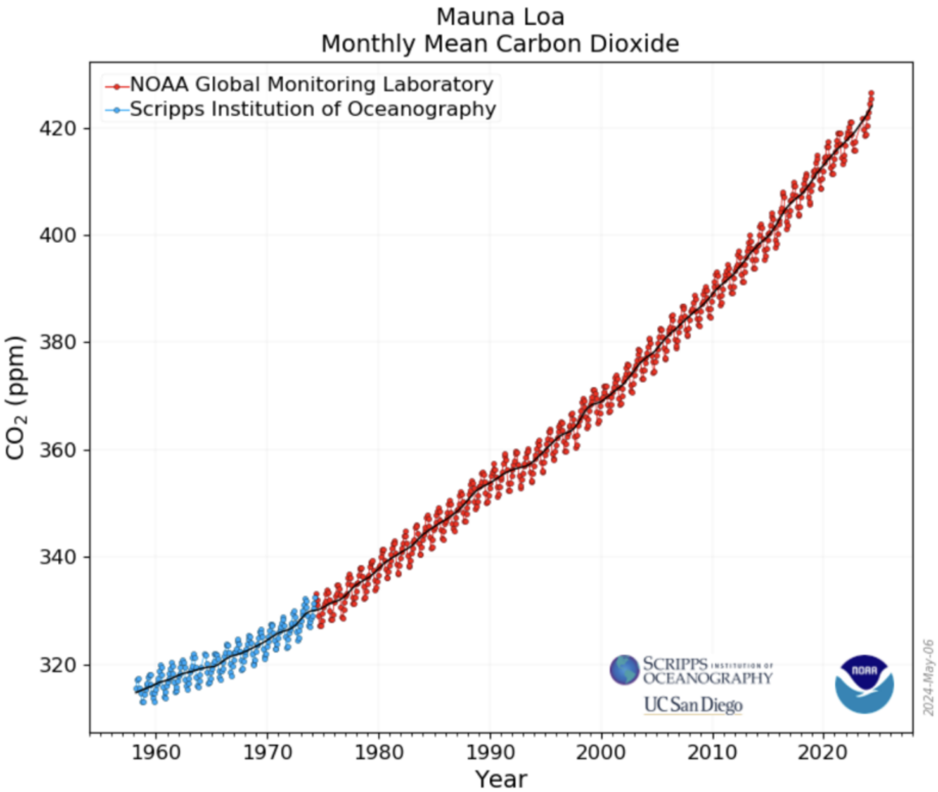
CO_2 Levels


Met Office
CO₂ at Mauna Loa now reaching 50% above pre-industrial levels
CO₂ concentration (parts per million)
450
400
350
300
250
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
417 ppm
Pre-industrial
278 ppm
Ice core data from MacFarling Meure et al. (2006), Mauna Loa data from the Scripps CO₂ program. 2021 forecast from Met Office.

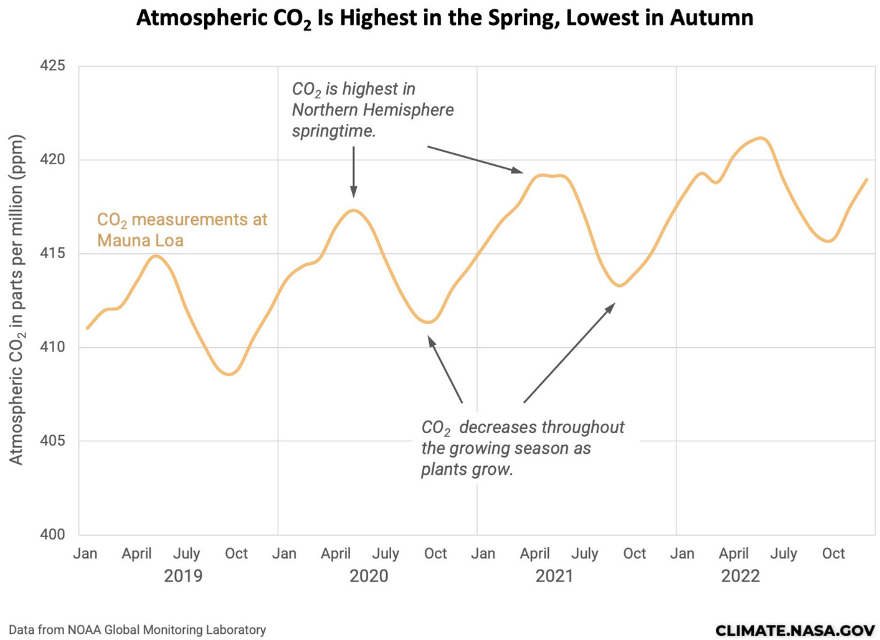
CO_2 Levels

- Anthropogenic CO_2 emissions have led to a substantial increase in atmospheric CO_2 concentrations
- The global emission rate has accelerated markedly, particularly since 1950
- Although this rise originated during the Industrial Revolution in late 19th-century Europe, it intensified from the 1960s onward as industrialisation expanded and the extraction and combustion of fossil fuels increased
- Seasonal and annual fluctuations in atmospheric CO_2 levels are observed

CO_2 Levels

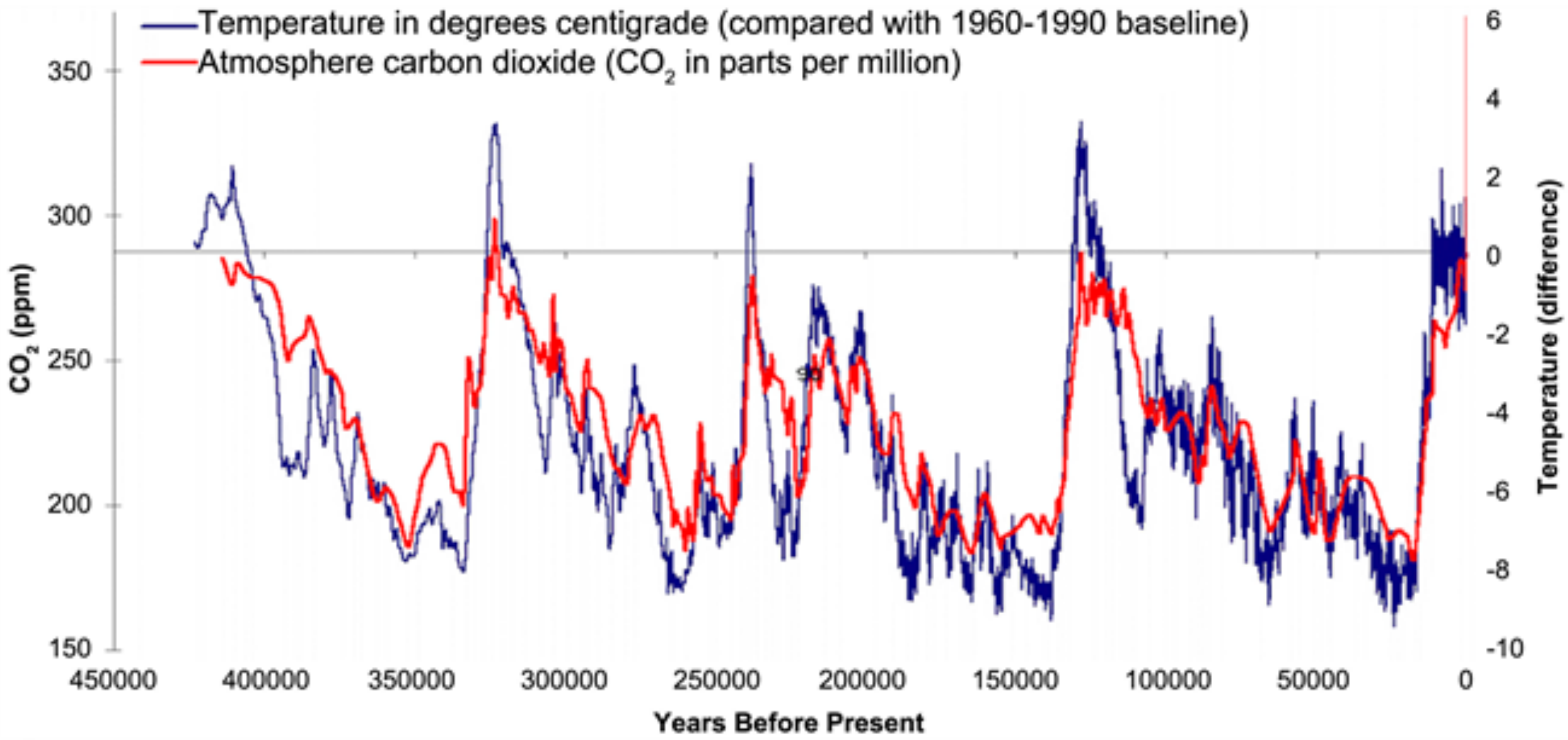


Source: *NOAA Global Monitoring Laboratory*



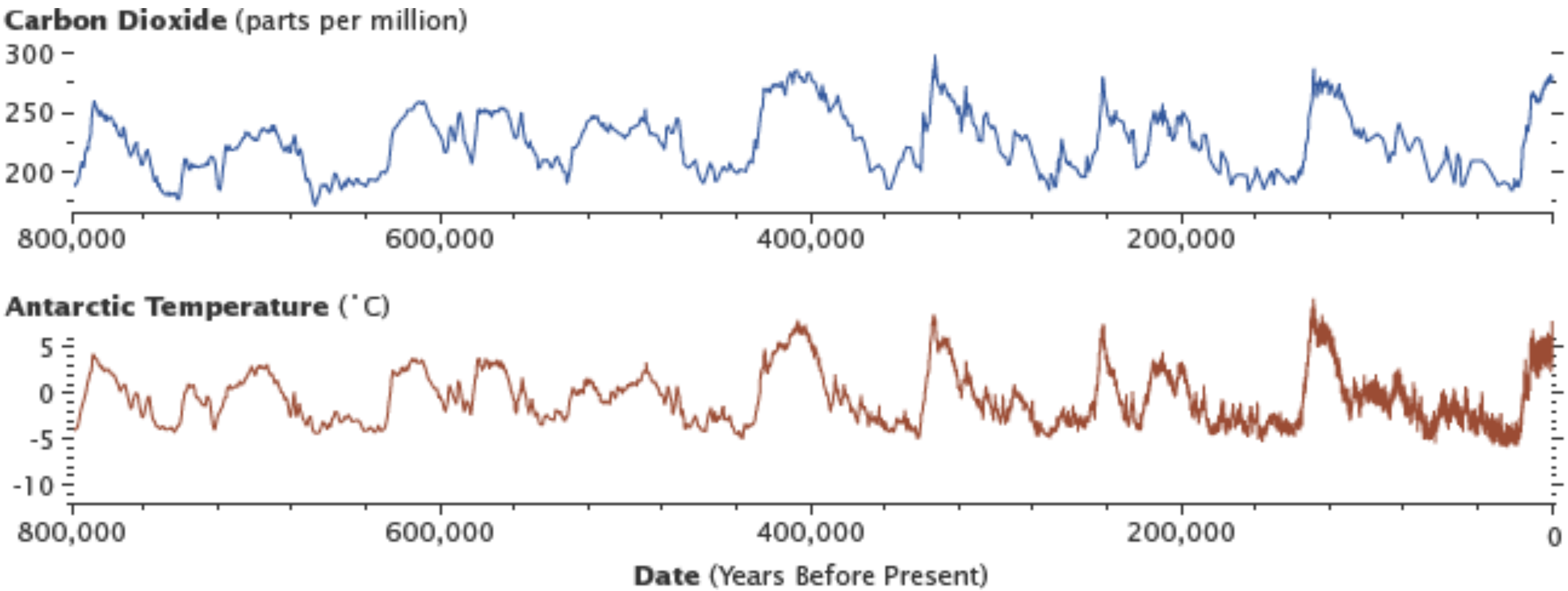
Source: Climate.nasa.gov

Temperature and carbon dioxide levels



Source: Valone F. T., 2021

Temperature and carbon dioxide levels



Source: Earthobservatory.nasa.gov

Temperature and carbon dioxide levels

- A strong **positive correlation** exists between atmospheric CO_2 concentrations and global temperatures
- This relationship is supported by direct measurements dating back to approximately 1850 and by indirect proxies, including ice core analyses, dendrochronology, and sediment records, all of which consistently demonstrate a positive association between atmospheric CO_2 levels and global temperature.

Temperature and carbon dioxide levels

- Atmospheric concentrations of CO_2 have exhibited a strong correlation with global temperature variations over the past 800,000 years.
- These fluctuations in temperature were primarily initiated by Milankovitch cycle-induced variations in Earth's orbital patterns, which produced alternating glacial and interglacial periods.
- Rising global temperatures subsequently released additional CO_2 into the atmosphere, thereby amplifying warming through positive feedback mechanisms.
- Evidence from Antarctic ice core records demonstrates this long-term relationship until approximately 1900, at which point anthropogenic activities began transferring carbon from the slow carbon cycle to the fast carbon cycle, fundamentally altering the natural balance.

[AHL] Further Evidence of Climate Change

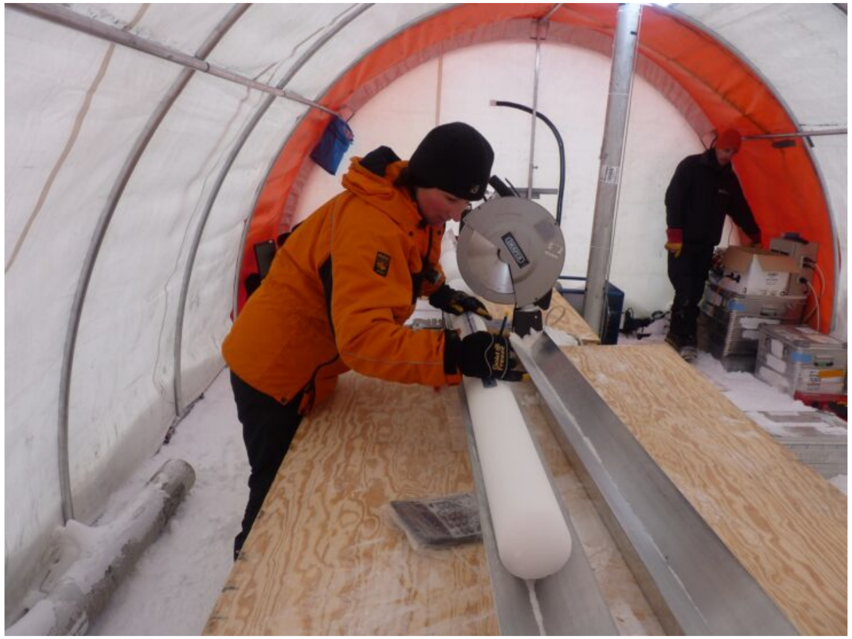
- Advancements in weather forecasting and climate prediction are supported by data from:
  - Satellites
  - Weather stations
  - Observatories
  - Radar systems
  - Computerized data networks
- Long-term datasets enable the study of:
  - Climate change
  - Land use alterations
  - Variables such as temperature and greenhouse gas concentrations
- Climate models:
  - Test hypotheses regarding complex systems
  - Depend on the accuracy and volume of collected data
  - Greater data quality and quantity improve model precision and reliability

[AHL] Climate measurements

- Direct measurements – provide current climate information
  - Include temperature, humidity, precipitation, air pressure, wind speed and direction, atmospheric gas concentrations, cloud formations, and pollution levels
  - Direct CO_2 measurements extend only to the 1950s
- Indirect (proxy) measurements – allow reconstruction of past climates
  - Include ice cores, tree rings, sediment cores, fossilized organisms, and pollen preserved in peat and lake sediments
- Both direct and indirect data:
  - Are essential for developing and validating climate models
  - Historical data enhance model accuracy

[AHL] Ice Cores

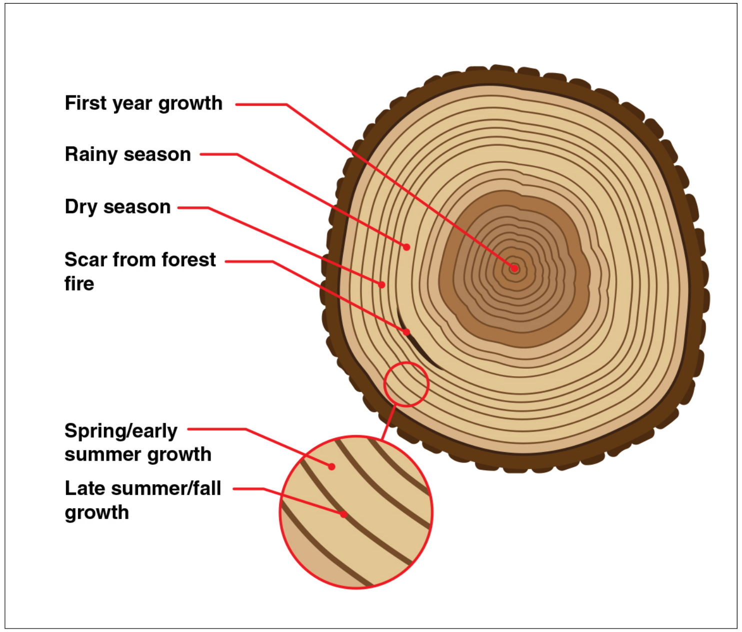
- Carbon dioxide concentrations remained stable at approximately 280 ppm for the past 10,000 years.
- Levels began to rise in the early 19th century with the onset of coal combustion during the Industrial Revolution.
- By February 2023, atmospheric CO_2 reached 417 ppm, while methane concentrations have more than doubled relative to pre-industrial levels.
- Antarctic ice cores reveal glacial-interglacial cycles of approximately 100,000 years, with CO_2 concentrations lower during glacial periods and higher during warmer interglacials.



Ice cylinders being analysed. Source: bas.ac.uk

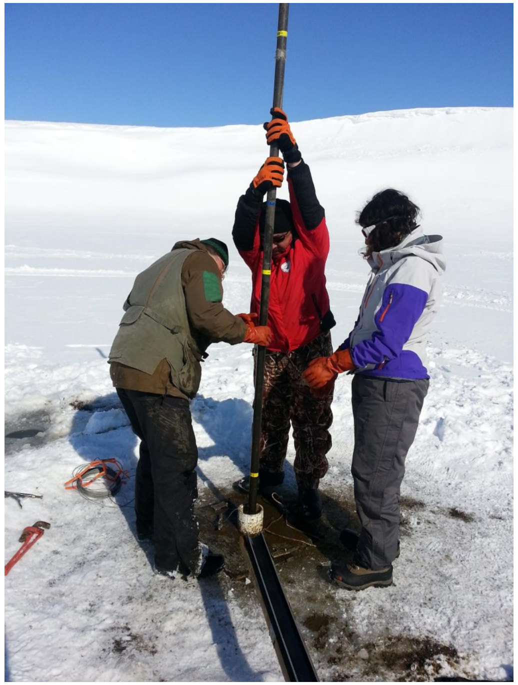
[AHL] Tree Rings

- Trees, some living over a millennium, record annual growth in concentric rings.
- Growth depends on sunlight and water, with warmer temperatures generally promoting faster growth.
- Rings laid down during summer have larger cells, while winter rings are smaller, producing a visible annual pattern.
- Analysis of tree rings through coring or felling allows reconstruction of both tree age and historical climate conditions.



[AHL] Pollen and Fossil Analysis

- Pollen and fossils preserved in peat bogs, lake sediments, and rock strata provide long-term ecological records.
- Pollen deposited in sediments reflects the vegetation present at the time of deposition, while fossilised organisms and pollen can be dated to reveal past environmental conditions.



Researchers collecting fossils

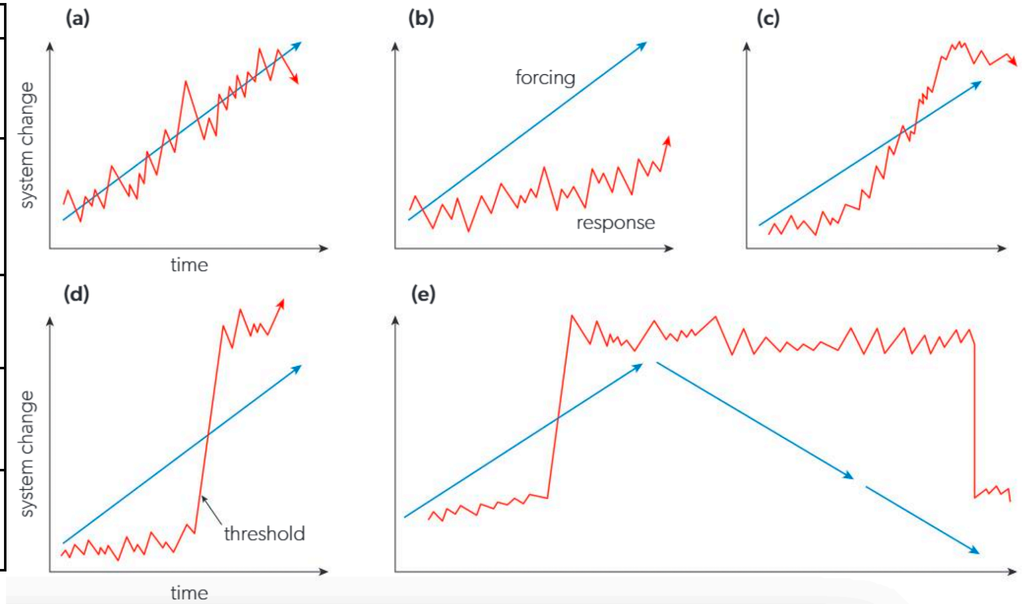
Modelling Climate Change

Models to explore

- Systems diagrams and climate models are essential tools for representing the causes and effects of climate change.
- These models can depict feedback mechanisms—both positive and negative—as well as alterations in the global energy balance.
- Changes in atmospheric greenhouse gas (GHG) concentrations can affect the climate in multiple ways,

Modelling Climate Change

Description	Graph
Delayed acceleration to a new equilibrium: The climate may initially respond slowly, then accelerate as positive feedbacks dominate, eventually reaching a new equilibrium.	
Hysteresis or locked-in states: Once a threshold is crossed, the climate may remain at the new equilibrium even if forcing decreases, only shifting rapidly again if another threshold is surpassed. Such changes can occur over short timescales, potentially within a few decades.	
Direct positive feedback: Increases in solar radiation, reductions in surface albedo, or enhanced methane release can amplify climate change through positive feedback loops.	
Threshold or tipping point behaviour: The climate may remain relatively stable until forcing reaches a critical threshold, after which rapid change occurs until a substantially higher equilibrium is established.	
Buffering or insensitivity: In some cases, climate forcing may increase, but the climate response is non-linear, exhibiting relative insensitivity or being moderated by negative feedback mechanisms.	



Planetary Boundary

Paris Agreement targets:

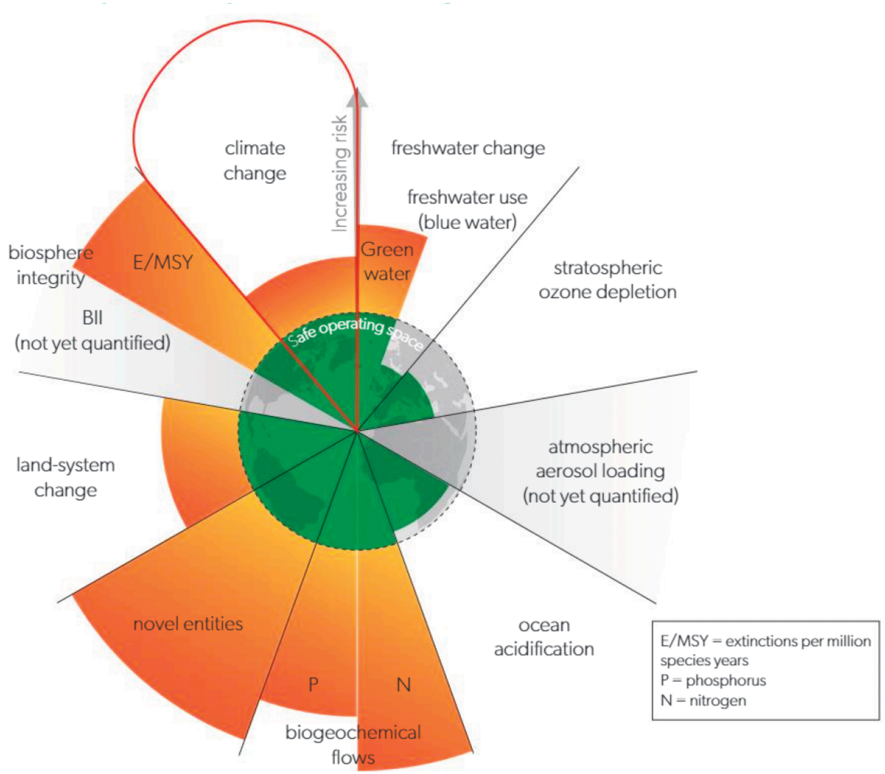
- Limit global temperature increase to below 2°C above pre-industrial levels
- Aim to keep temperature rise ideally below 1.5°C

Basis for temperature limits:

- Global temperature targets are calculated based on atmospheric CO_2 concentrations
- The safe threshold for CO_2 is below 350 ppm

Current status:

- The atmospheric CO_2 concentration has already exceeded 350 ppm
- This indicates that the boundary set by the Paris Agreement has been crossed



Climate Change and Carbon Cycle

Carbon release from fossil fuels:	2009 emissions data:	Atmospheric concentrations:	Rate of CO_2 increase:	Impact:
• Naturally released slowly over millions of years via the slow carbon cycle (e.g., volcanic activity) • Human combustion of coal, oil, and natural gas accelerates this process • Vast amounts of carbon accumulated over geological timescales are emitted annually	• Approximately 8.4 billion tonnes of carbon released by fossil fuel burning and cement production • Cement production accounts for up to 8% of CO_2 emissions • About half of annual emissions are absorbed by the fast carbon cycle; the remainder persists in the atmosphere	• CO_2: ~417 ppm, highest in two million years • CH_4: increased from 715 ppb in 1750 to 1,895 ppb in 2021, highest in at least 650,000 years • Methane has a global warming potential significantly higher than CO_2	• Late 1960s: ~1 ppm per year • Early 21st century: ~2 ppm per year • Last decade: ~2.5 ppm per year	• Although annual increases may appear small, the cumulative effect on the climate system is substantial

Gains and Losses

Economic impacts of climate change:

- Climate change will generate both gains and losses for national economies.
- Agricultural production may increase in higher-latitude regions but decrease in tropical regions.
- Africa is expected to experience reductions in food production and rainfall.
- Northern Darfur has already undergone extensive desertification, with millions of additional hectares at risk.
- Extraction of fossil fuels and minerals may become easier in higher-latitude areas.

Economic valuation and mitigation:

- Quantifying the economic effects of climate change is challenging.
- The Stern Review (2006) suggested that investing ~1% of global GDP in mitigation could prevent losses of up to 20% of global GDP in future economic recessions.
- Estimates of the total cost of global climate change by 2050 range from USD 14 trillion to USD 23 trillion.
- Significant uncertainty remains regarding the precise economic costs.

Gains and losses – Some predicted negative effects of global warming