



MACHINE LEARNING FOR CLIMATE ACTION

CS-E407519 Lecture 1



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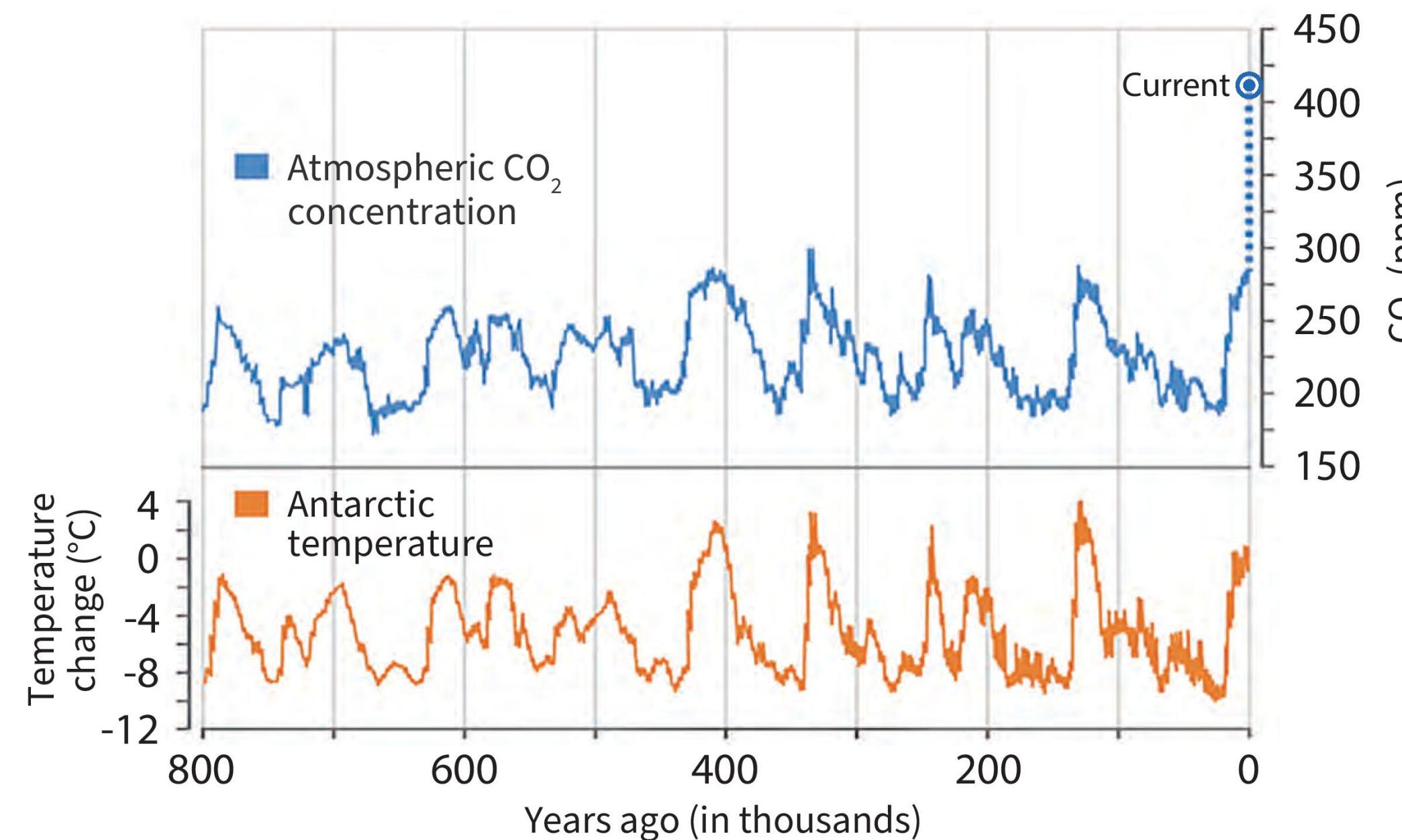
*Shaikhum Monira,
Teaching Assistant*

OUTLINE

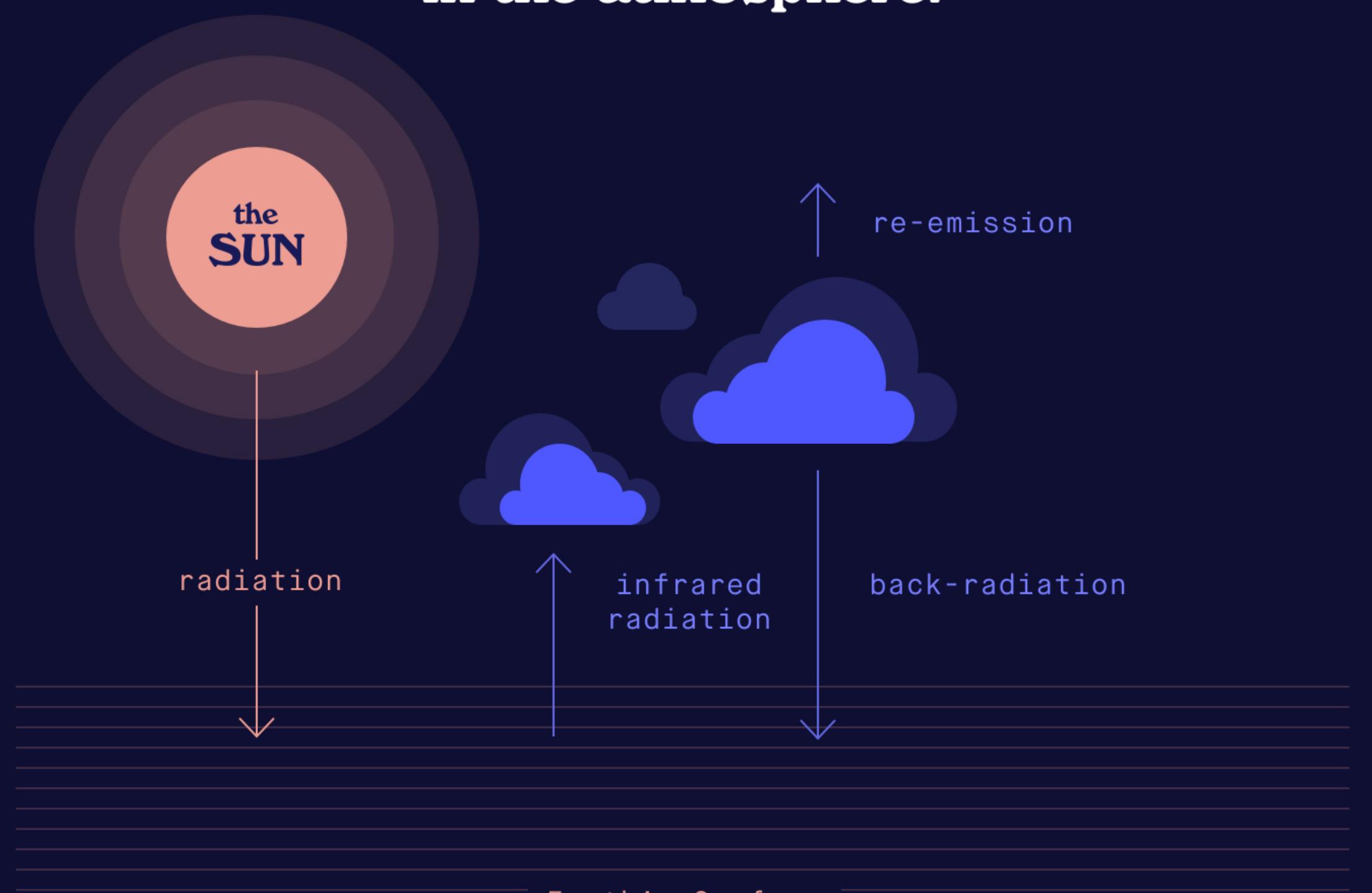
- **Background for climate action**
 - Why are we here?
 - Macro picture for climate action
 - Challenges of measuring and modelling climate change
- **Role of ML in climate action**
 - Potential positive and negative impact of ML on climate action
 - ML methods covered in the course
- **Practicalities and expectations**

WHY ARE WE HERE?

UNPRECEDENTED INCREASE IN CO₂



Source: The Royal Society, based on figure by Jeremy Shakun, data from Lüthi et al., 2008 and Jouzel et al., 2007.



GREENHOUSE GASES

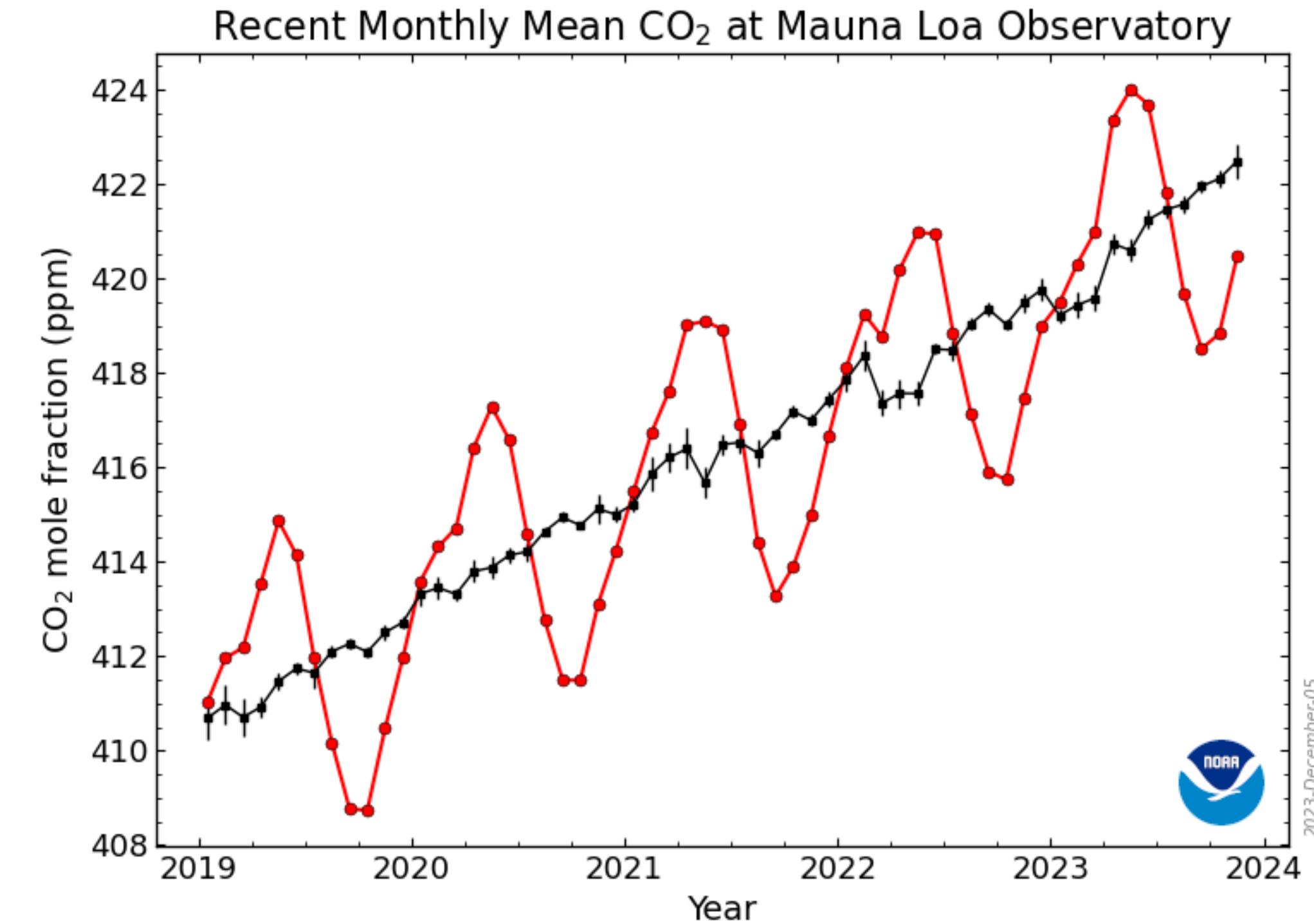
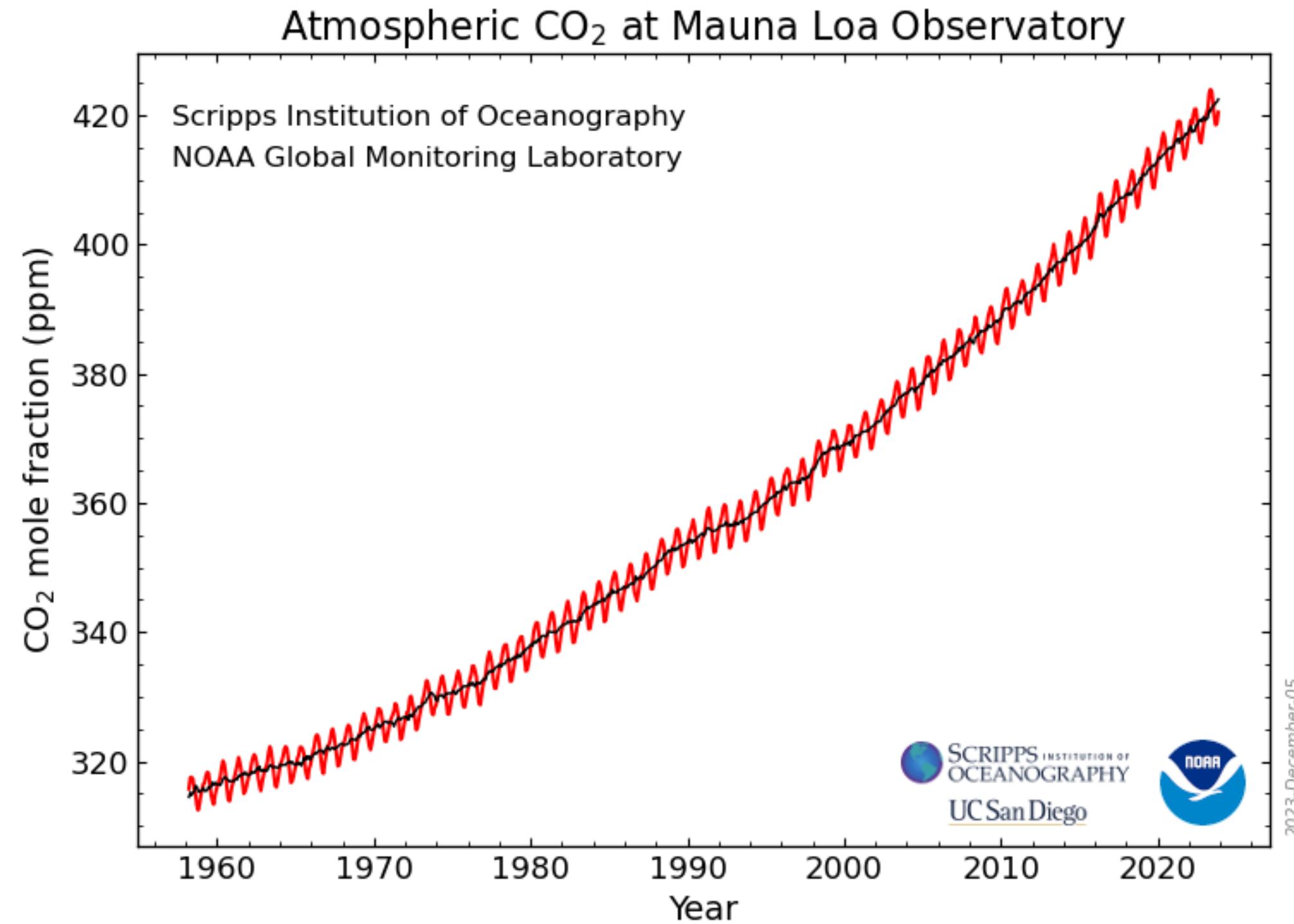
- Natural greenhouse affect maintains the average Earth temperature of 15° C
- If carbon dioxide was removed completely, the temperature would drop by 33° C
- Main greenhouse gases - total of 53.8 Gt CO₂ eq (CO₂ eq is the amount of heat an equal amount of CO₂ would be expected to trap over the next 100 years):
 - Carbon dioxide (CO₂) - 71.6%
 - Methane (CH₄) - 21%
 - Nitrous oxide (N₂O) - 4.8%
 - Fluorinated gases - 2.6%

POLL: DID THE LEVEL OF ATMOSPHERIC CO₂ GO DOWN DURING THE PANDEMIC?



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NO PHOTOCHEMICAL DESTRUCTION OF ATMOSPHERIC CO₂



The carbon dioxide data on Mauna Loa constitute the longest record of direct measurements of CO₂ in the atmosphere.

CARBON DIOXIDE (CO₂)

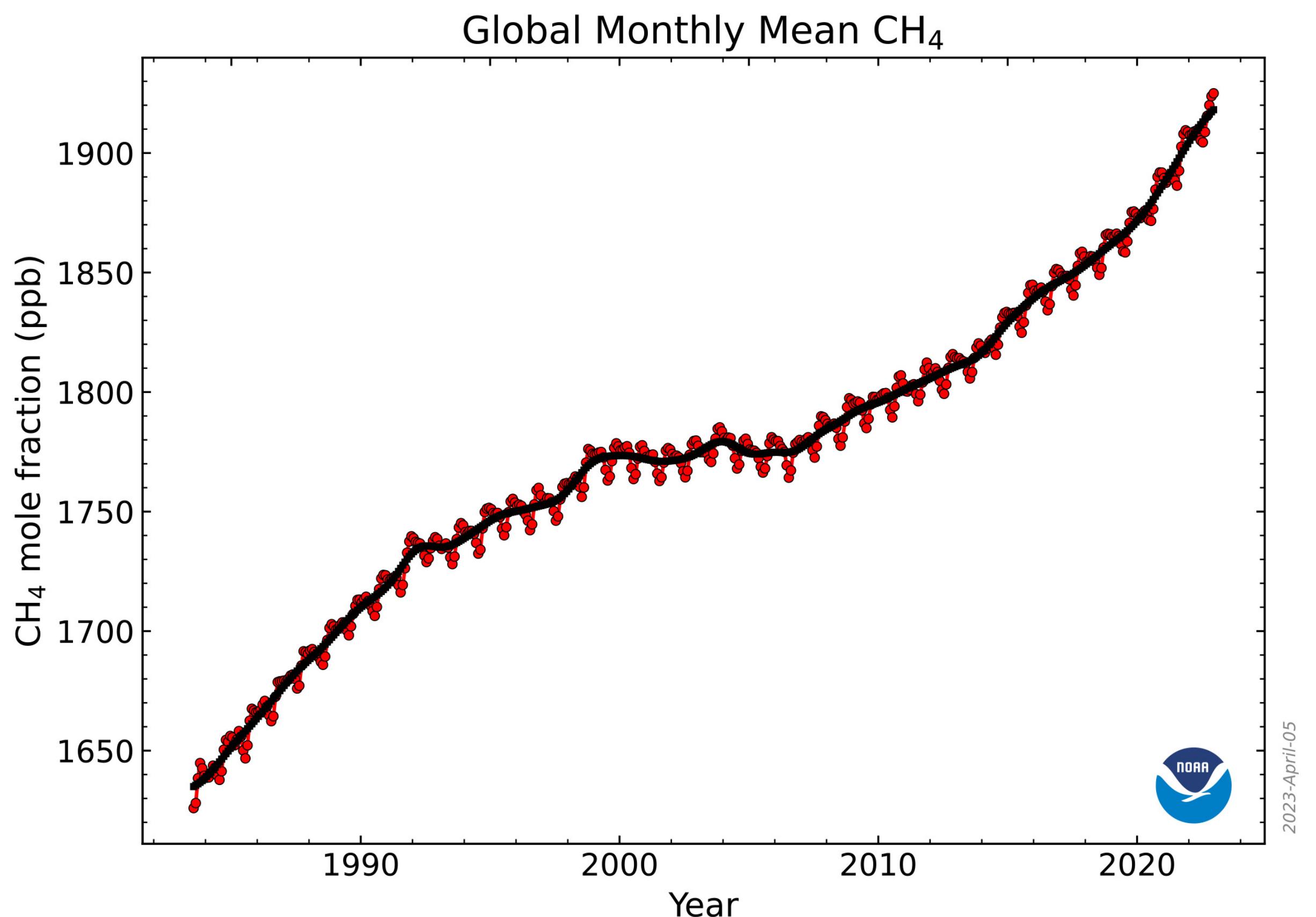


- In 2022: 38.5 Gt emissions in 2022 (71.6% of all GHG emissions) and 3236.4 Gt in the atmosphere
- Long lifetime in the atmosphere:
 - 40% remains after 100s of years
 - 20% after 1000s of years
 - 10% after 10000s of years
- Industries rely on carbon-rich fuels
- Difficult to monitor: annual anthropogenic emissions about 1.2% of atmospheric concentration, seasonality

Sources: NRDC 2023, Crippa et al. 2023, NOAA 2023

Photo by Jas Min on Unsplash

METHANE (CH_4)



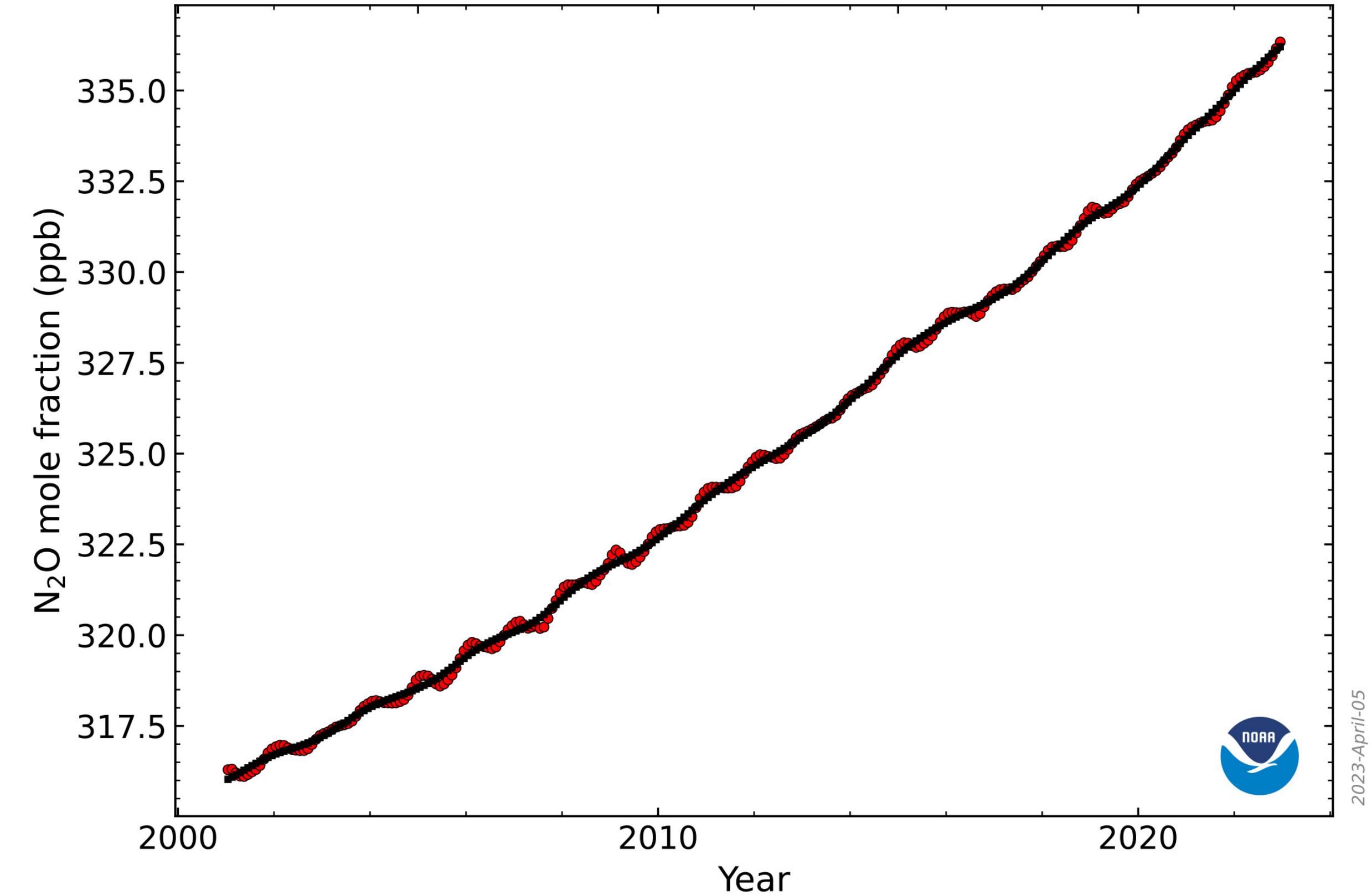
This graph shows the globally-averaged, monthly mean atmospheric methane abundance determined from marine surface sites since the inception of NOAA measurements starting in 1983. (Image credit: NOAA Global Monitoring Laboratory)

- 28 CO₂ eq: reflects 100x more heat than CO₂ but lifetime 10 years
- Cause of increase from 2006 is not fully known:
 - 85% is attributed to livestock, agriculture, waste, wetlands and aquatic sources.
 - Rest attributed to fossil fuel emissions (leaks from gas wells and pipes)
 - Possibly a feedback loop? (Warmer climate causes more methane emissions which in turn warms the climate)

Sources: NOAA 2023, MIT Climate Portal

NITROUS OXIDE (N_2O)

Global Monthly Mean N_2O



- 273 CO₂ eq: stays in the atmosphere for 100s of years
- Main source: nitrogen-based fertilizers in agriculture. Other sources: industrial activities, combustion of fossil fuels and solid waste, treatment of wastewater

This graph shows the globally-averaged, monthly mean atmospheric nitrous oxide abundance determined from marine surface sites since 2001. (Image credit: NOAA Global Monitoring Laboratory)

Sources: NOAA 2023, MIT Climate Portal

FLUORINATED GASES ('F-GASES')

- Many gases: hydrofluorocarbons (HFCs) - 90%, perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), and nitrogen trifluoride (NF₃).
- Up to 14,600 CO₂ eq
- Used in refrigerators, air conditioners and other industrial processes



Sources: MIT Climate Portal

Photo by Eduardo Soares on Unsplash

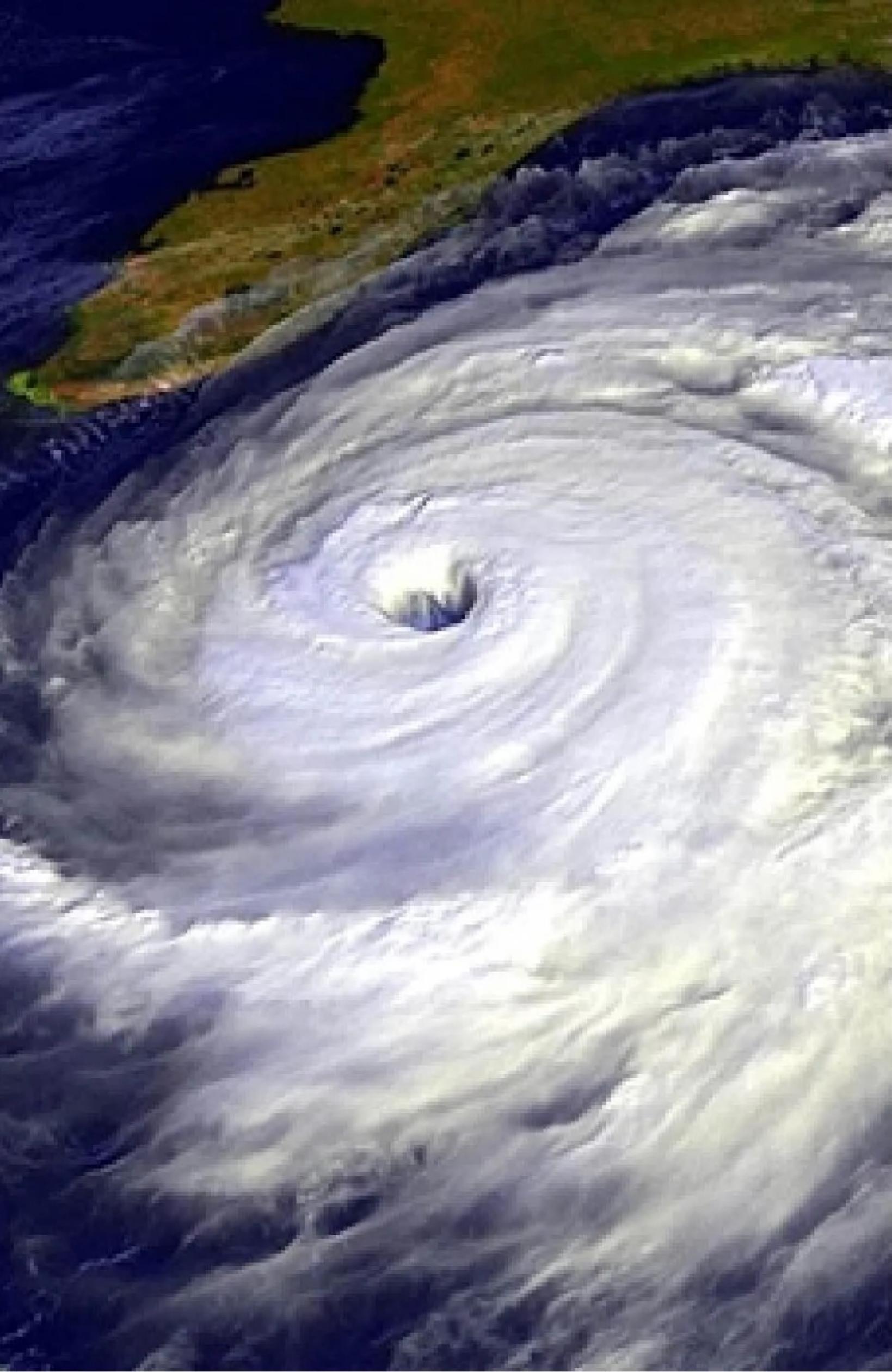


Photo: NASA (left - Mike McMillan/USFS, center - Tomas Castelazo / Wikimedia Commons / CC BY-SA 4.0, right - NASA)

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 (<i>Vibrio vulnificus</i>)	Rising sea surface temperature, changes in precipitation and runoff affecting coastal salinity	Recreational water or shellfish contaminated with <i>Vibrio vulnificus</i>	<i>Vibrio vulnificus</i> induced diarrhea & intestinal illness, wound and blood-stream infections, death Increases in water temperatures will alter timing and location of <i>Vibrio vulnificus</i> growth, increasing exposure and risk of water-borne illness.
 Food-Related Infection (<i>Salmonella</i>)	Increases in temperature, humidity, and season length	Increased growth of pathogens, seasonal shifts in incidence of <i>Salmonella</i> exposure	<i>Salmonella</i> infection, gastrointestinal outbreaks Rising temperatures increase <i>Salmonella</i> 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.

IMPACT OF CLIMATE CHANGE

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- Weather
- Environment
- Agriculture
- Animals
- Humans

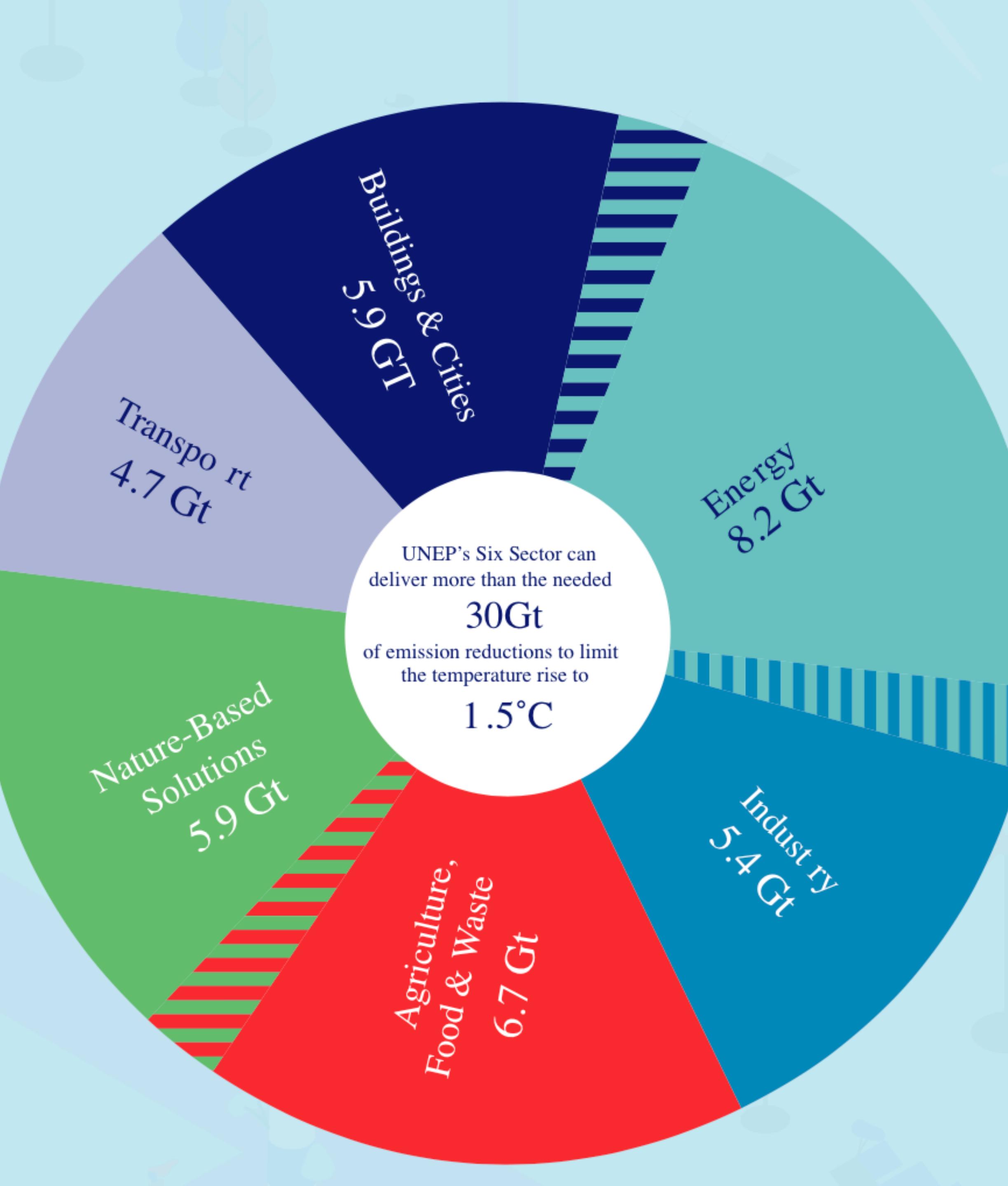
Figure by Crimmins et al. (2016)

POLL: WHAT IS THE CURRENT TEMPERATURE GOAL FOR GLOBAL WARMING?



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**MACRO PICTURE: INTRODUCE
POLICIES AND MONITOR THEIR
IMPACT**



MAIN AGREEMENTS

- United Nations Framework Convention on Climate Change - UNFCCC (1992):
 - Multilateral treaty to stabilise anthropogenic GHG emissions, in force since 1994
 - Currently 198 parties
- Kyoto Protocol (1997):
 - Operationalises UNFCCC, binding for developed countries
 - 192 parties, in force since 2005
- Paris Agreement (2015):
 - Legally binding (196 parties, in force since 2016)
 - Hold the increase of global average temperature to well below 2°C above pre-industrial levels and limit the temperature increase to 1.5°C above pre-industrial levels (1°C was reached in 2017)
 - For 1.5°C: GHG emissions need to peak by 2015 and need to cut 30 Gt GHG emissions/year by 2030
 - Nationally determined contributions

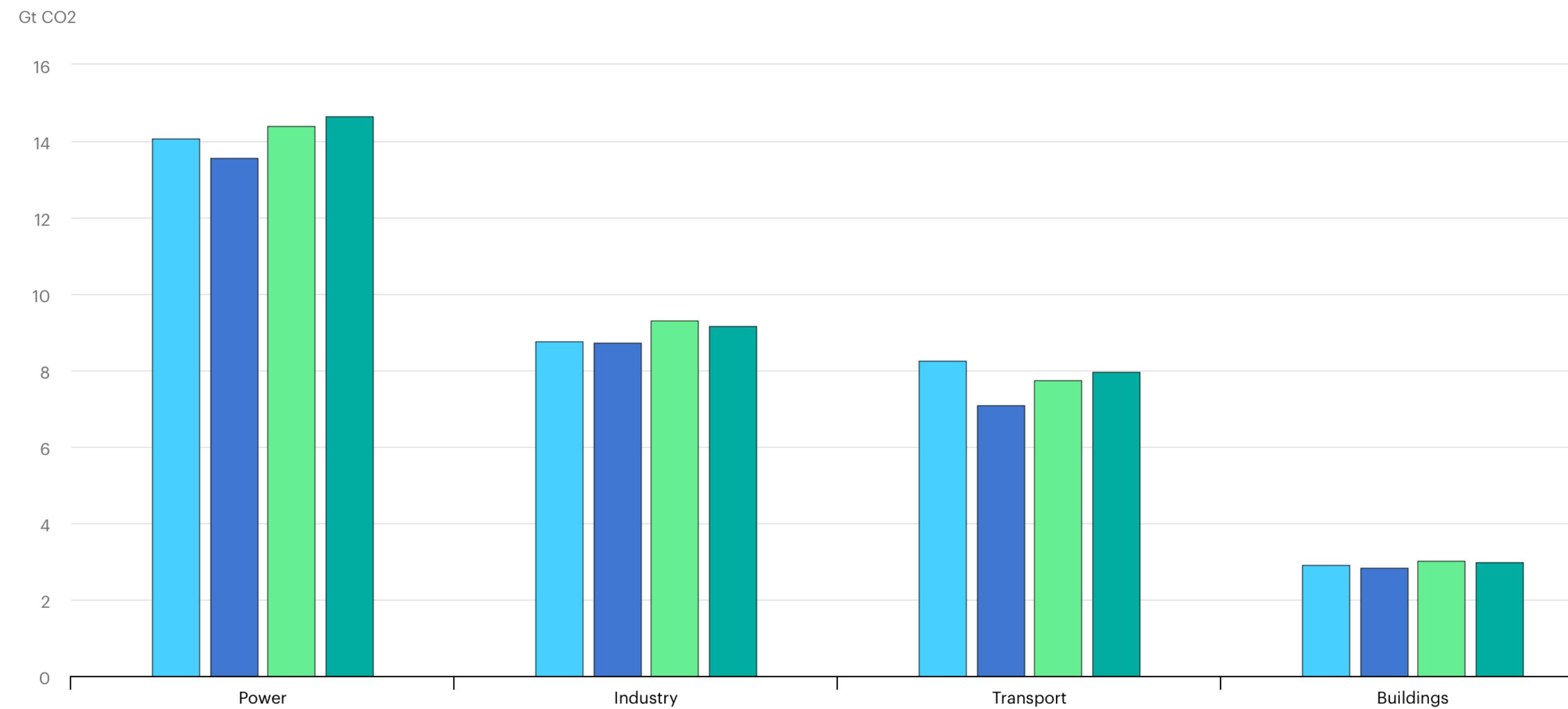
Sources: UNEP, UNFCCC

POLL: WHICH SECTOR IS THE BIGGEST CONTRIBUTOR OF CO2 EMISSIONS GLOBALLY



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GLOBAL CO₂ EMISSIONS BY SECTOR

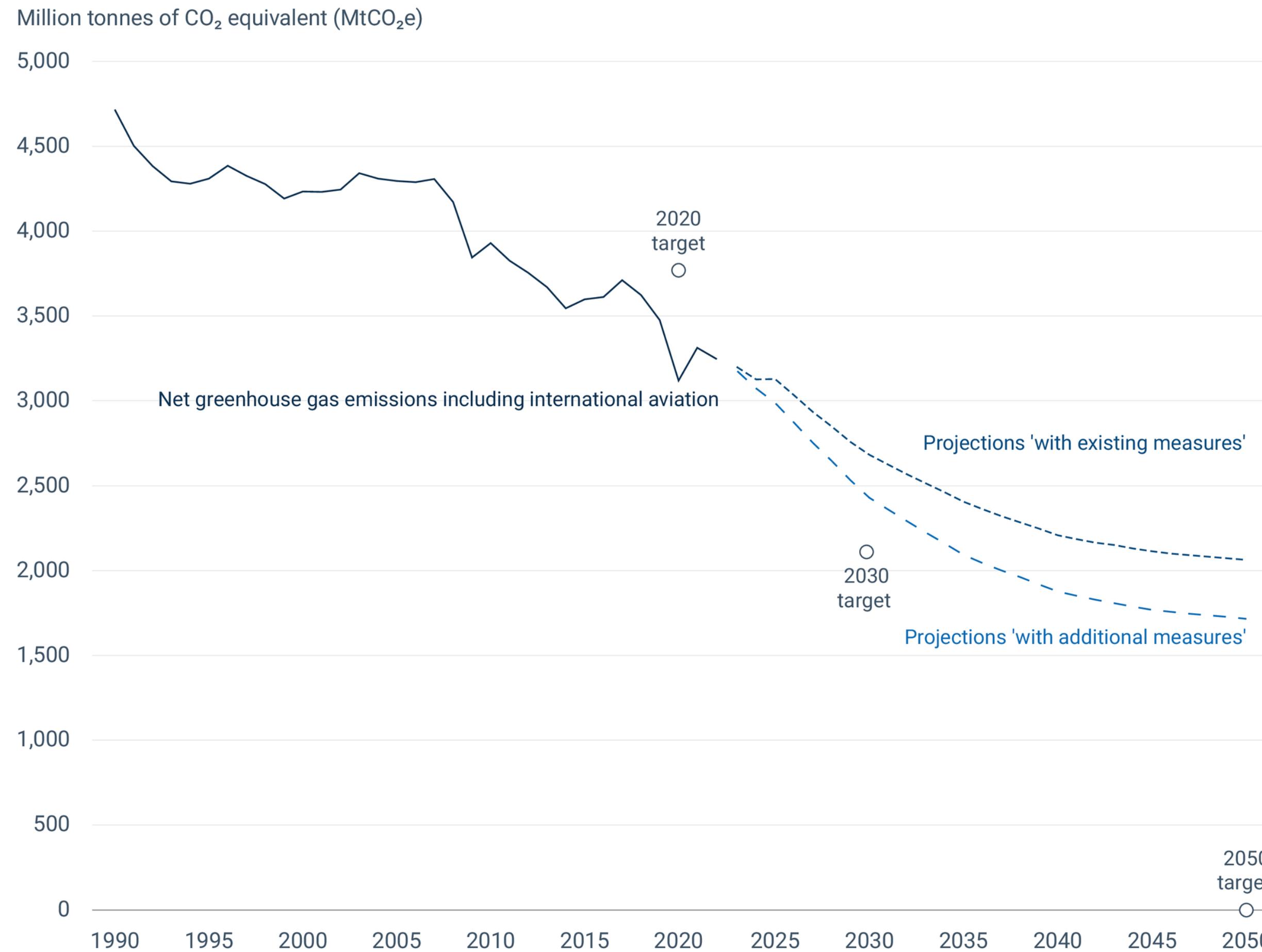


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● 2019 ● 2020 ● 2021 ● 2022

CHALLENGES OF MEASURING AND MODELLING CLIMATE CHANGE

MAIN CHALLENGES



- Modelling assumptions and interactions between variables
- Reliability and availability of data
- Conflicts of interest and maladaptation

Figure: EEA - Progress towards achieving climate targets in the EU-27



REMOTE SENSING

- Objective
- Global
- Still: coverage, clouds, high background concentration, natural variation, noise

Photo by NASA on Unsplash

THE COPERNICUS PROGRAMME



The Copernicus Sentinel missions offer Earth observation data for applications such as climate change monitoring and natural disaster response.

- Sentinel-1: images Earth's surface through rain and cloud regardless of whether it is day or night.
- Sentinel-2: carries a high-resolution multispectral optical imager to monitor changes in vegetation.
- Sentinel-3: supplies data related mainly to the marine environment.
- Sentinel-4: is an ultraviolet, visible and near-infrared spectrometer.
- Sentinel-5P: carries the Tropomi imaging spectrometer to provide information on trace gases (NO₂, CO, CH₄, ...) and aerosols affecting air quality and climate.

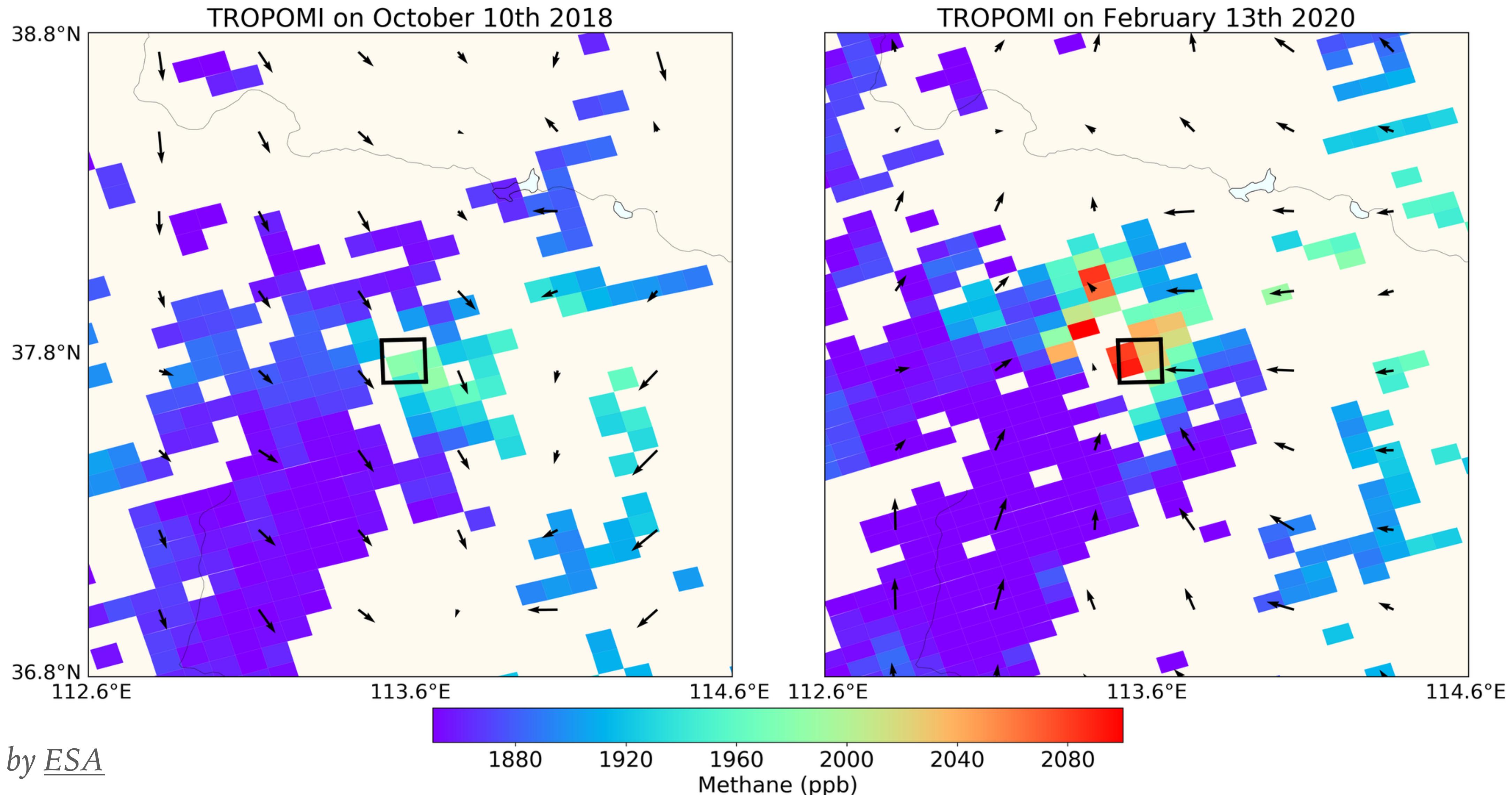
MONITORING CO₂ EMISSIONS

- OCO-2 (Orbiting Carbon Observatory-2): was launched in 2014 by NASA. It monitors global CO₂ concentrations.
- OCO-3 was launched in 2019, mounted on the International Space Station (ISS). It is a follow-up mission to OCO-2. Being at ISS, it allows for more targeted observations, measuring specific cities or regions



OCO-2 and OCO-3 overpass on April 17, 2020

METHANE HOTSPOTS DETECTED WITH COPERNICUS SENTINEL-5P (TROPOMI)



ROLE OF ML IN CLIMATE ACTION

ML AND CLIMATE ACTION

- 13.1 Strengthen resilience and adaptive capacity
- 13.2 National policies, strategies and planning
- 13.3 Improve education, awareness-raising and human and institutional capacity
- 13.A Developed countries mobilizing jointly \$100 billion annually by 2020
- 13.B Effective climate change-related planning and management in least developed countries and small island developing states

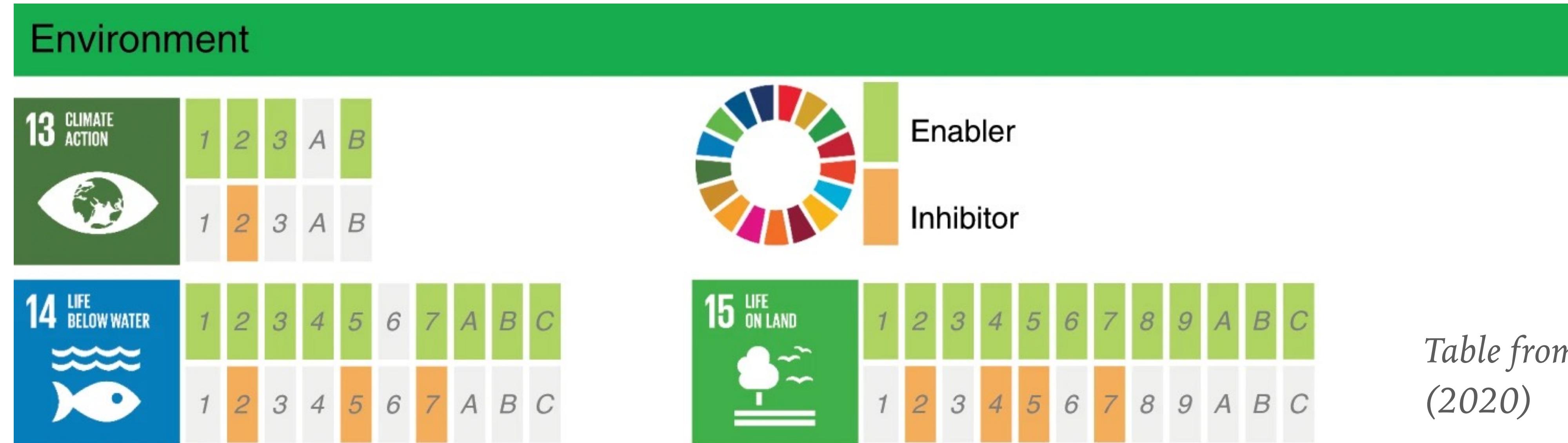


Table from Vinuesa et al.
(2020)

DISCUSSION: HOW ML CAN BE USED TO ENABLE AND INHIBIT CLIMATE ACTION



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Word co-occurrence network graphs among bibliographic metadata using Scopes under 2015–2020 time slice from Zennaro et al. (2021)

PUBLICATIONS THAT WILL BE COVERED IN THIS COURSE

- Power D. P. Finch, P. I. Palmer, and T. Zhang (2022). *Automated detection of atmospheric NO₂ plumes from satellite data: a tool to help infer anthropogenic combustion emissions.* Atmospheric Measurement Techniques, 15(3):721–733, 2022.
- Industry Schuit, B. J., Maasakkers, J. D., Bijl, P., Mahapatra, G., Van den Berg, A. W., Pandey, S., Aben, I. (2023). *Automated detection and monitoring of methane super-emitters using satellite data.* Atmospheric Chemistry and Physics Discussions, 1-47.
- Transport Paolo, F., Kroodsma, D., Raynor, J. et al. *Satellite mapping reveals extensive industrial activity at sea.* Nature 625, 85–91 (2024). <https://doi.org/10.1038/s41586-023-06825-8>
- Buildings TBD
- Uncertainty quantification TBD

PRACTICALITIES

SCHE

- **Lectures** - Mondays, 12:15 - 14:00, R001/Y313
- **Exercises**
 - Thu 11.01.2024 10:15 - 12:00, R037/1521-1522 AS6
 - Thu 18.01.2024 10:15 - 12:00, R030/A136 T6
 - Thu 25.01.2024 10:15 - 12:00, R037/1521-1522 AS6
 - Thu 01.02.2024 10:15 - 12:00, R030/A136 T6
 - Thu 08.02.2024 10:15 - 12:00, R030/A136 T6
 - Thu 15.02.2024 10:15 - 12:00, R030/A136 T6

Bring your laptop to the exercise sessions!

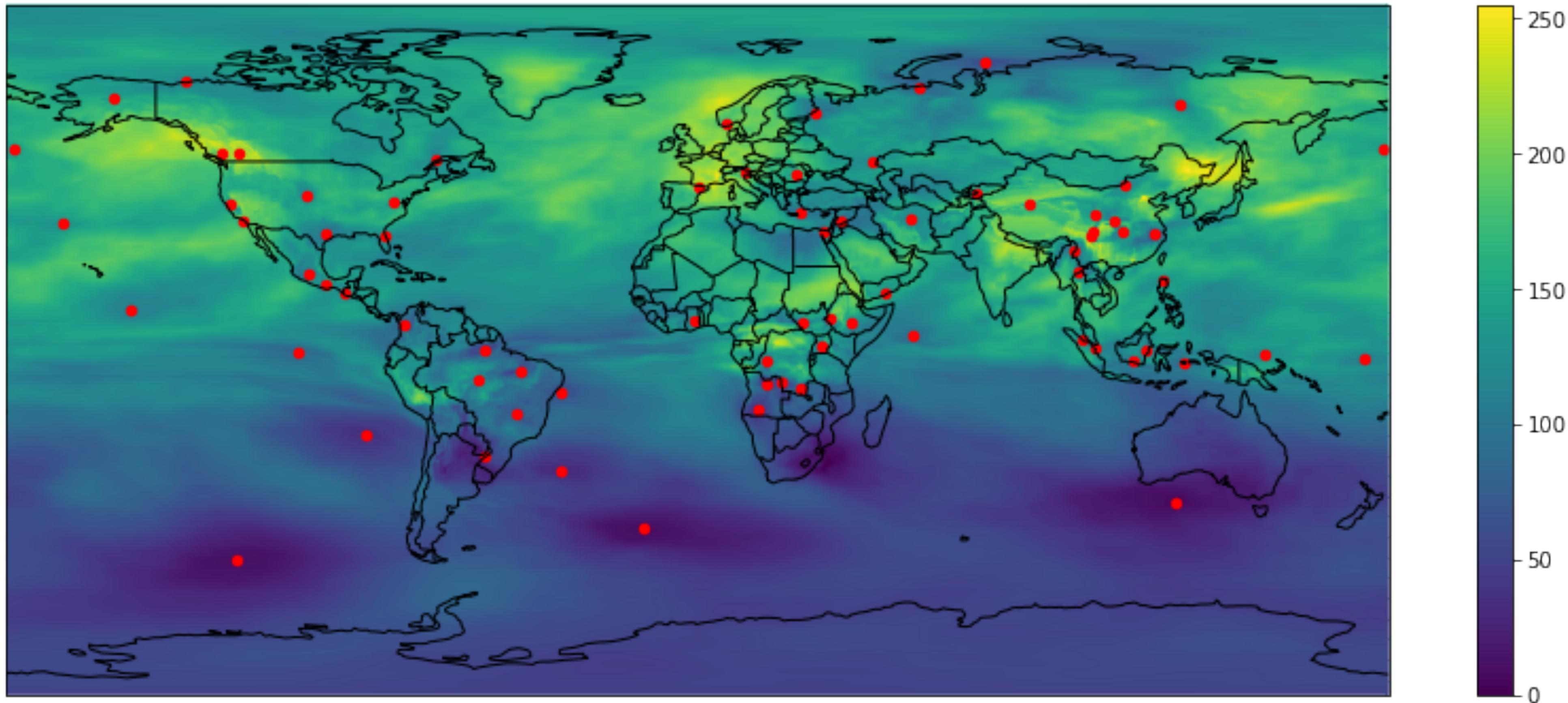
CONTACT US

- Primary channel: Zulip
- Email: cs-e407519@aalto.fi
- Office hours: upon request

EXPECTATIONS

- How to pre-read a paper
 - Read abstract, figures, tables, discussion and results
 - Skim through introduction, methodology and data
- Exercises - think of it as a first rough experiment for a Master's thesis project
 - What worked?
 - What didn't work?
 - What would be a good next step/analysis/improvement of the algorithm?

EXAMPLE: DETECTING CO₂ ANOMALIES USING TOPOLOGICAL DATA ANALYSIS



Normalised change in yearly mean CO₂ levels from 2015 to 2021

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- Crippa, M., Guizzardi, D., Pagani, F., Banja, M., Muntean, M., Schaaf E., Becker, W., Monforti-Ferrario, F., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Köykkä, J., Grassi, G., Rossi, S., Brandao De Melo, J., Oom, D., Branco, A., San-Miguel, J., Vignati, E., (2023) GHG emissions of all world countries, Publications Office of the European Union, Luxembourg, doi:10.2760/953322, JRC134504.
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- NASA, What is the greenhouse effect? <https://climate.nasa.gov/faq/19/what-is-the-greenhouse-effect/#:~:text=Greenhouse> gases consist of carbon, that initially caused the warming. (Accessed Dec 2023)
- NOAA, Greenhouse gases continued to increase rapidly in 2022 <https://www.noaa.gov/news-release/greenhouse-gases-continued-to-increase-rapidly-in-2022> (Accessed Dec 2023)
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