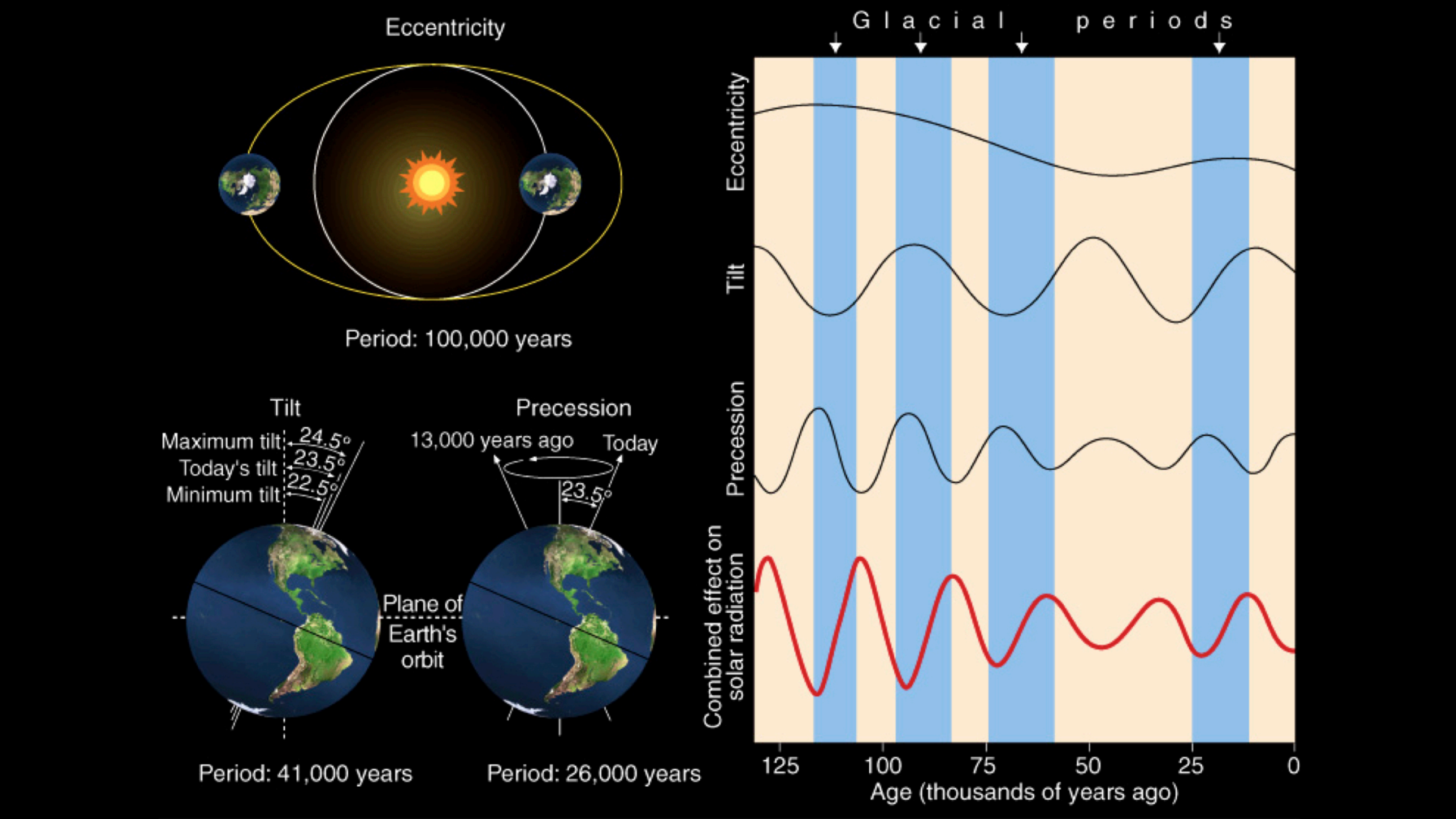
A Perspective on Revolutions, Revisions, Rights, and Responsibilities in the Geosciences

https://CroninProjects.org/October2024/

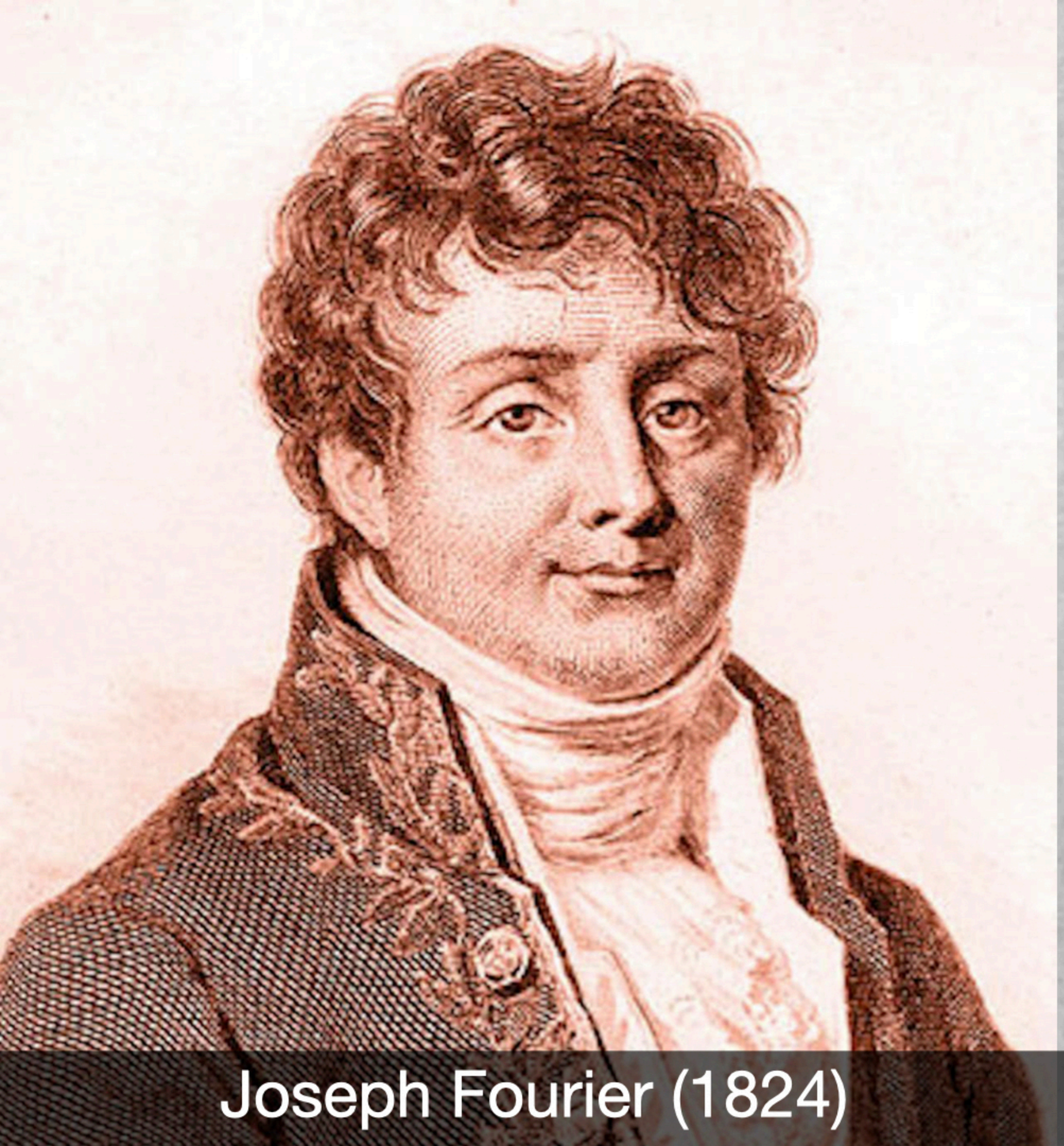
Kimberly, Australia, from Planet Snapshots, www.planet.com

A Brief Primer on Global Warming

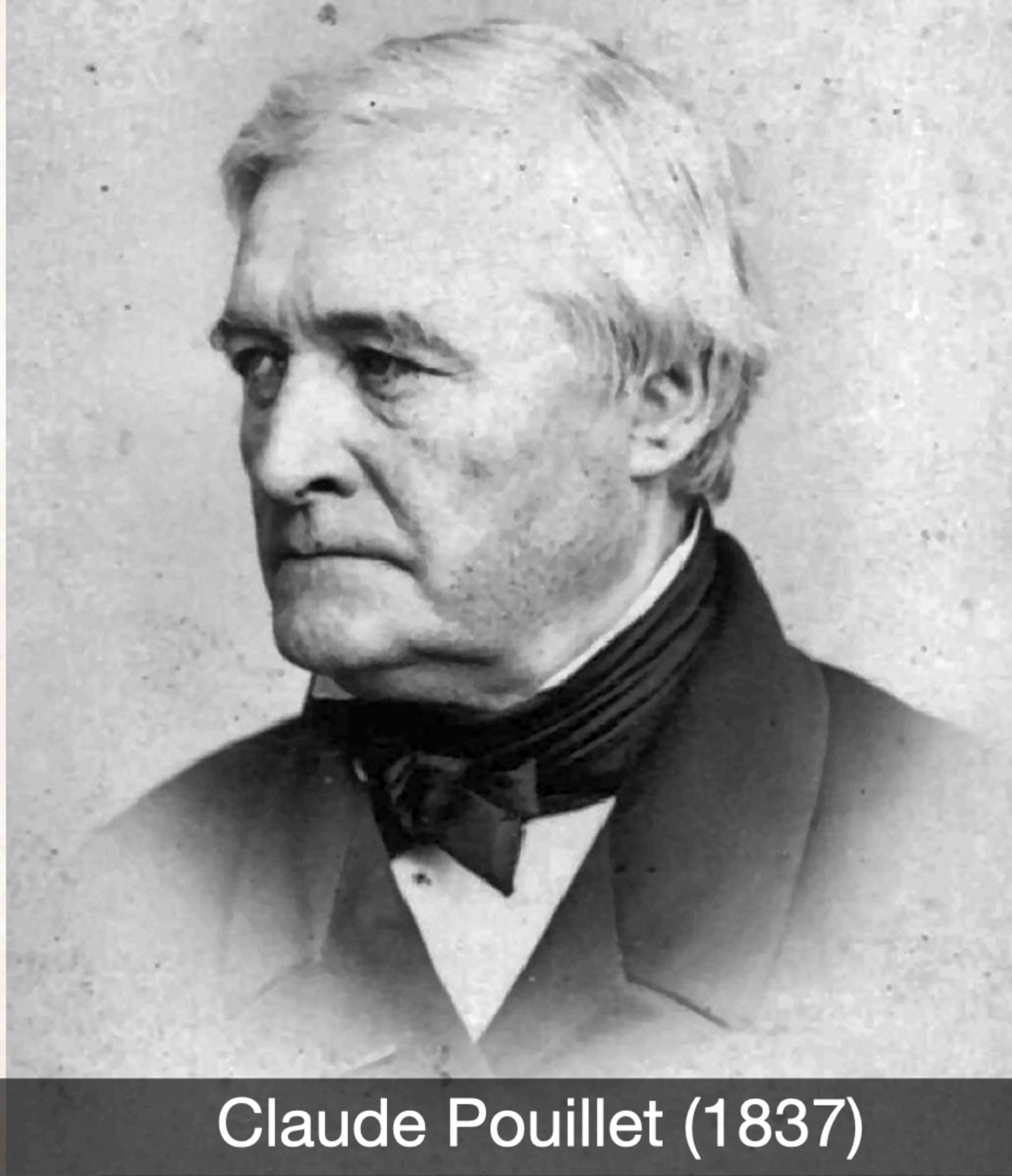
https://CroninProjects.org/October2024/Climate


Eccentricity
Period: 100,000 years
Tilt
Maximum tilt
Today's tilt
Minimum tilt
24.5°
23.5°
22.5°
Period: 41,000 years
Precession
13,000 years ago
Today
23.5°
Plane of Earth's orbit
Period: 26,000 years
Glacial periods
Eccentricity
Tilt
Precession
Combined effect on solar radiation
125
100
75
50
25
0
Age (thousands of years ago)

History of how scientists came to (partly) understand the problem of climate change: **https://history.aip/org/climate**



Joseph Fourier (1824)



Claude Pouillet (1837)

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

Eunice Newton Foote, 1856, American Journal of Science and Arts, v. 22, p. 377-383

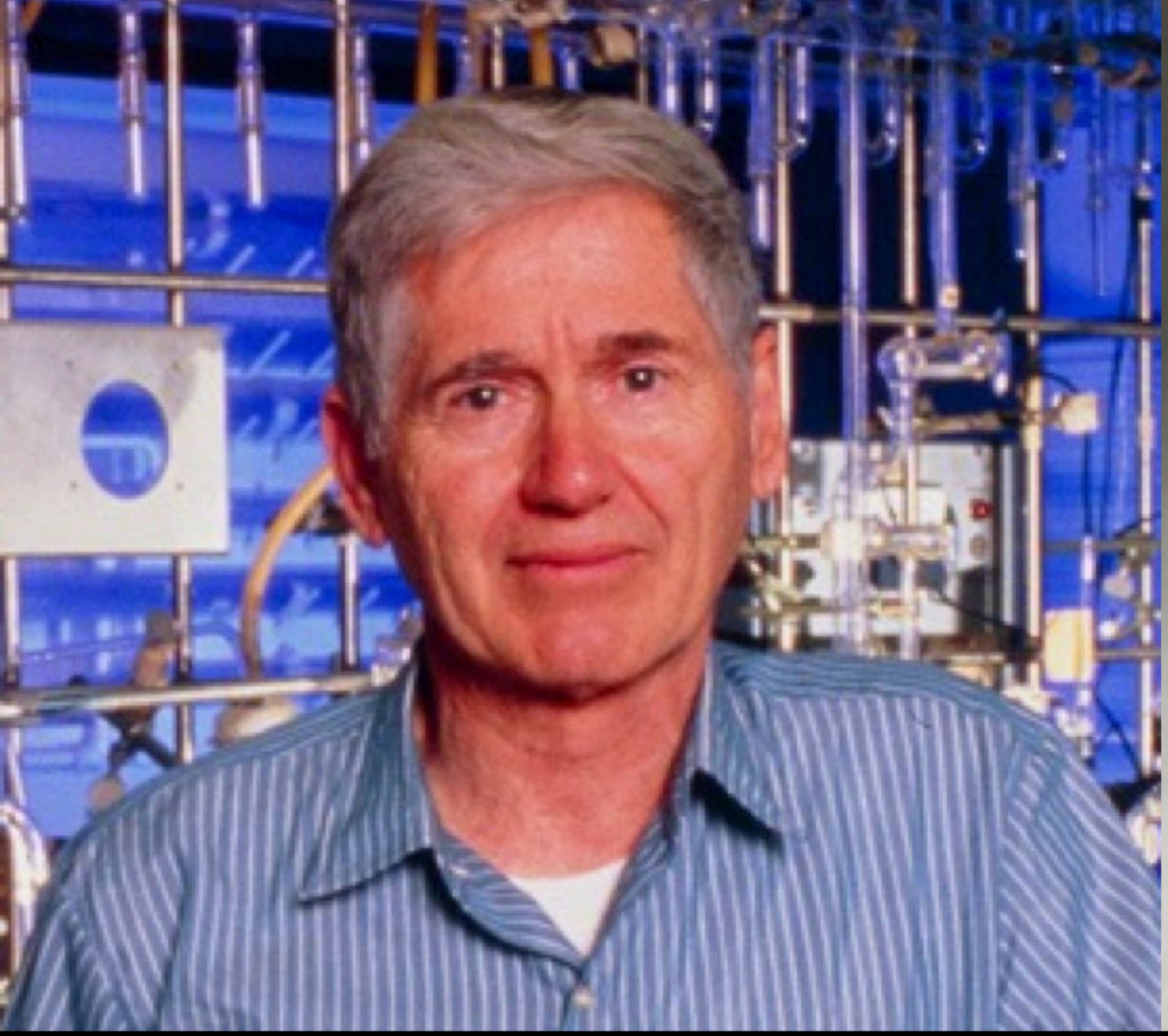
Mason Hill

A.O. “Woody” Woodford

Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future.

Revelle and Suess, 1957

Roger Revelle



Charles David Keeling

Roger Revelle

https://commons.wikimedia.org/wiki/File:170830-H-NI589-563_(36766744932).jpg


Road damage in North Carolina, Hurricane Helene, 2024
Photo from NC DOT

The only ethical principle which has made science possible is that the truth shall be told all the time.

Physicist C.P. Snow (1932)

The Tasks Ahead

First:

Second:

Third:

The Tasks Ahead

First: Develop your knowledge

Second:

Third:

The Tasks Ahead

First: Develop your knowledge

Second: Communicate your knowledge to help society develop its understanding

Third:

The Tasks Ahead

First: Develop your knowledge

Second: Communicate your knowledge to help society develop its understanding

Third: Apply your knowledge to help solve problems

Michael Fahey

Born in 1844 in County Clare, Ireland

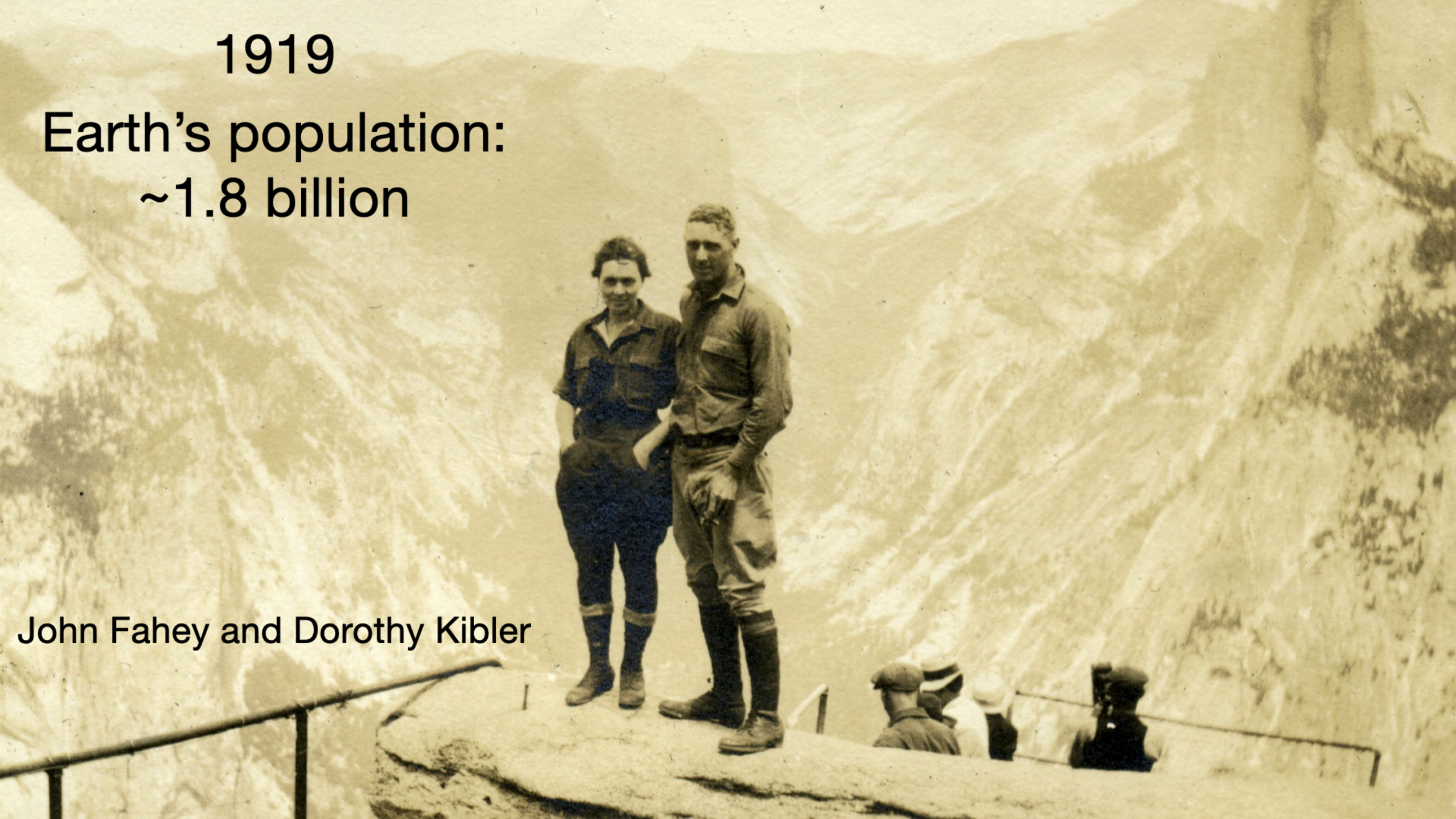
The population of Los Angeles County in 1844 was ~5,000.

The human population of Earth then was just under 1.2 billion.


1894
Earth's population:
~1.55 billion
Infant John Fahey in California

1919

Earth’s population:
~1.8 billion



John Fahey and Dorothy Kibler


1948
Earth’s population:
~2.5 billion


1957
Earth’s population:
~2.9 billion


1997
Earth’s population:
~5.9 billion

Today

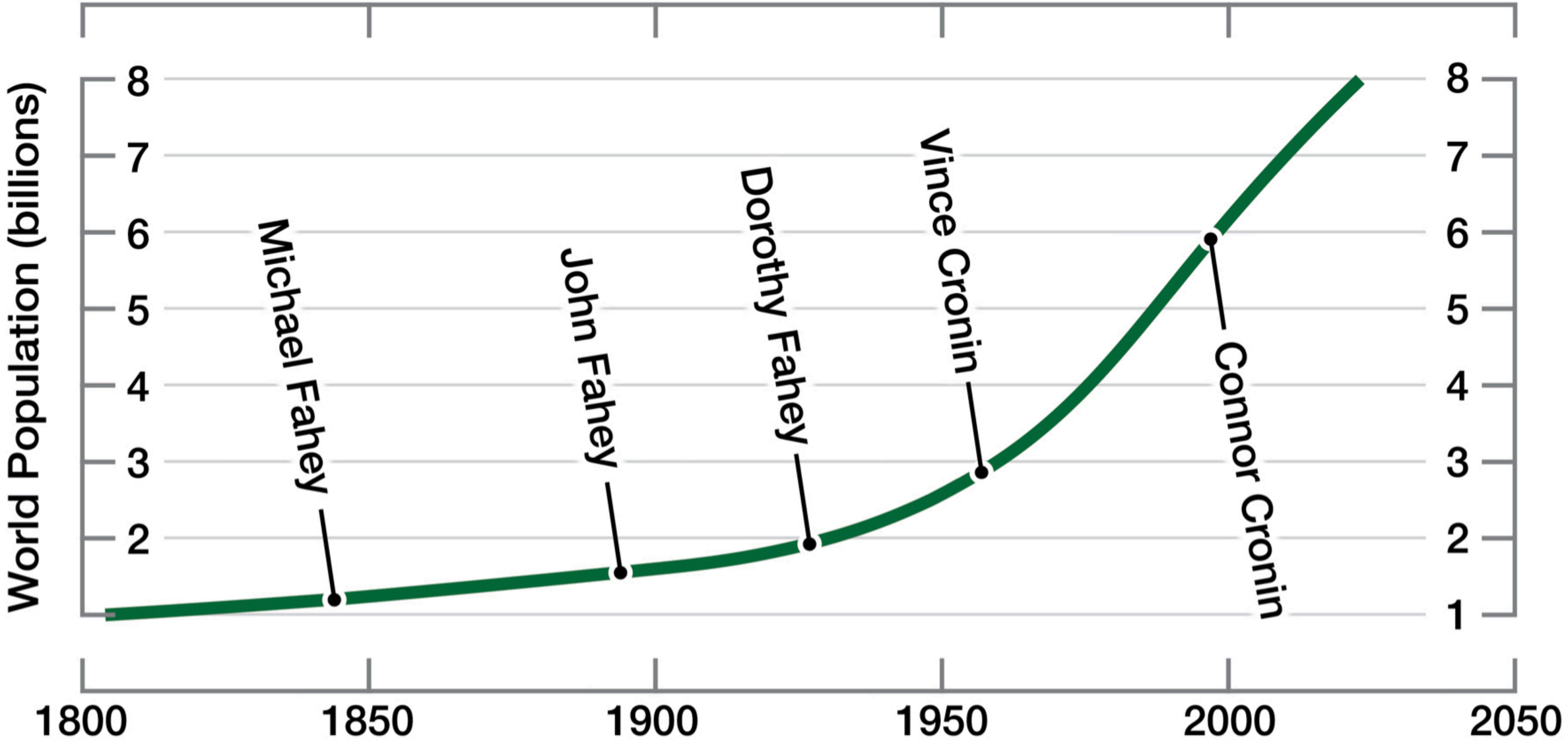
Over 5 generations, the population of Los Angeles County has increased from 5000 to ~10.7 million

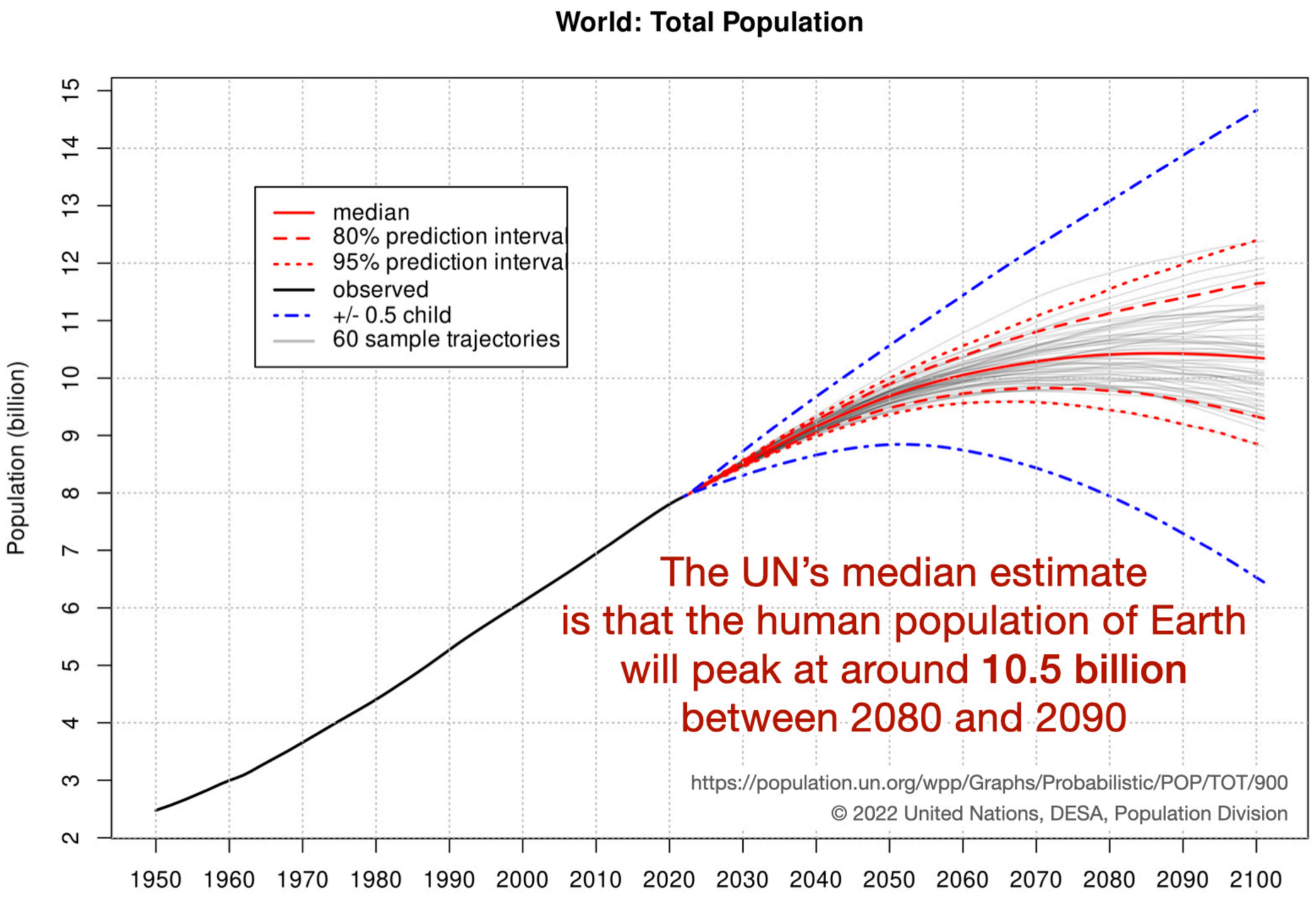
Today

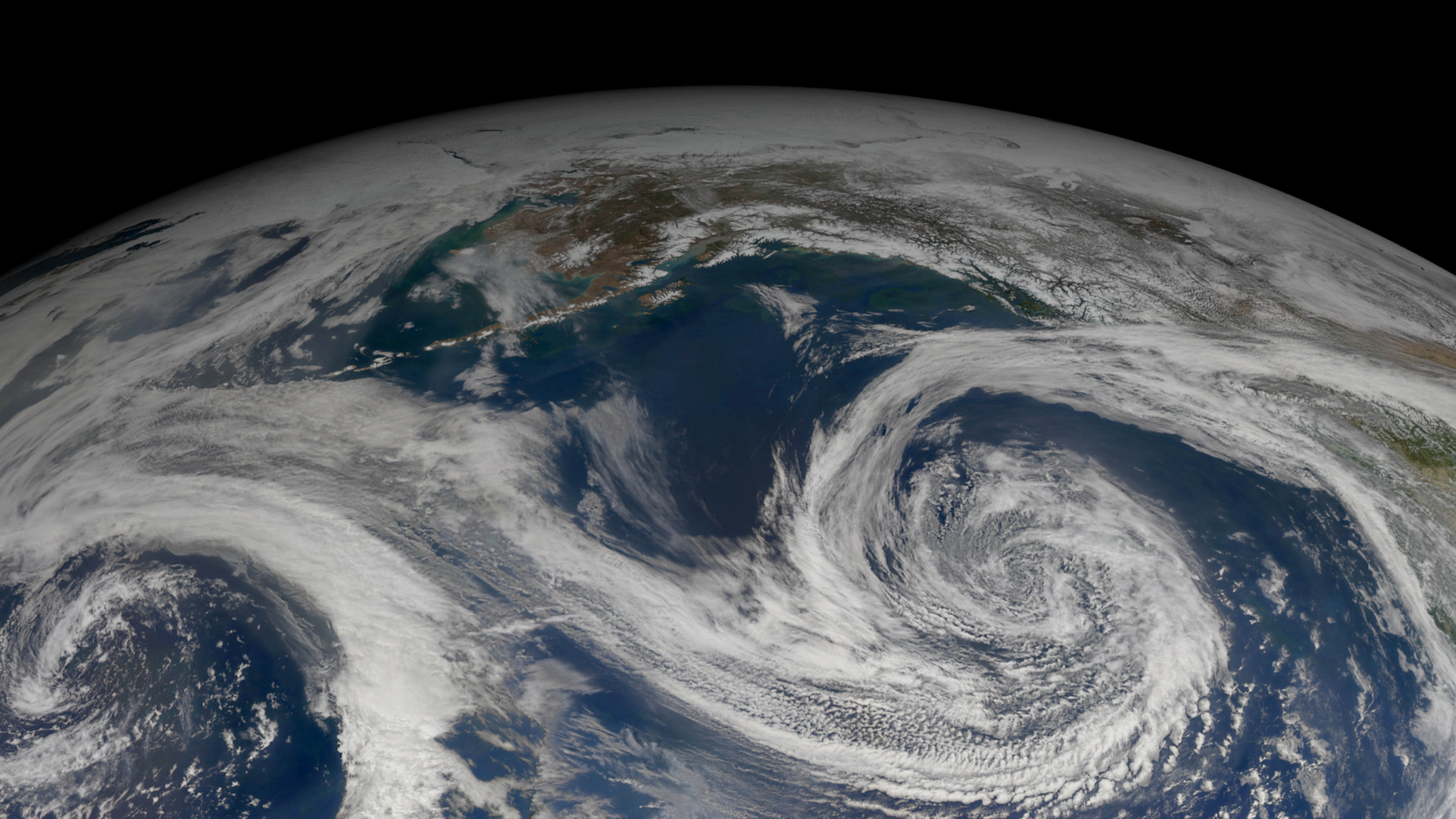
Over 5 generations, the population of Los Angeles County has increased from 5000 to ~10.7 million

…and Earth's human population increased by a factor of ~6.7, from 1.2 to 8 billion

World Population Growth Over 5 Generations of the Fahey-Cronin Family




World: Total Population
Population (billion)
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
median
80% prediction interval
95% prediction interval
observed
+/- 0.5 child
60 sample trajectories
The UN's median estimate
is that the human population of Earth
will peak at around **10.5 billion**
between 2080 and 2090
https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900
© 2022 United Nations, DESA, Population Division




Truth is what stands the
test of experience.
Al Einstein

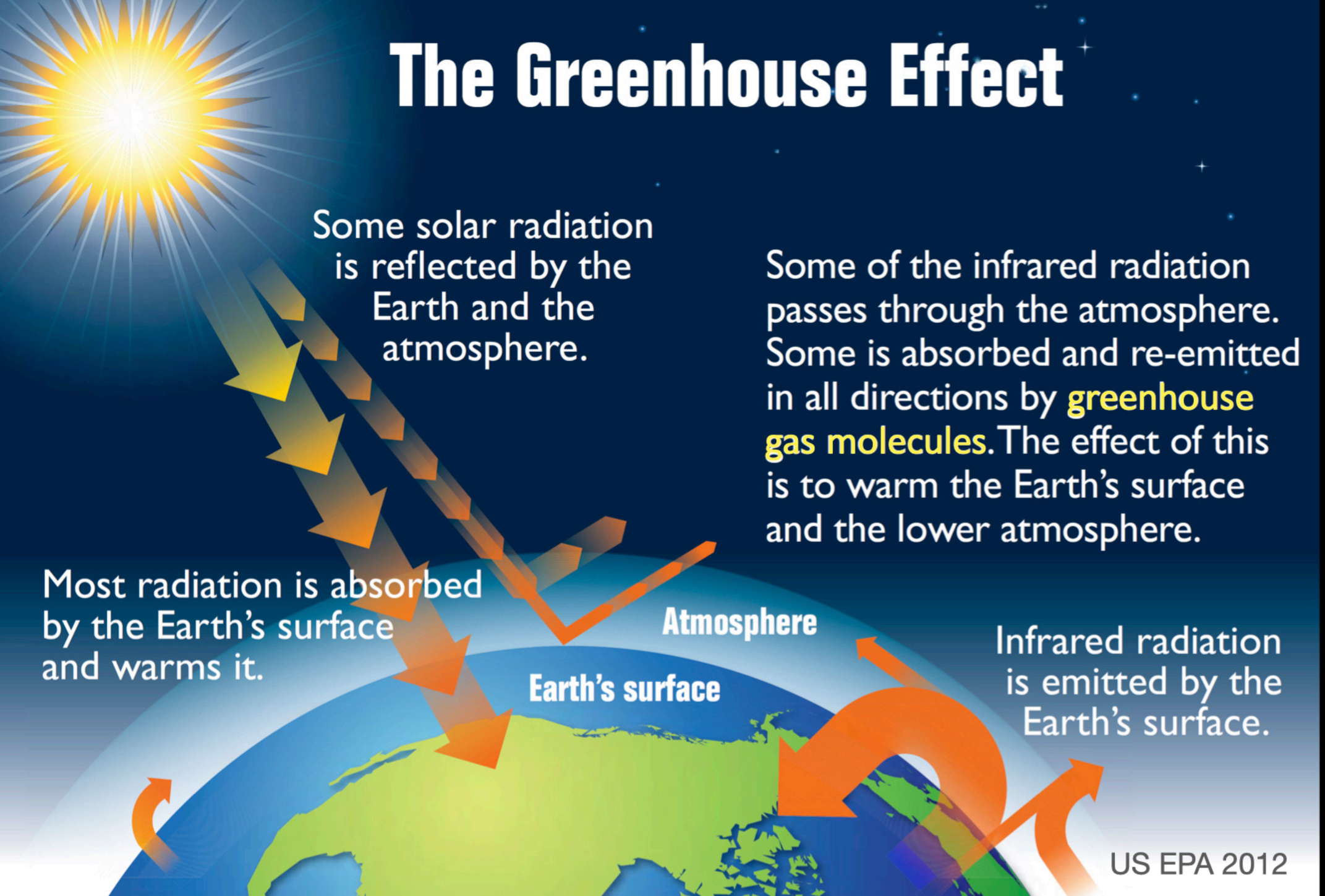
Greenhouse gases in the atmosphere

The lower atmosphere's temperature is controlled by water vapor and a few gases that do not condense in the atmosphere—

The lower atmosphere's temperature is controlled by water vapor and a few gases that do not condense in the atmosphere—

mostly **carbon dioxide** (CO_2), **methane** (CH_4), **nitrous oxide** (N_2O), ozone (O_3), and human-made fluorinated gases.

The Greenhouse Effect



Some Greenhouse Gases

carbon dioxide

methane

nitrous oxide

water vapor

ozone

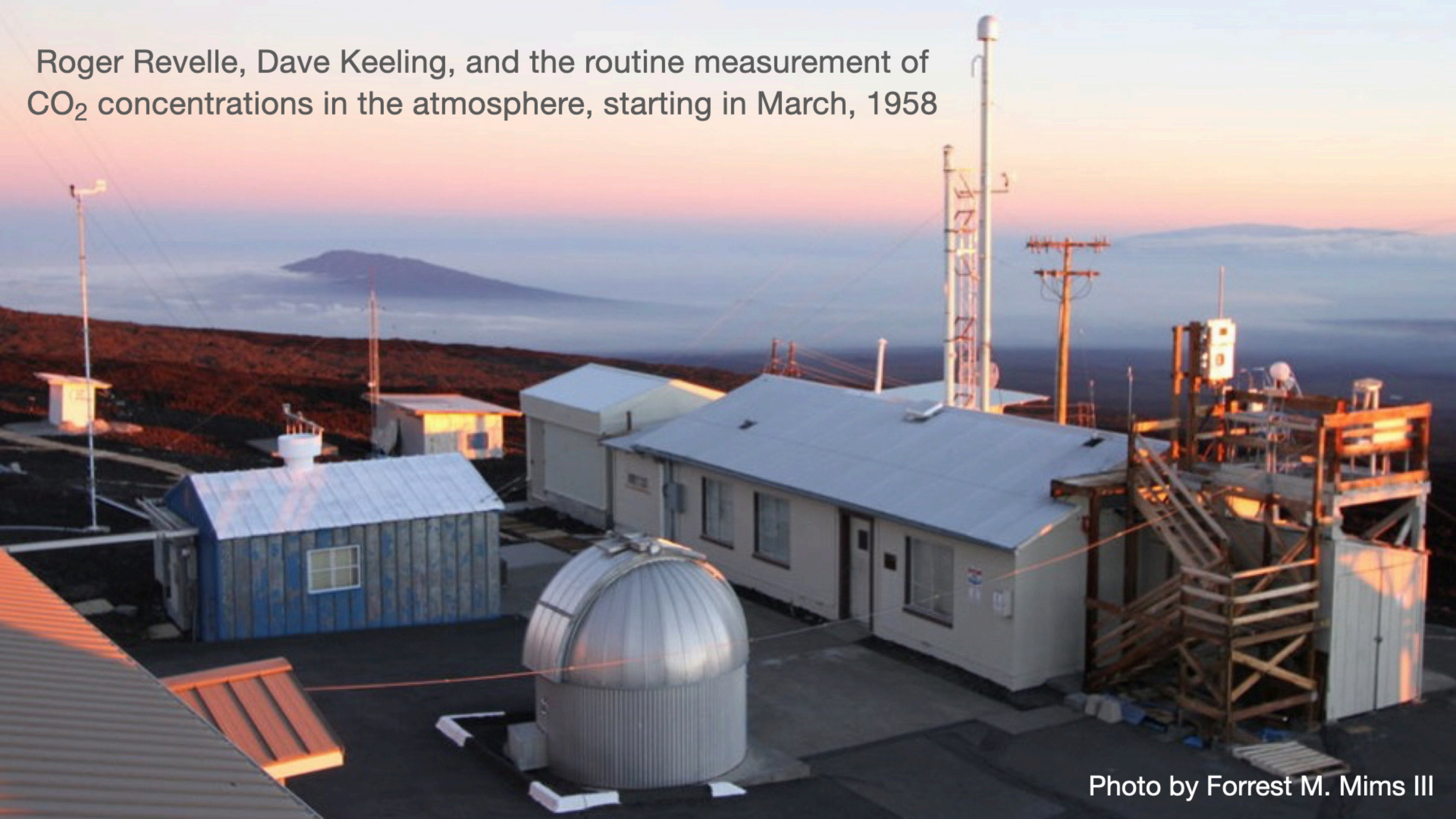
Warming caused by the increase in non-condensible gases results in an increase in water vapor in the atmosphere, adding to the warming effect.

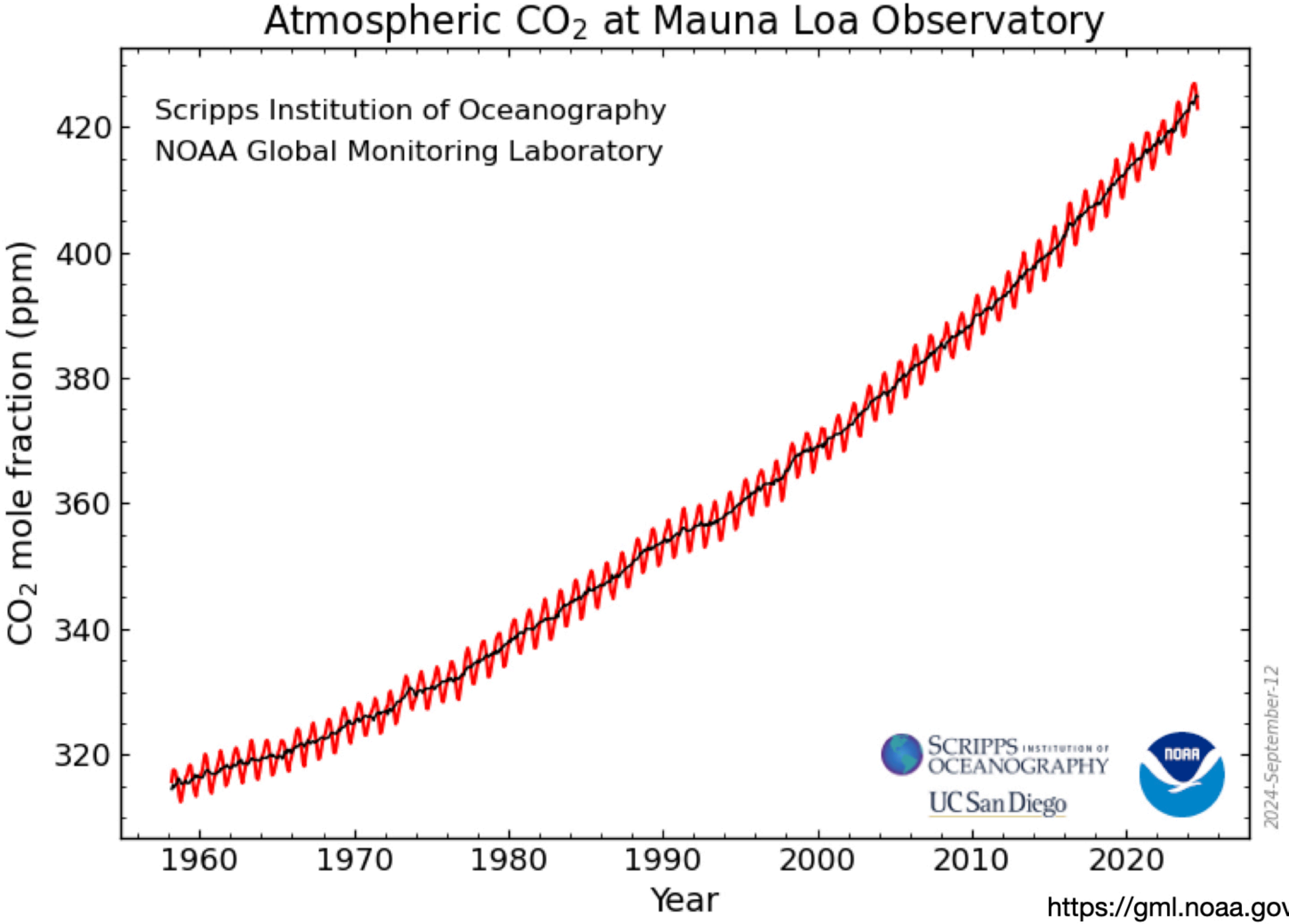
Warming caused by the increase in non-condensible gases results in an increase in water vapor in the atmosphere, adding to the warming effect.

Tiny aerosol particles in the air, such as soot, volcanic ash, and sulfate droplets, have a ***cooling*** effect on the atmosphere's temperature.

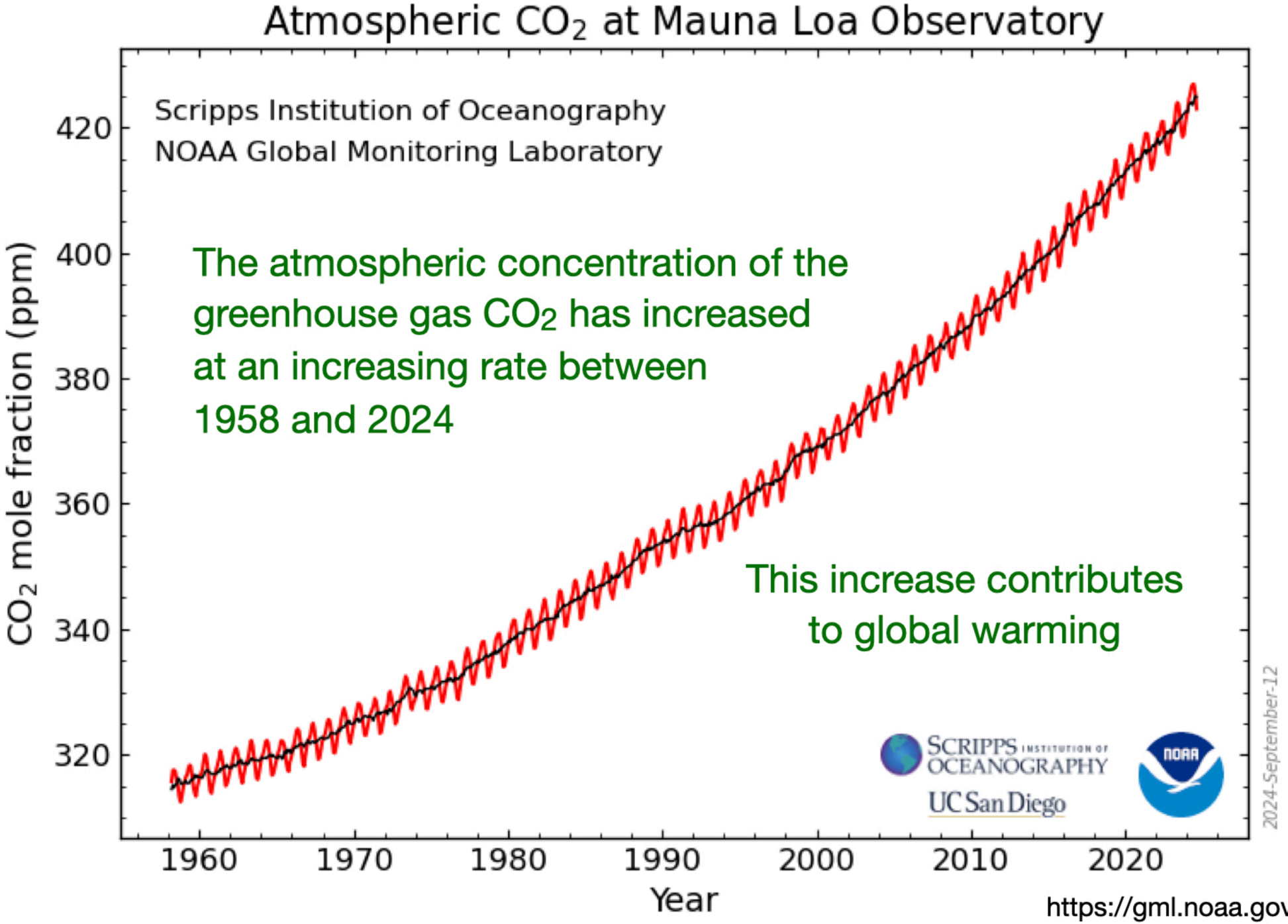

Photo by Dave Harlow, USGS

Have we measured whether atmospheric concentrations of the greenhouse gases **carbon dioxide** (CO_2), **methane** (CH_4), or **nitrous oxide** (N_2O) are changing?


Roger Revelle, Dave Keeling, and the routine measurement of
CO_2 concentrations in the atmosphere, starting in March, 1958
Photo by Forrest M. Mims III



https://gml.noaa.gov/ccgg/trends/



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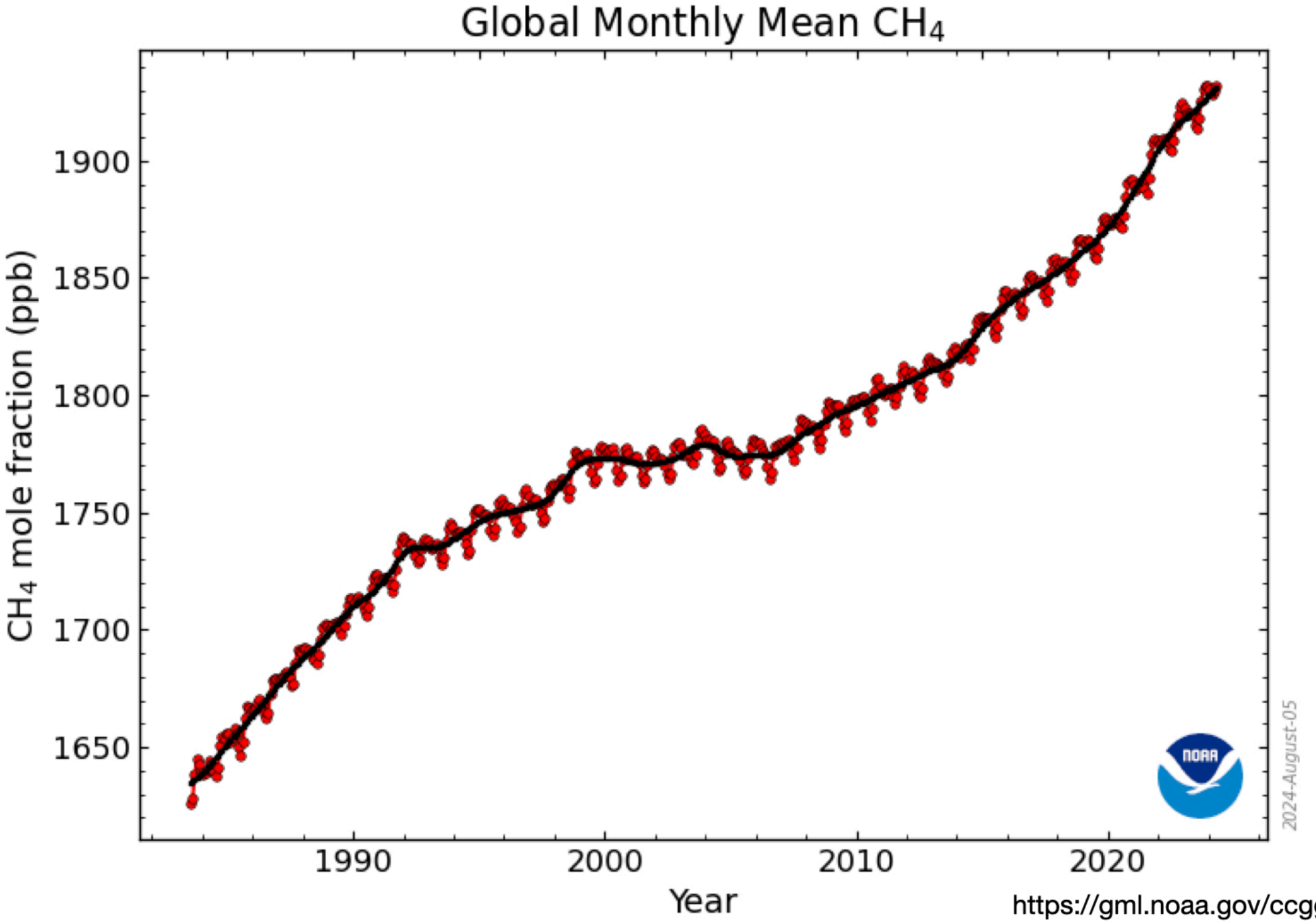
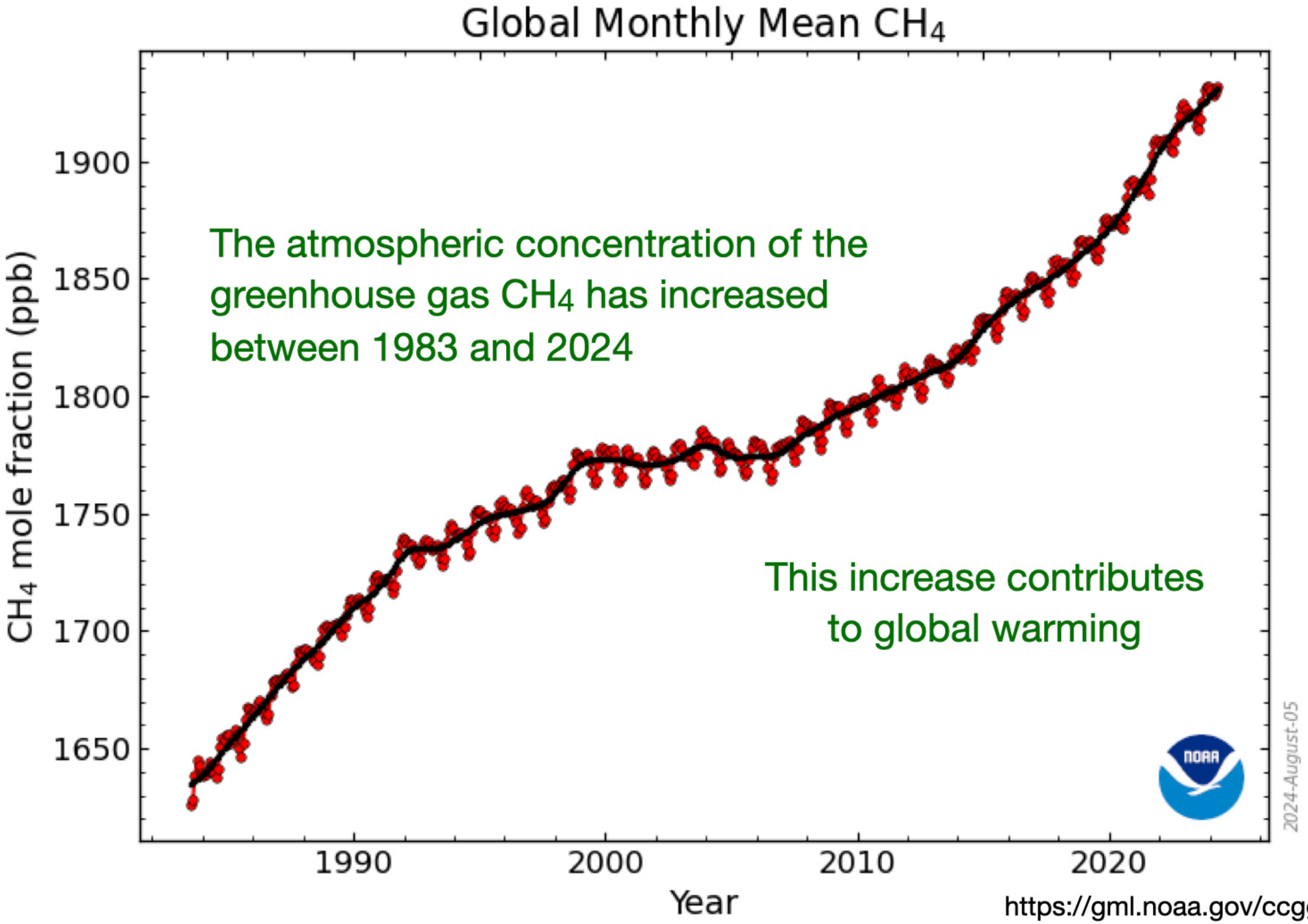


https://gml.noaa.gov/ccgg/trends_cj4/



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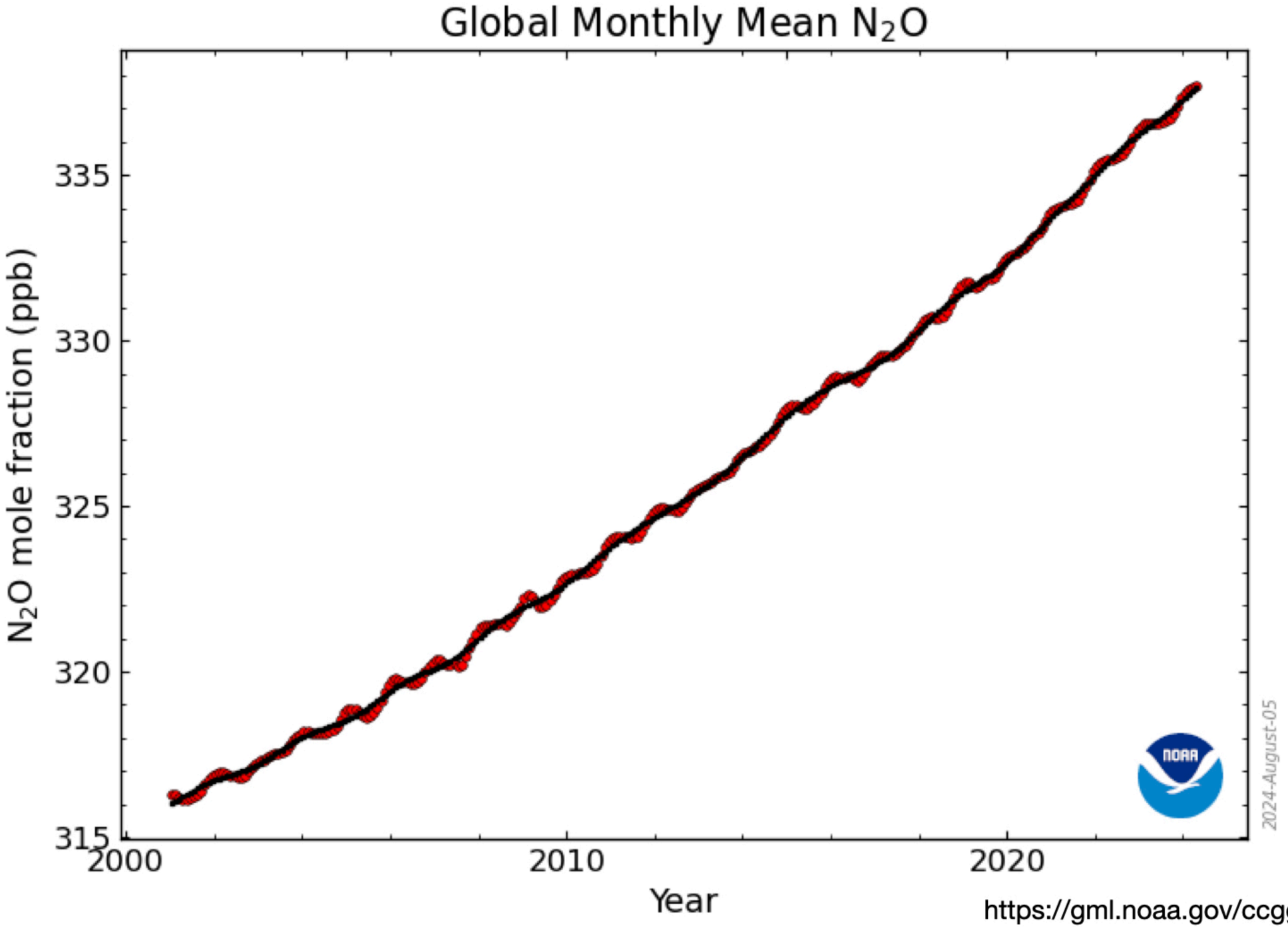
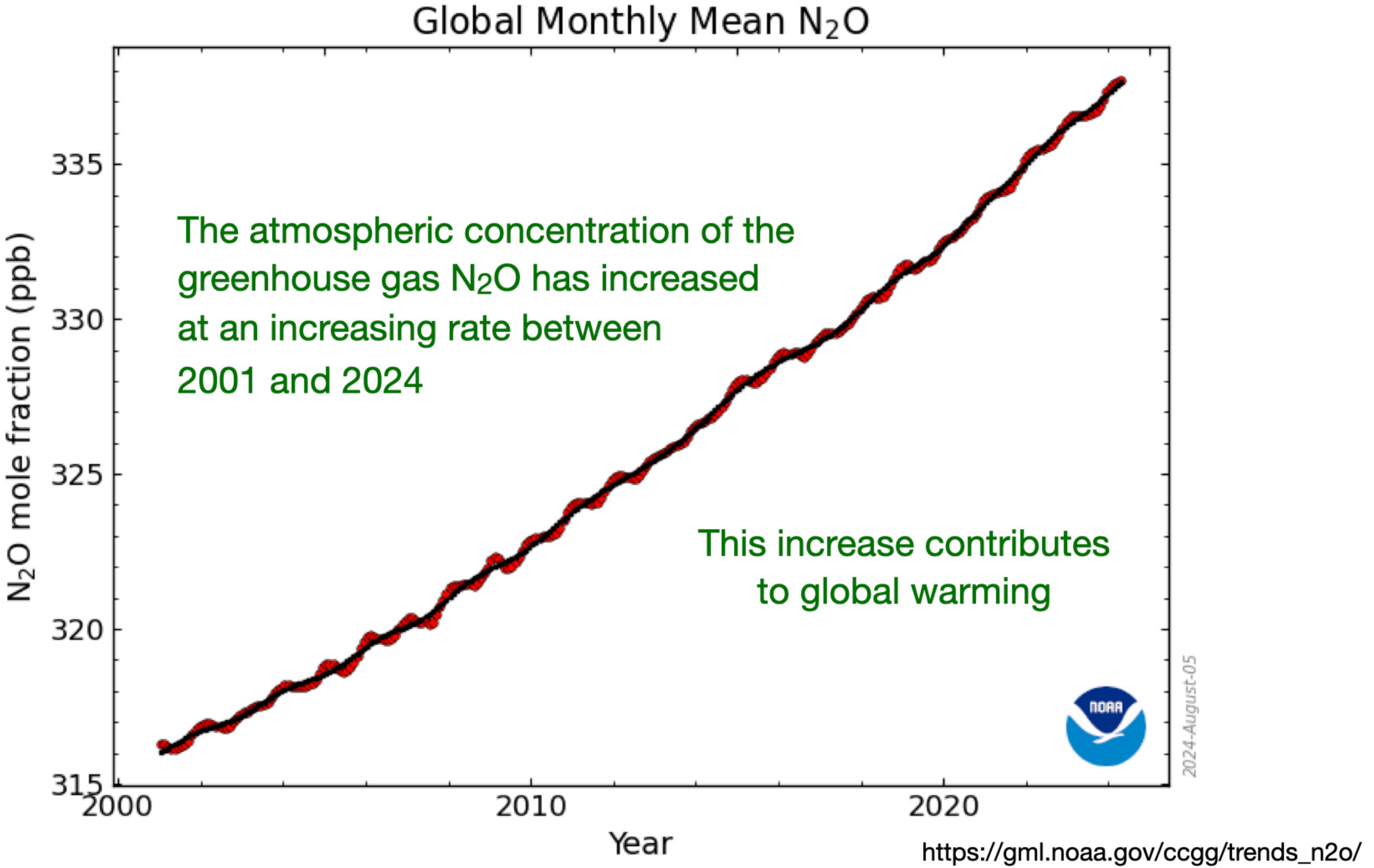
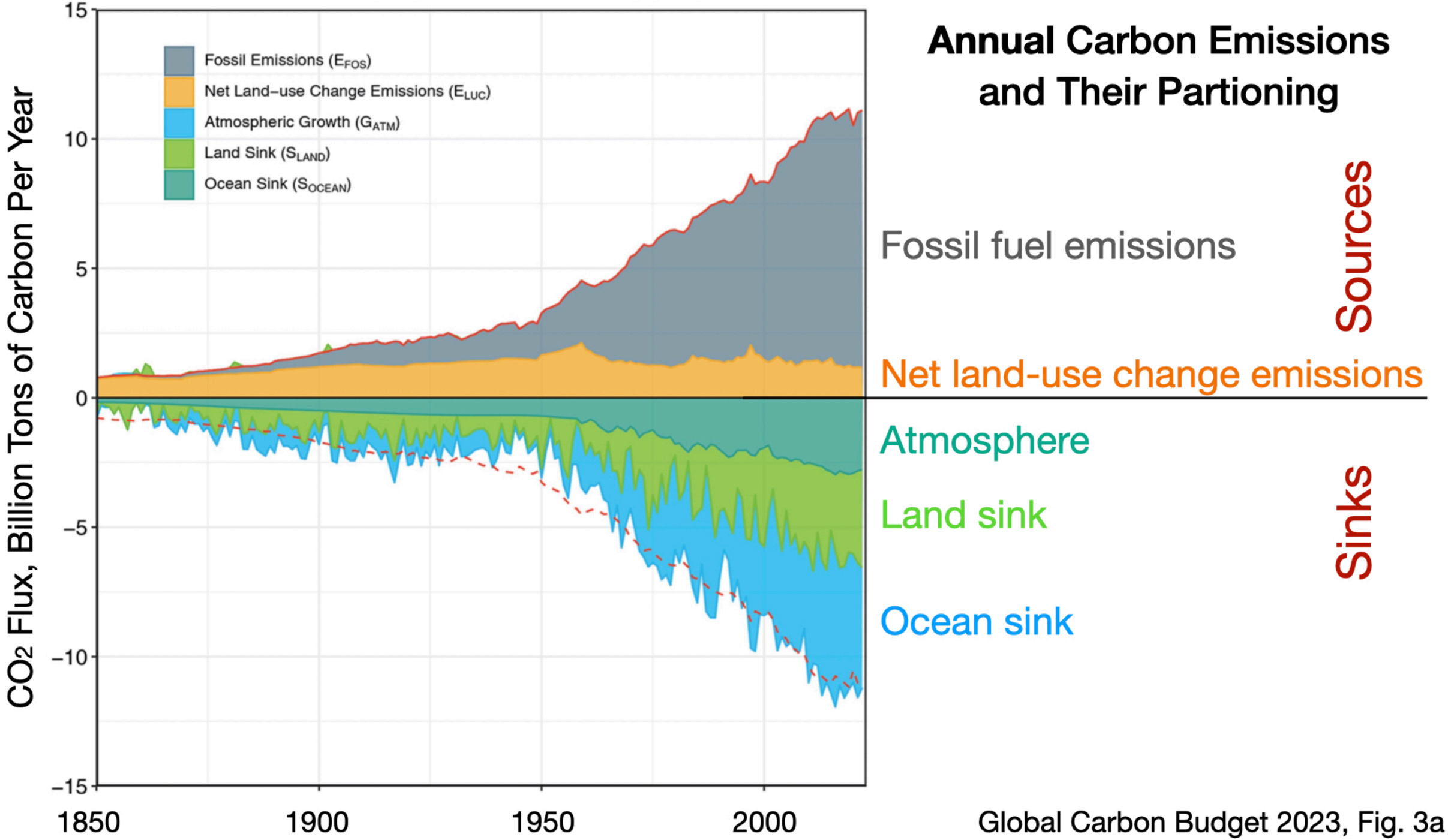


https://gml.noaa.gov/ccgg/trends_n2o/

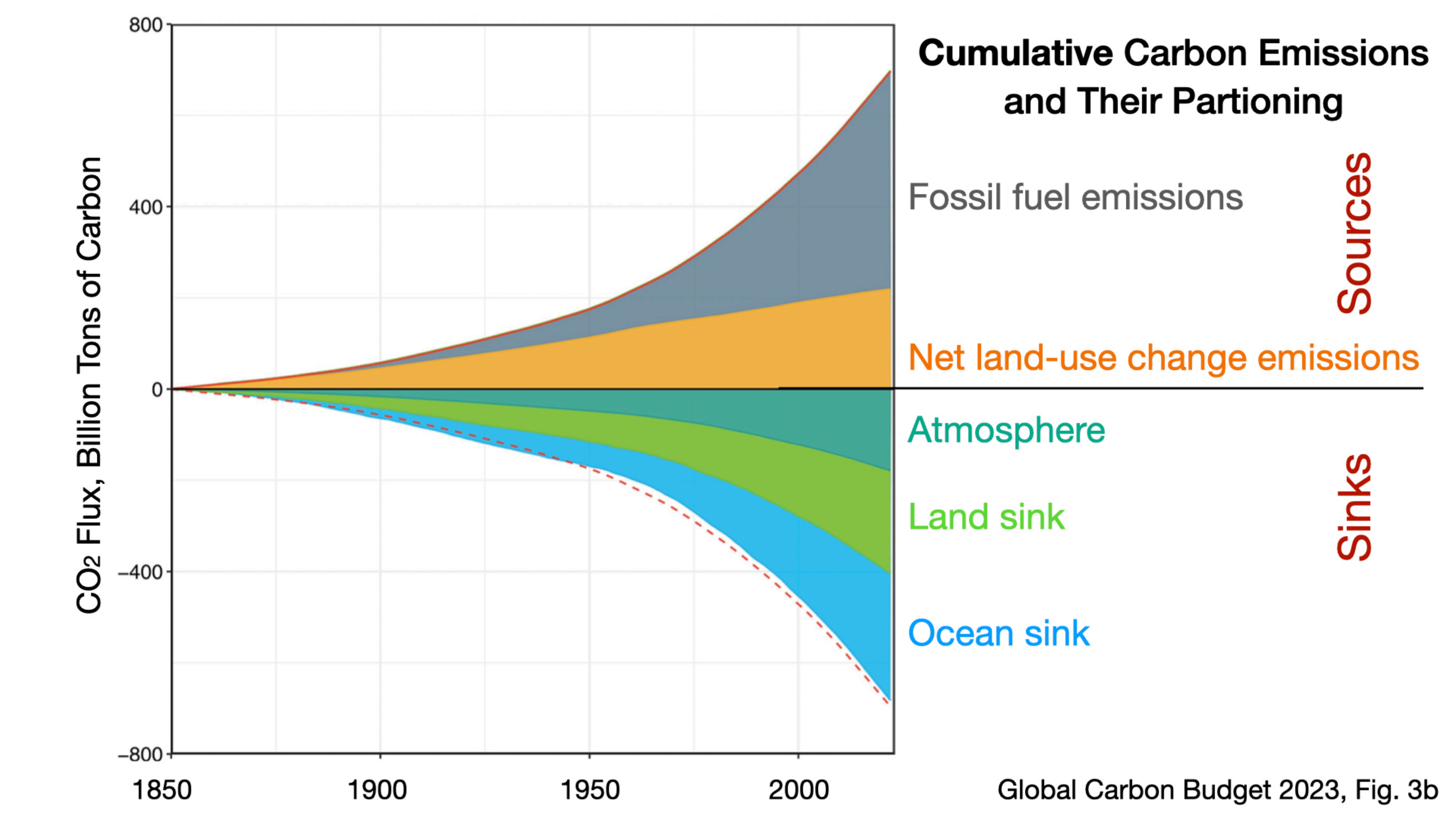


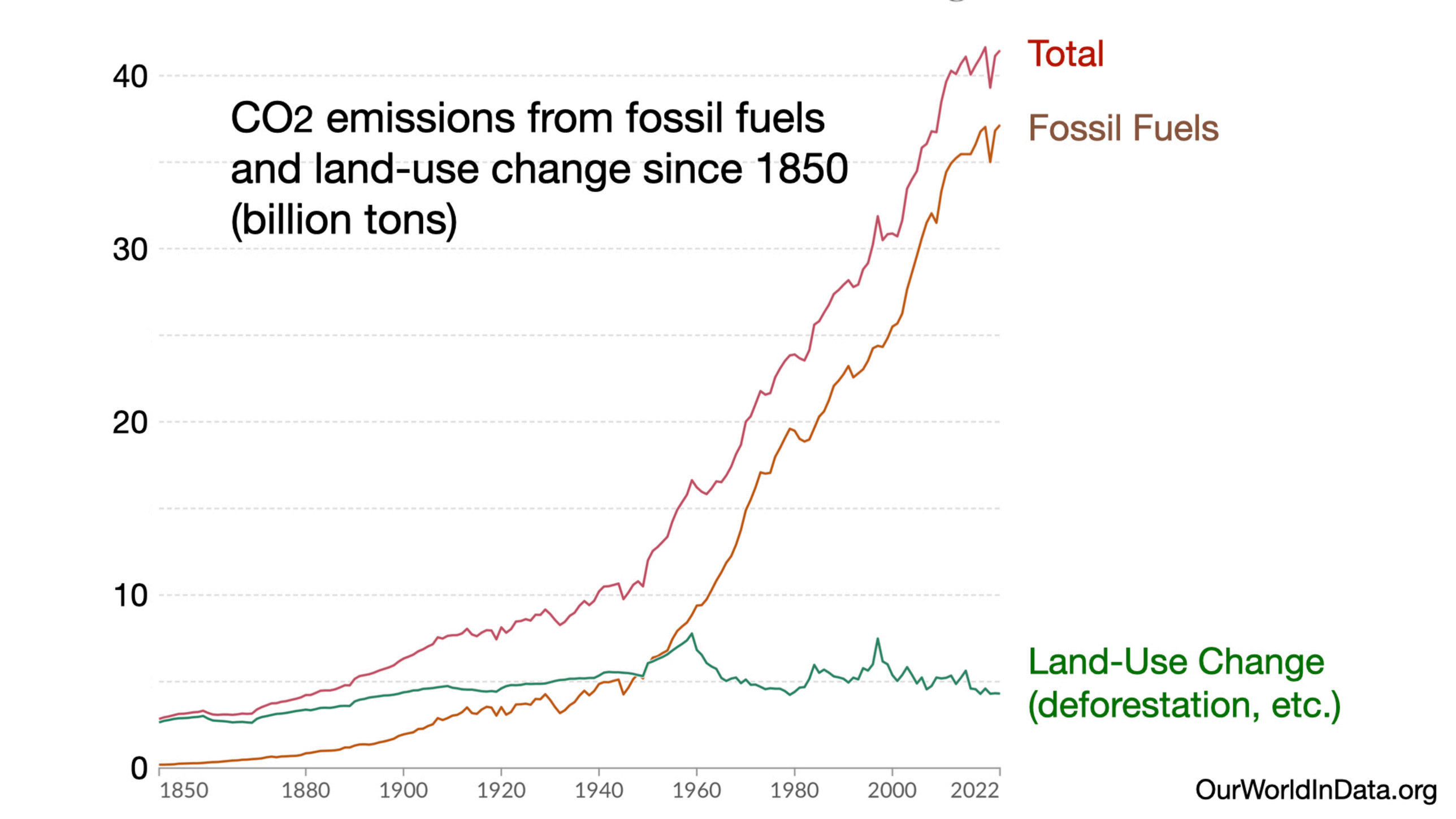
https://gml.noaa.gov/ccgg/trends_n2o/

Annual Carbon Emissions and Their Partioning



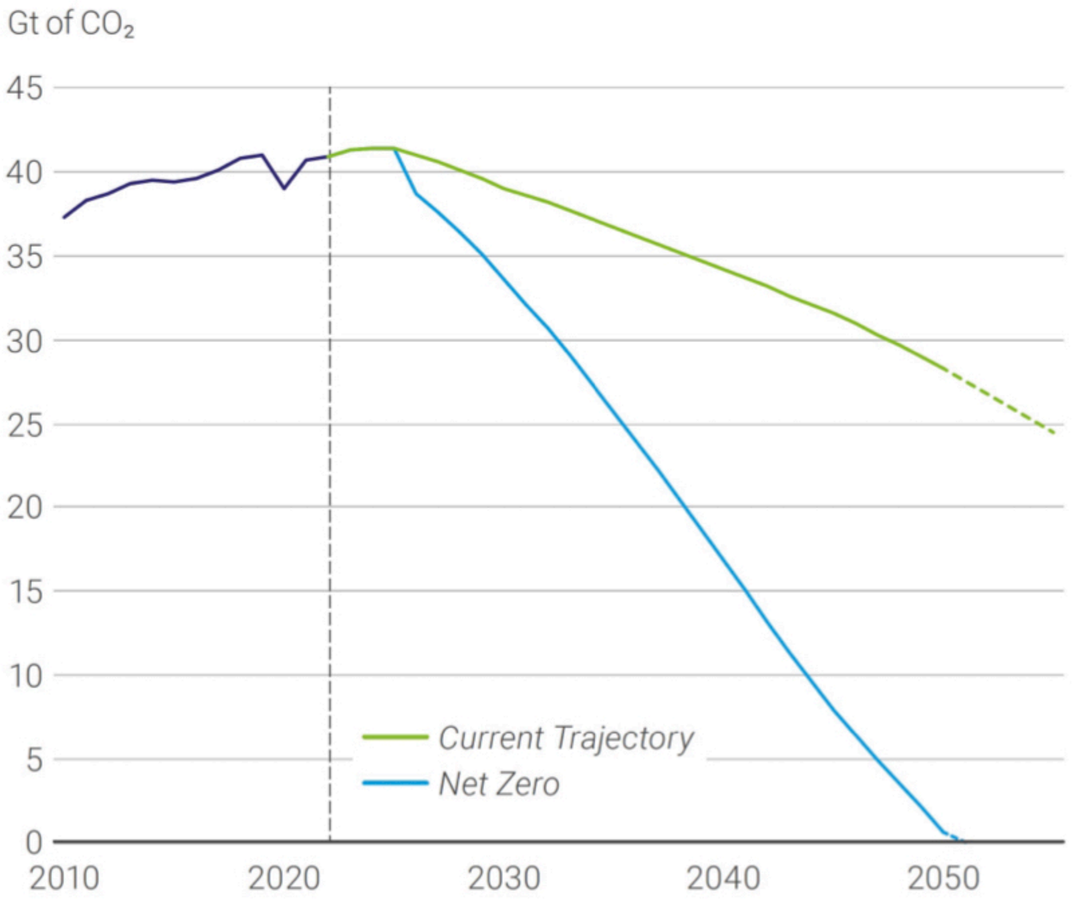
Global Carbon Budget 2023, Fig. 3a


Cumulative Carbon Emissions and Their Partioning
Fossil fuel emissions
Net land-use change emissions
Atmosphere
Land sink
Ocean sink
Sources
Sinks
CO2 Flux, Billion Tons of Carbon
800
400
0
−400
−800
1850
1900
1950
2000
Global Carbon Budget 2023, Fig. 3b

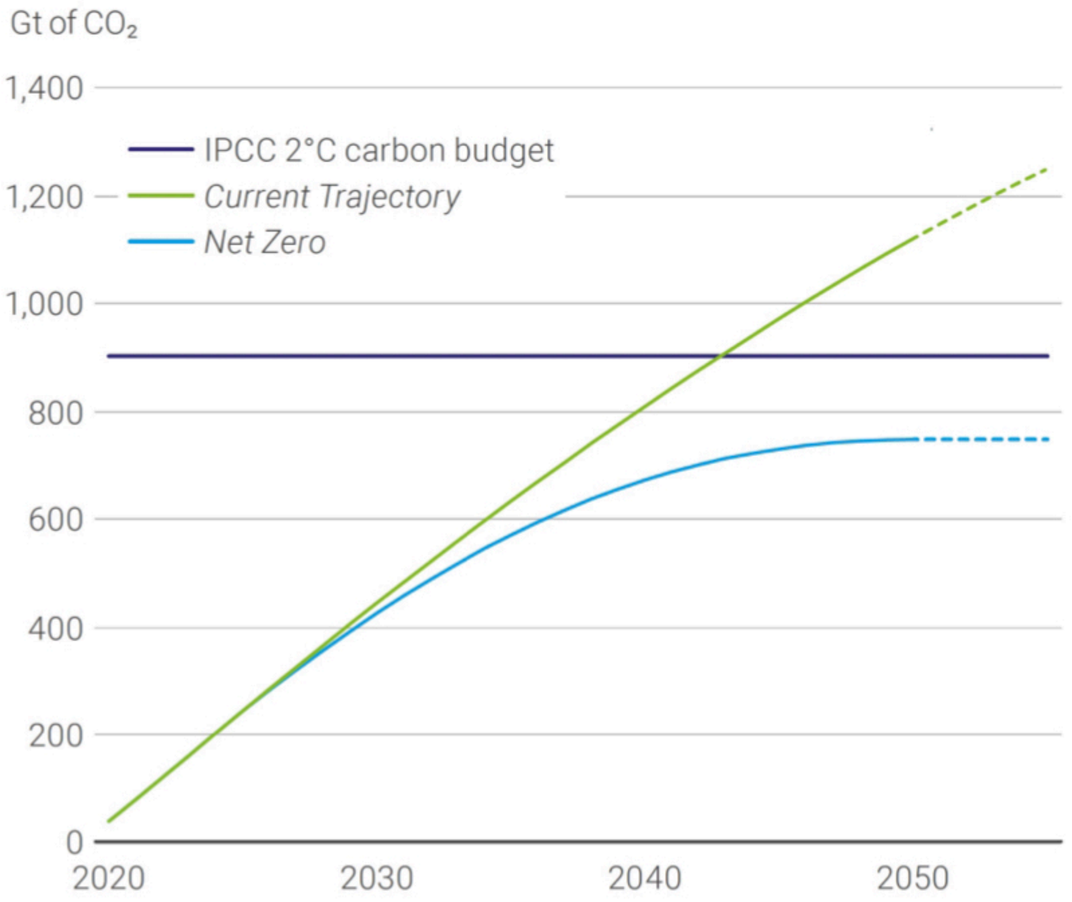

CO2 emissions from fossil fuels and land-use change since 1850 (billion tons)
Total
Fossil Fuels
Land-Use Change (deforestation, etc.)
40
30
20
10
0
1850
1880
1900
1920
1940
1960
1980
2000
2022
OurWorldInData.org

The pathway along which the global energy system is currently travelling, if continued, is not consistent with a 2°C carbon budget

CO_2 emissions



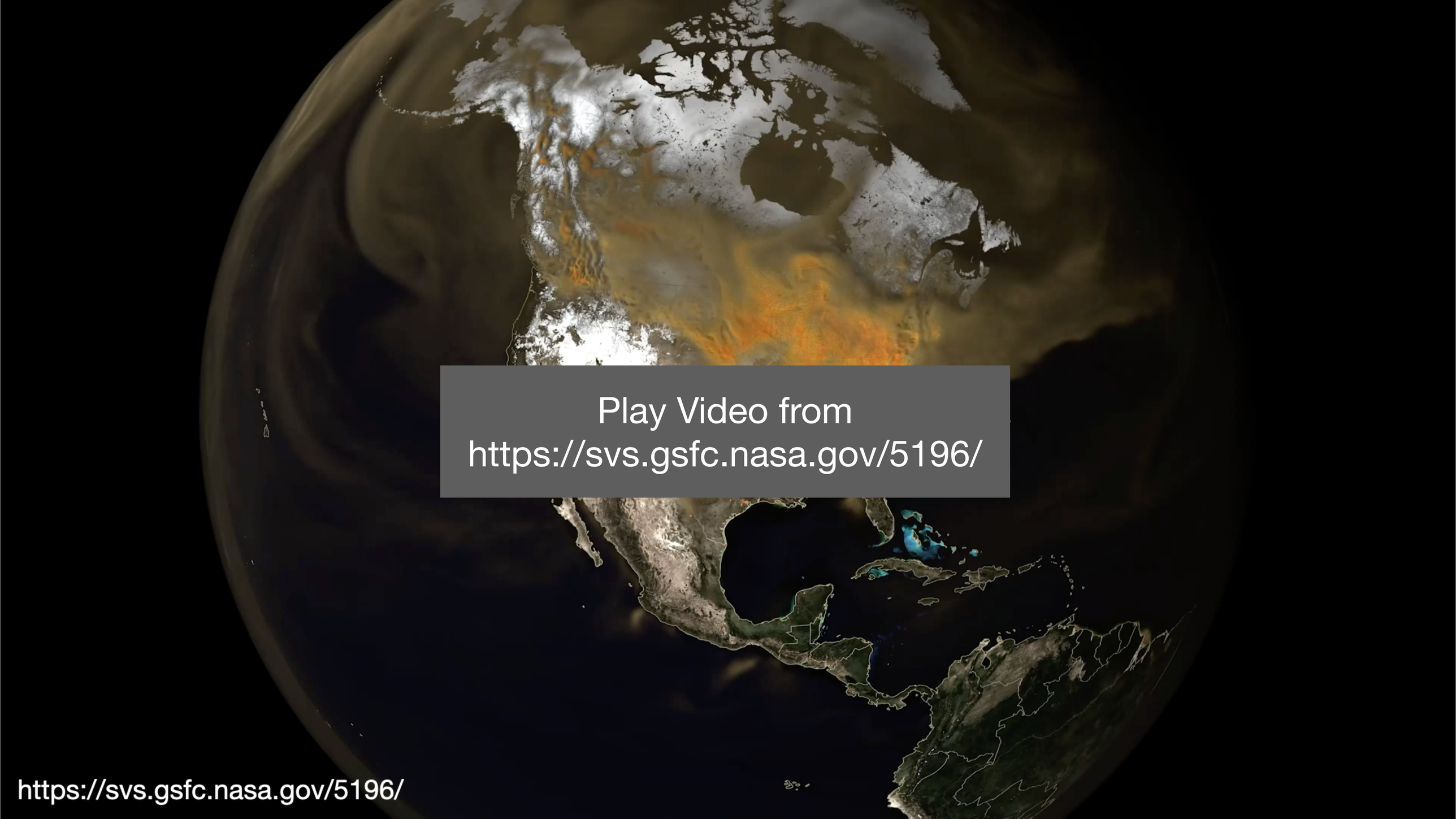
Cumulative CO_2 emissions, 2020 onwards

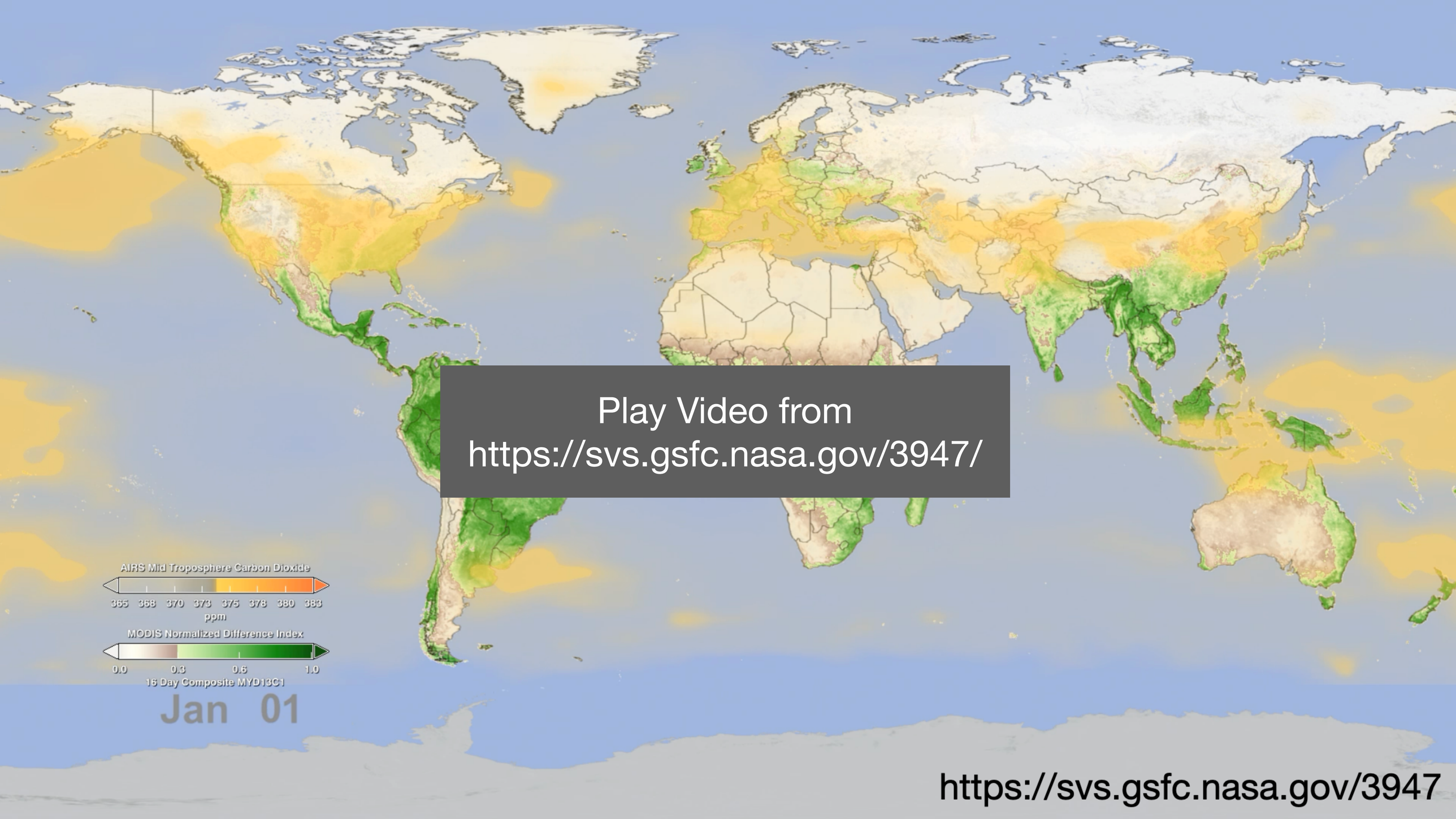


BP Energy Outlook 2024

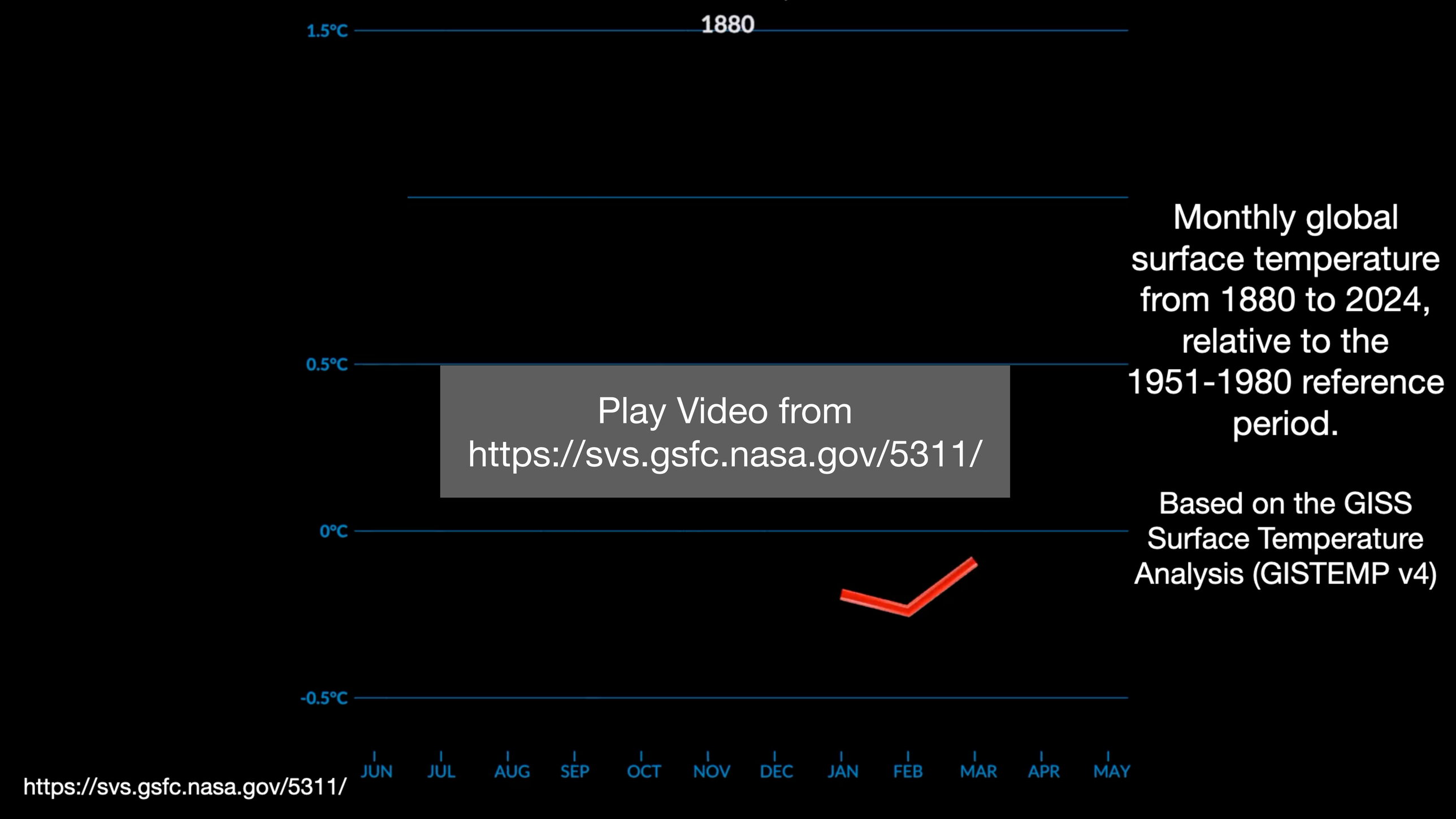
Orbiting Carbon Observatory (OCO) makes carbon dioxide measurements
Earth Surface Mineral Dust Source Investigation Mission (EMIT) is a methane and carbon dioxide plume mapper on the International Space Station

https://svs.gsfc.nasa.gov/5332/


Play Video from
https://svs.gsfc.nasa.gov/5196/
https://svs.gsfc.nasa.gov/5196/


Play Video from
https://svs.gsfc.nasa.gov/3947/
AIRS Mid Troposphere Carbon Dioxide
365 368 370 373 375 378 380 383
ppm
MODIS Normalized Difference Index
0.0 0.3 0.6 1.0
16 Day Composite MYD13C1
Jan 01
https://svs.gsfc.nasa.gov/3947

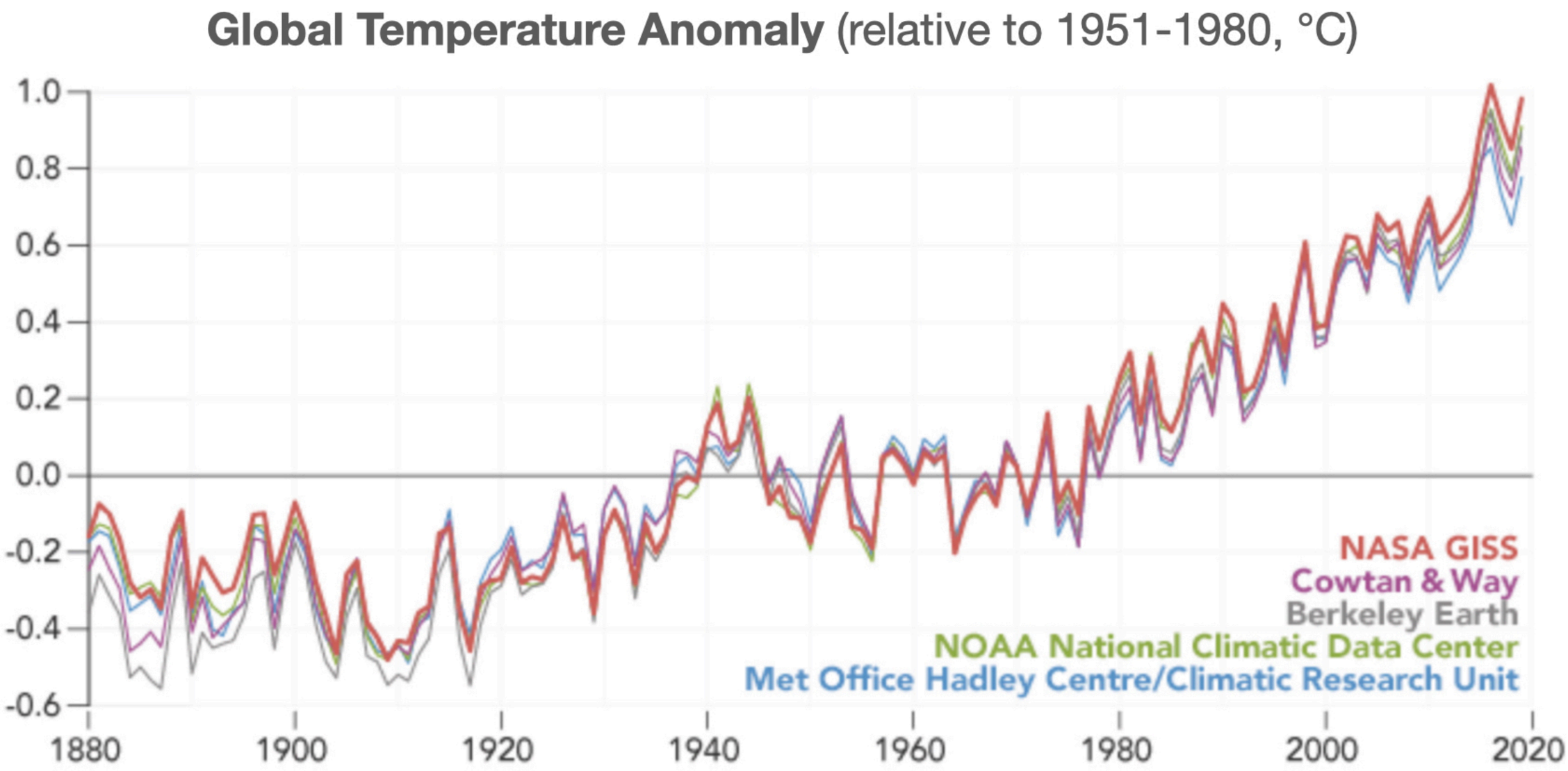
The Global Temperature Record



Monthly global surface temperature from 1880 to 2024, relative to the 1951-1980 reference period.

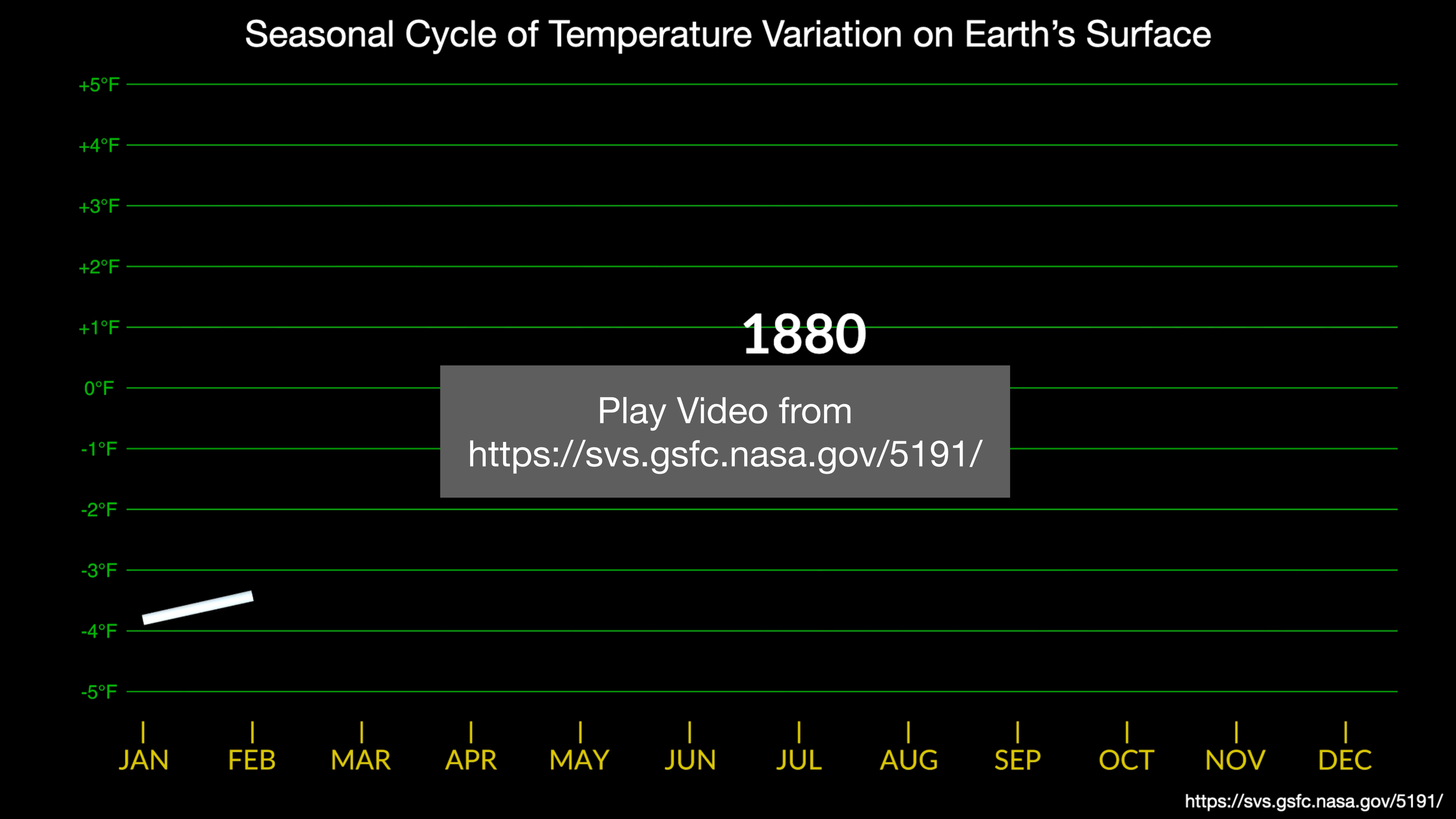
Based on the GISS Surface Temperature Analysis (GISTEMP v4)

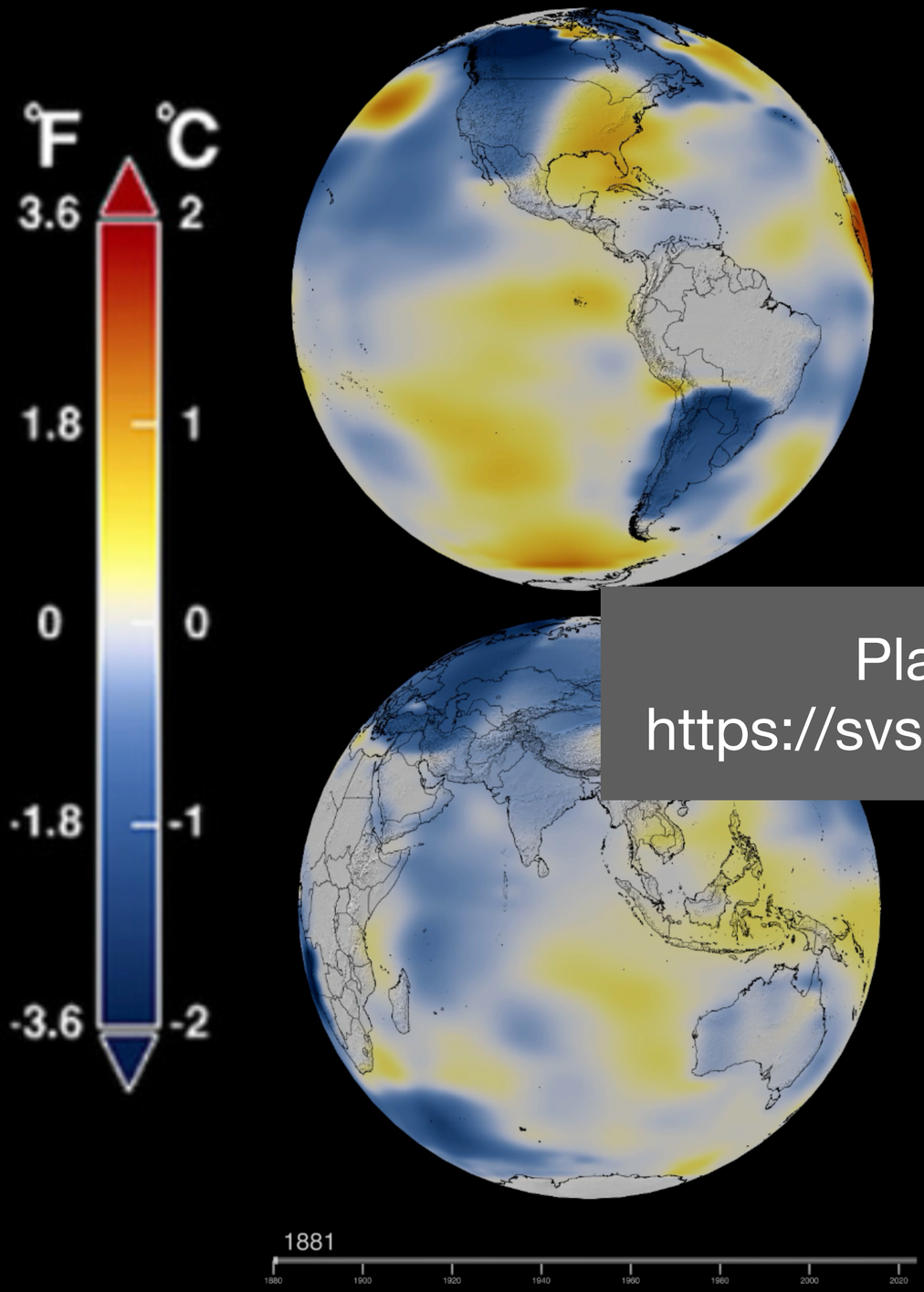
https://svs.gsfc.nasa.gov/5311/



https://earthobservatory.nasa.gov/world-of-change/global-temperatures

Seasonal Cycle of Temperature Variation on Earth's Surface



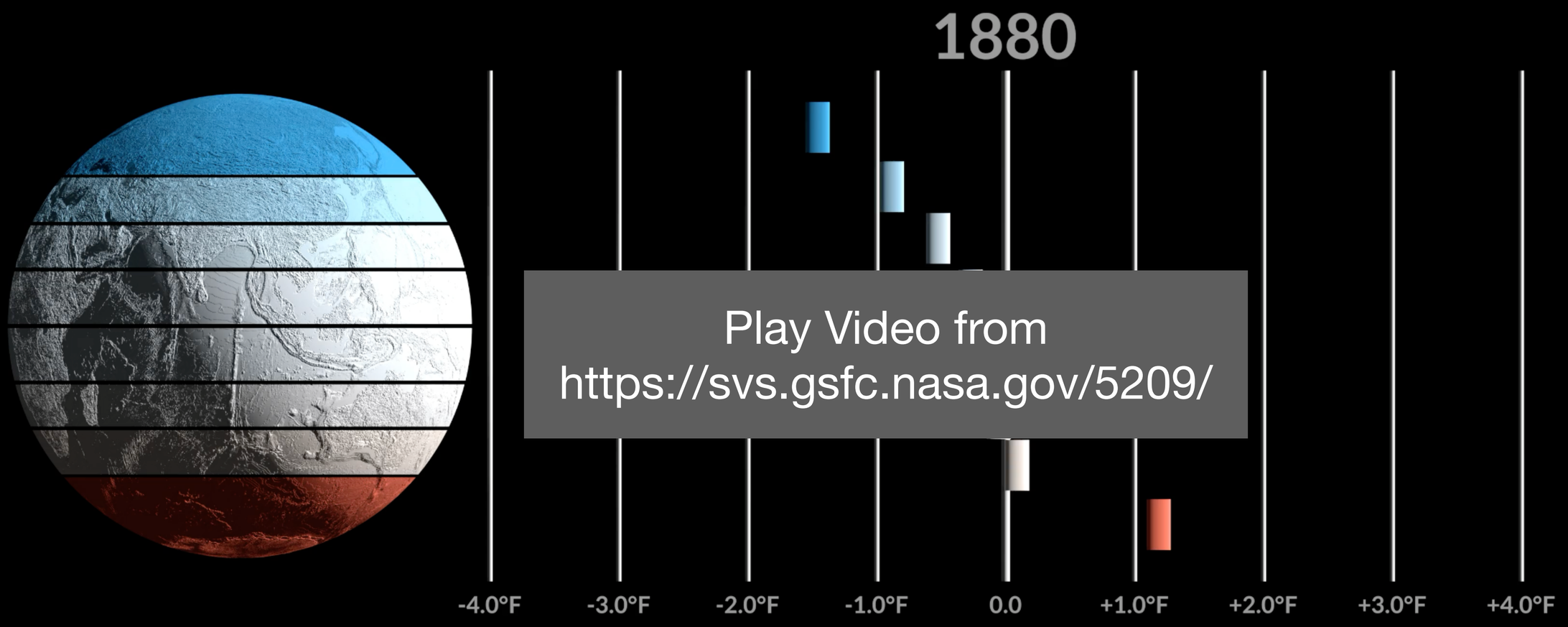


Play Video from
https://svs.gsfc.nasa.gov/5207/

Global Temperature Anomalies,
023, relative to
om 1951 - 1980

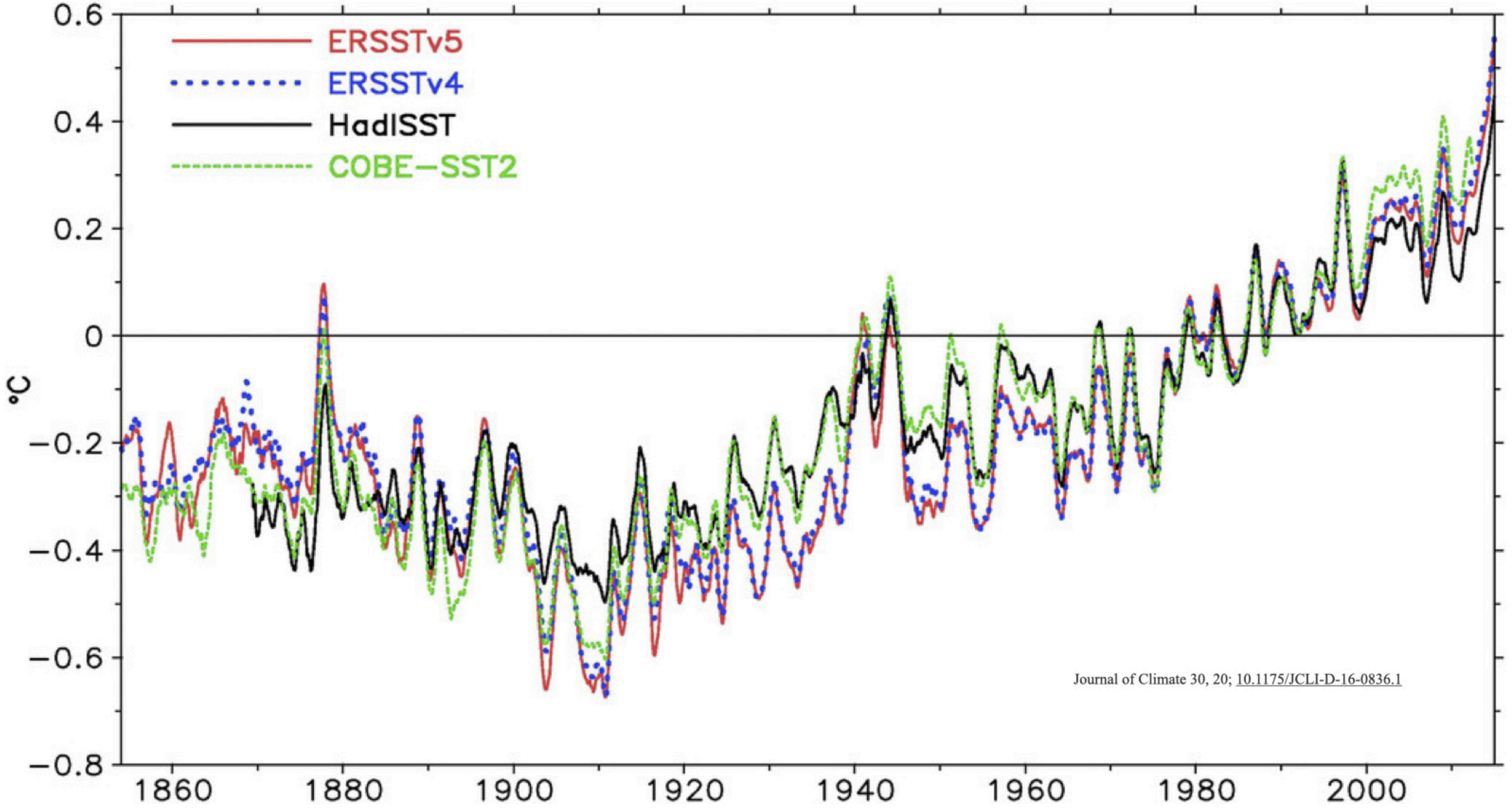
https://svs.gsfc.nasa.gov/5207/

Zonal Climate Anomalies, 1880-2023



https://svs.gsfc.nasa.gov/5209/

Globally Averaged Sea-Surface Temperature Anomaly (relative to 1971-2000, °C)

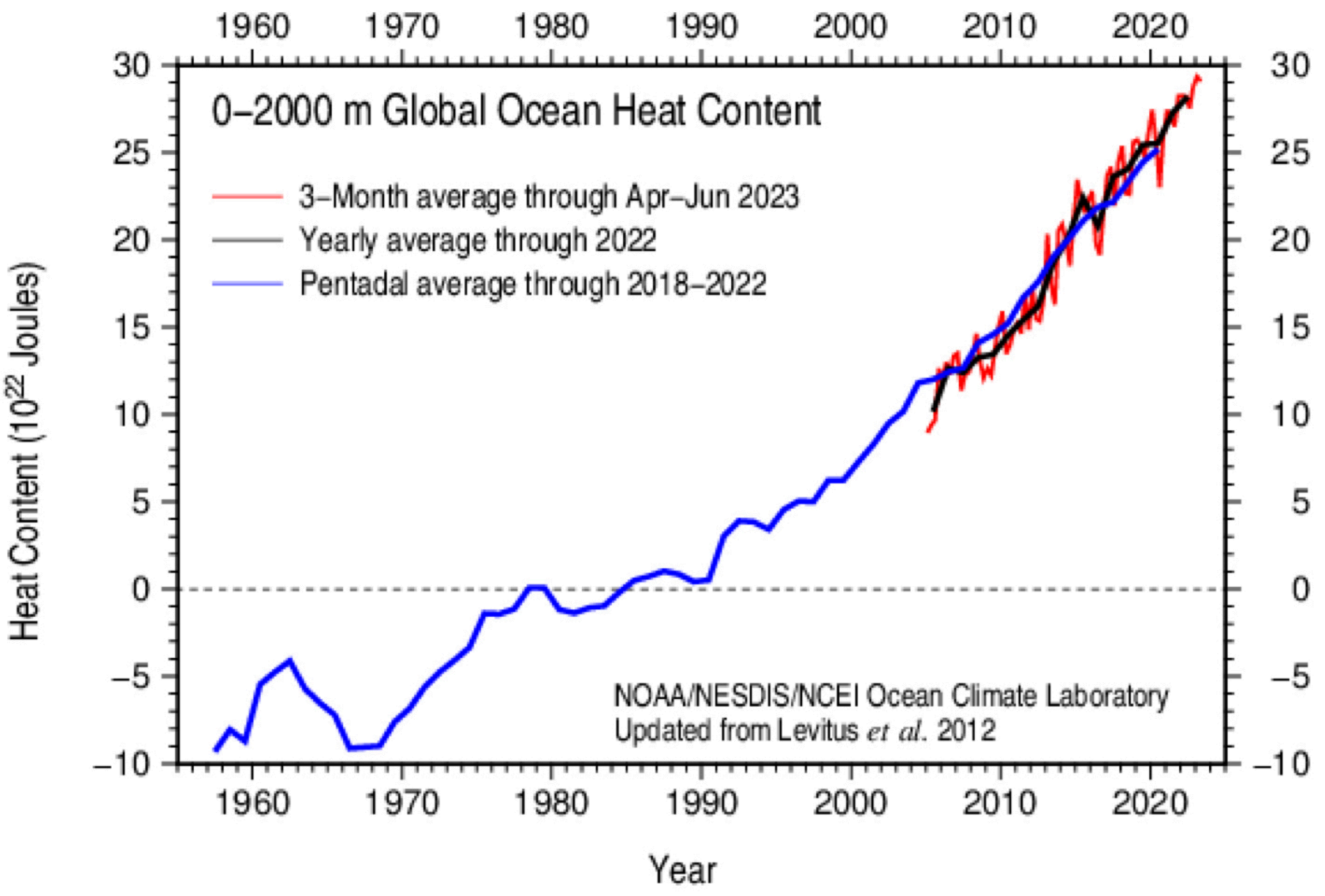


https://journals.ametsoc.org/view/journals/clim/30/20/jcli-d-16-0836.1.xml

Sea Surface Temperature (°C)

≤10° 21° 27.8° ≥32°C

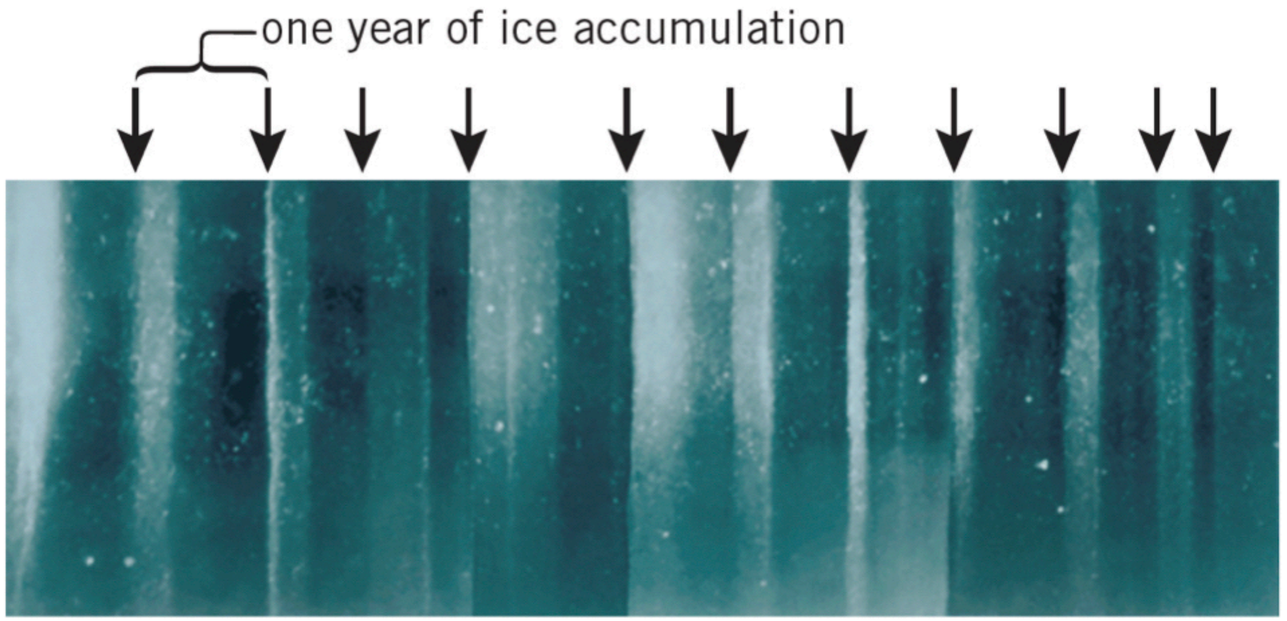
https://earthobservatory.nasa.gov/images/153376/ocean-heat-for-hurricane-helene



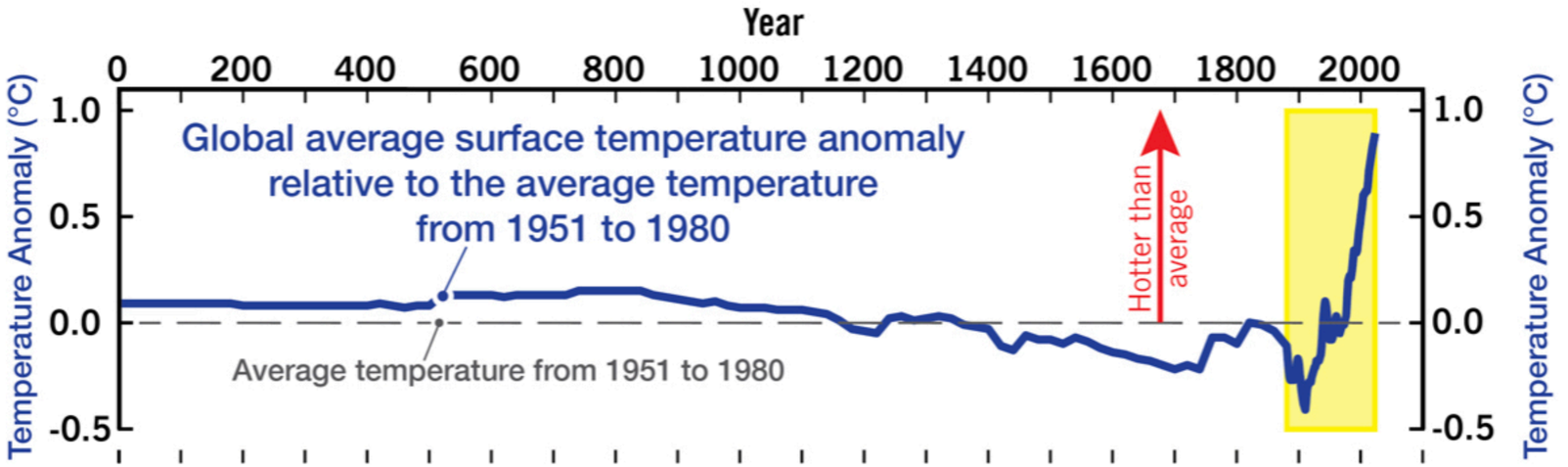
https://www.ncei.noaa.gov/access/global-ocean-heat-content/

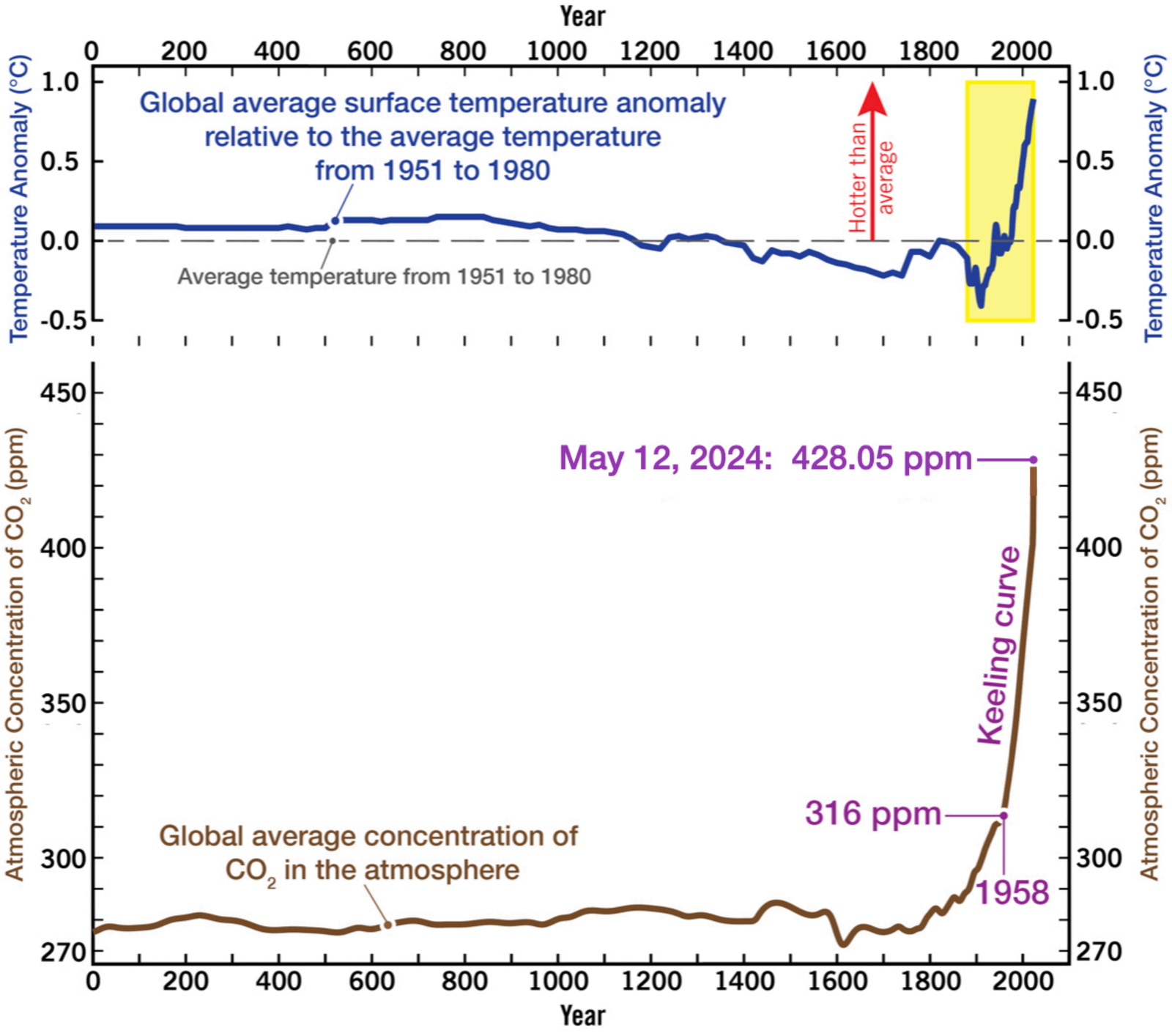
Longer records of atmospheric greenhouse gases and surface temperature variations over time

C



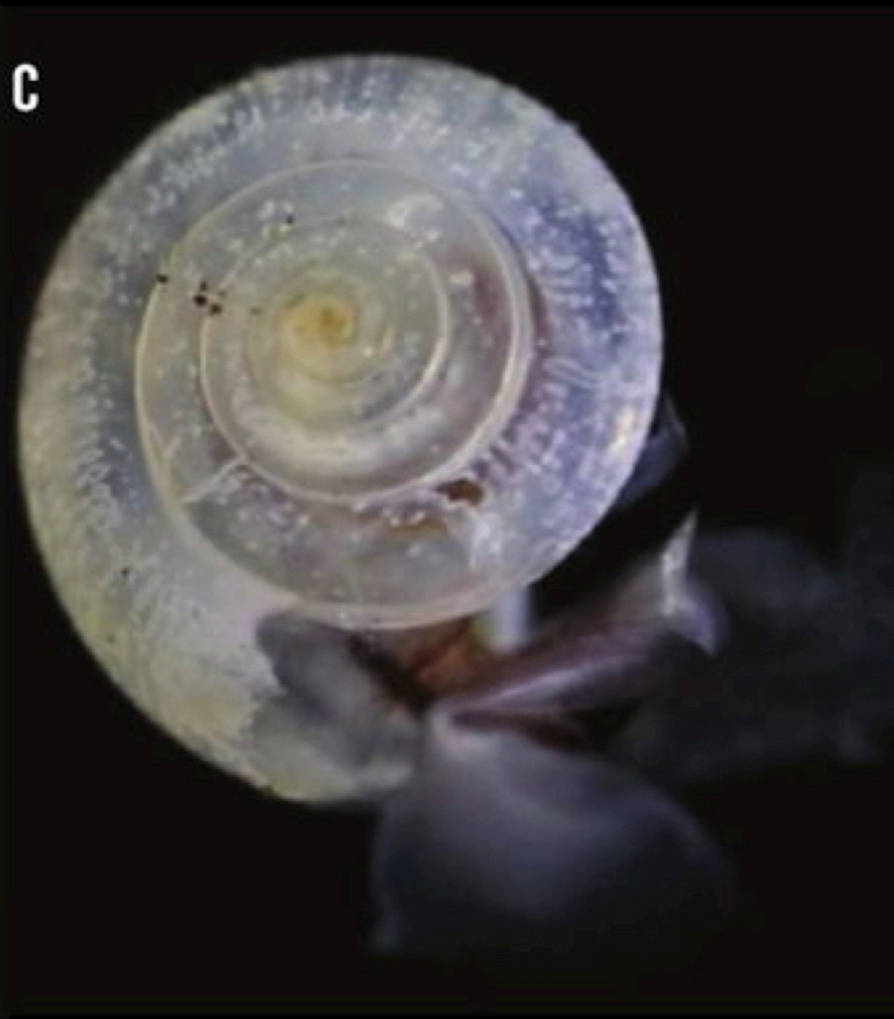
after Cronin, 2020, Fig. 17.9


Year
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
Global average surface temperature anomaly
relative to the average temperature
from 1951 to 1980
Hotter than
average
Average temperature from 1951 to 1980
Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5

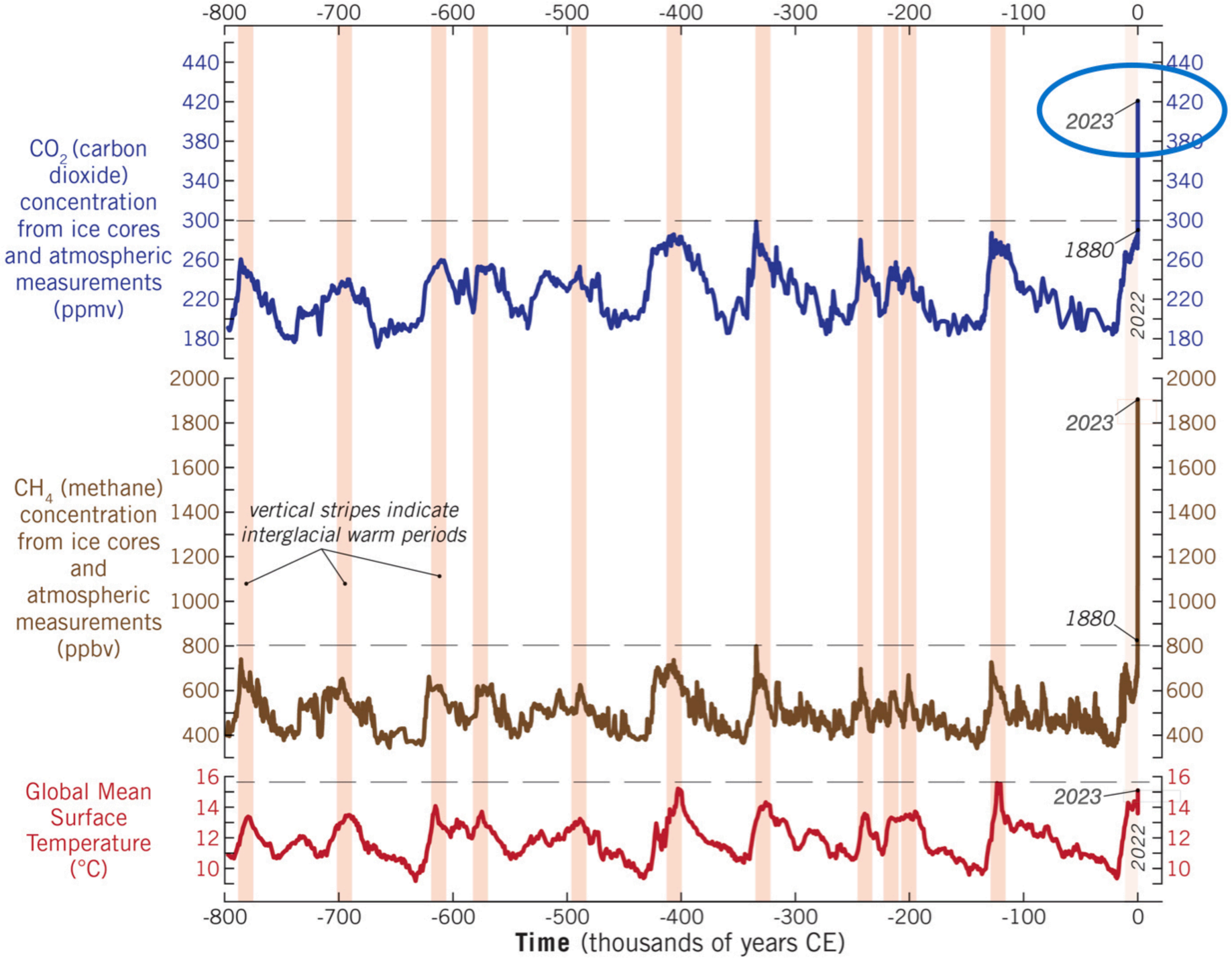

Year
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Temperature Anomaly (°C)
1.0
0.5
0.0
-0.5
Global average surface temperature anomaly
relative to the average temperature
from 1951 to 1980
Hotter than average
Average temperature from 1951 to 1980
Atmospheric Concentration of CO_2 (ppm)
450
400
350
300
270
May 12, 2024: 428.05 ppm
Keeling curve
316 ppm
1958
Global average concentration of
CO_2 in the atmosphere

Lower Water Acidity: Healthy

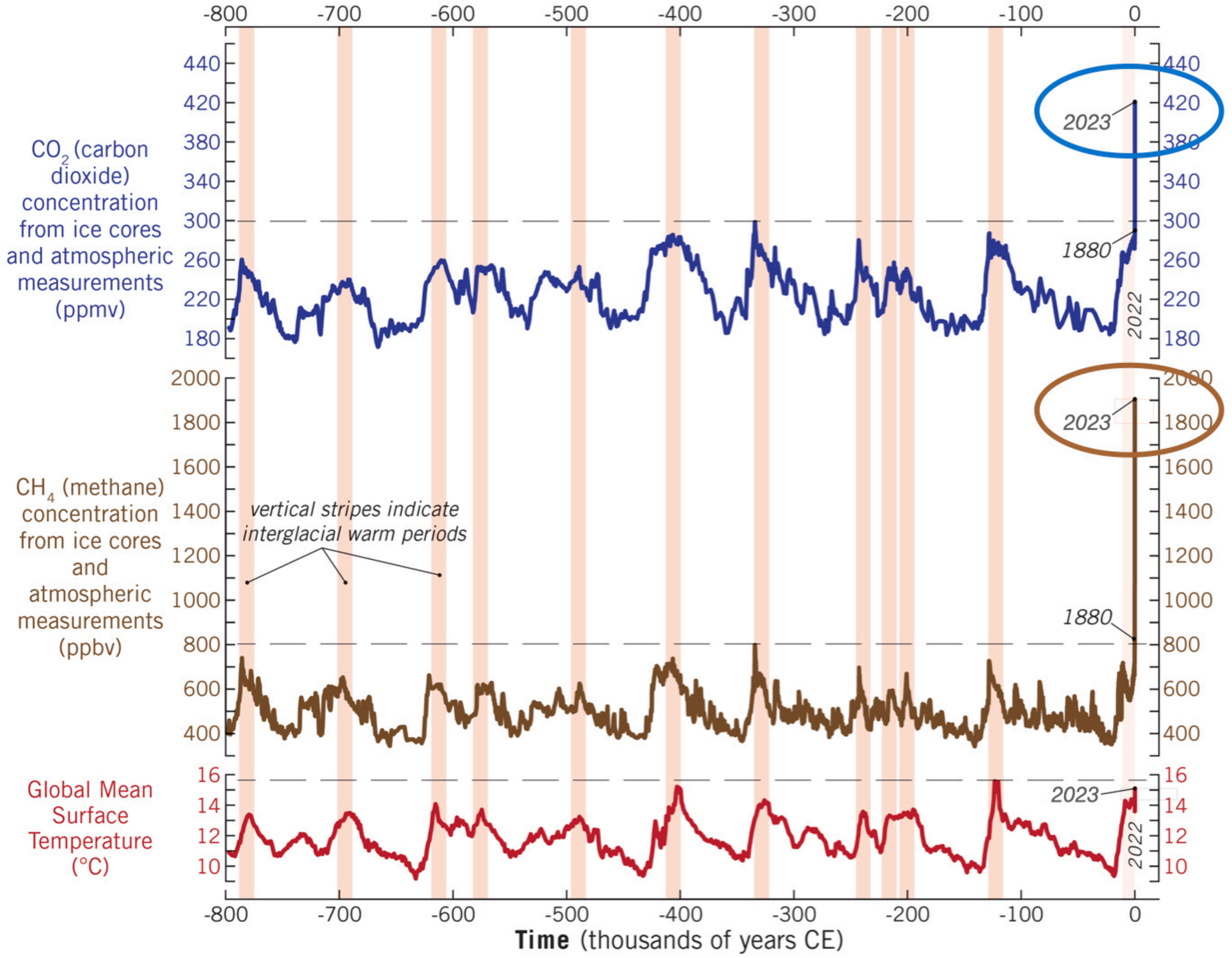
Higher Water Acidity: Struggling



Pteropod photos by Nina Bednarsek

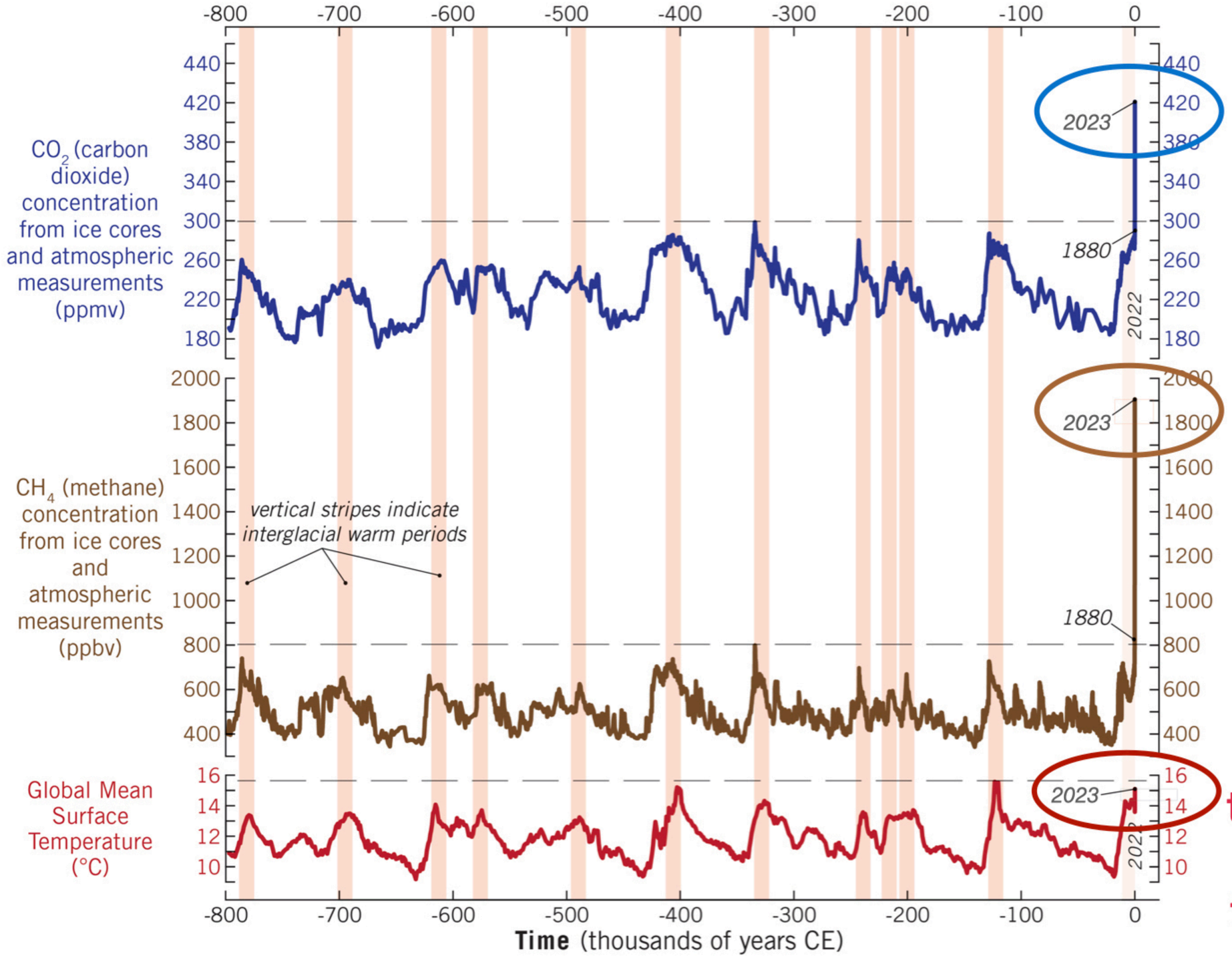


Atmospheric CO_2 levels are now greater than at any time in *at least* the last 800,000 years.



Atmospheric CO_2 levels are now greater than at any time in *at least* the last 800,000 years.

Atmospheric methane (CH_4) levels are now greater than at any time in *at least* the last 800,000 years.



Atmospheric CO_2 levels are now greater than at any time in *at least* the last 800,000 years.

Atmospheric methane (CH_4) levels are now greater than at any time in *at least* the last 800,000 years.

Global mean surface temperature is greater now than any time in the last 125,000 years

Much of the CO_2 already in the atmosphere will persist for a very long time.

Mean global surface temperature will continue to increase beyond 2100 because of the greenhouse gases already in the atmosphere.

As global surface temperatures increase over time, sea level rises

Local and global sea levels are measured routinely using tide gauges, robotic floats, and orbital satellites

NASA orbital satellites that contribute to our understanding of global sea level

Jason 1 (2002-), 2 (2008-), 3 (2016-)

ICESat (2003-2009), ICESat-2 (2018 to date)

Gravity Recovery And Climate Experiment (GRACE; 2002-2017)

GRACE-FO (2018 to date)

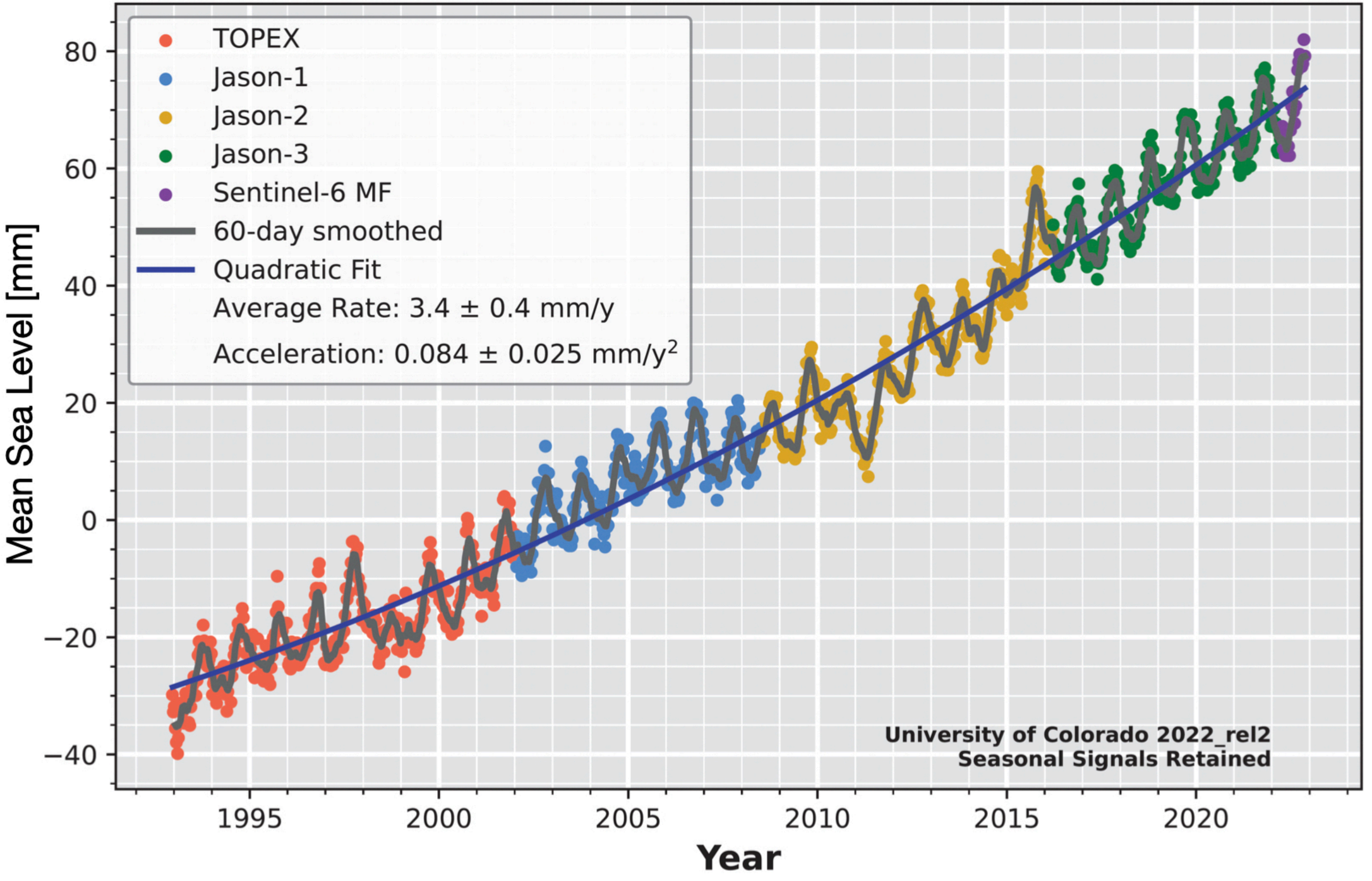
Sentinel-6 Michael Freilich (2020 to date)

Surface Water and Ocean Topography (SWOT; 2022 to date)

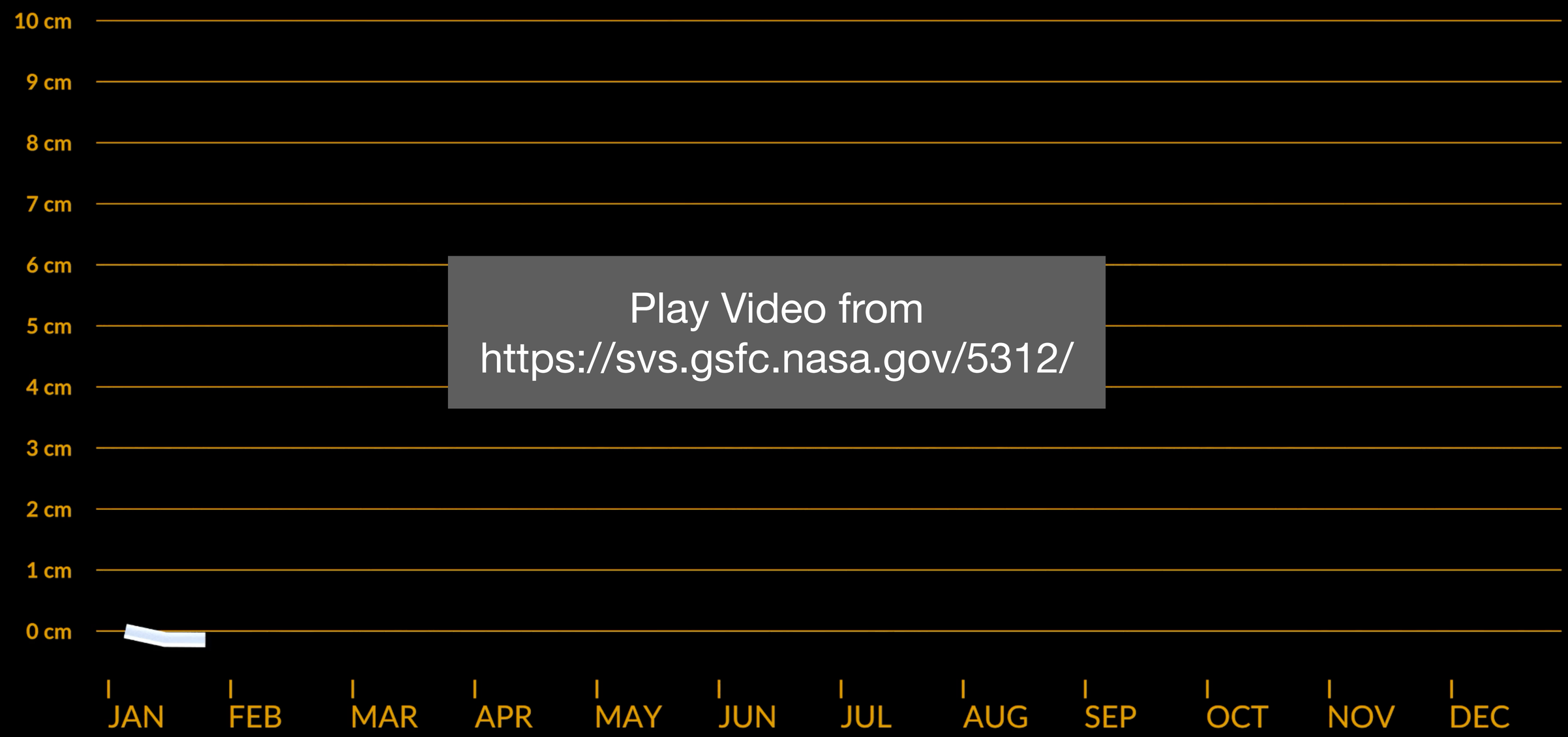
NASA-ISRO-SAR (NISAR; 2024)

Sentinel-6b (2025)

https://sealevel.nasa.gov/data/missions


TOPEX
Jason-1
Jason-2
Jason-3
Sentinel-6 MF
60-day smoothed
Quadratic Fit
Average Rate: 3.4 ± 0.4 mm/y
Acceleration: 0.084 ± 0.025 mm/y²
Mean Sea Level [mm]
80
60
40
20
0
−20
−40
1995
2000
2005
2010
2015
2020
Year
University of Colorado 2022_rel2
Seasonal Signals Retained

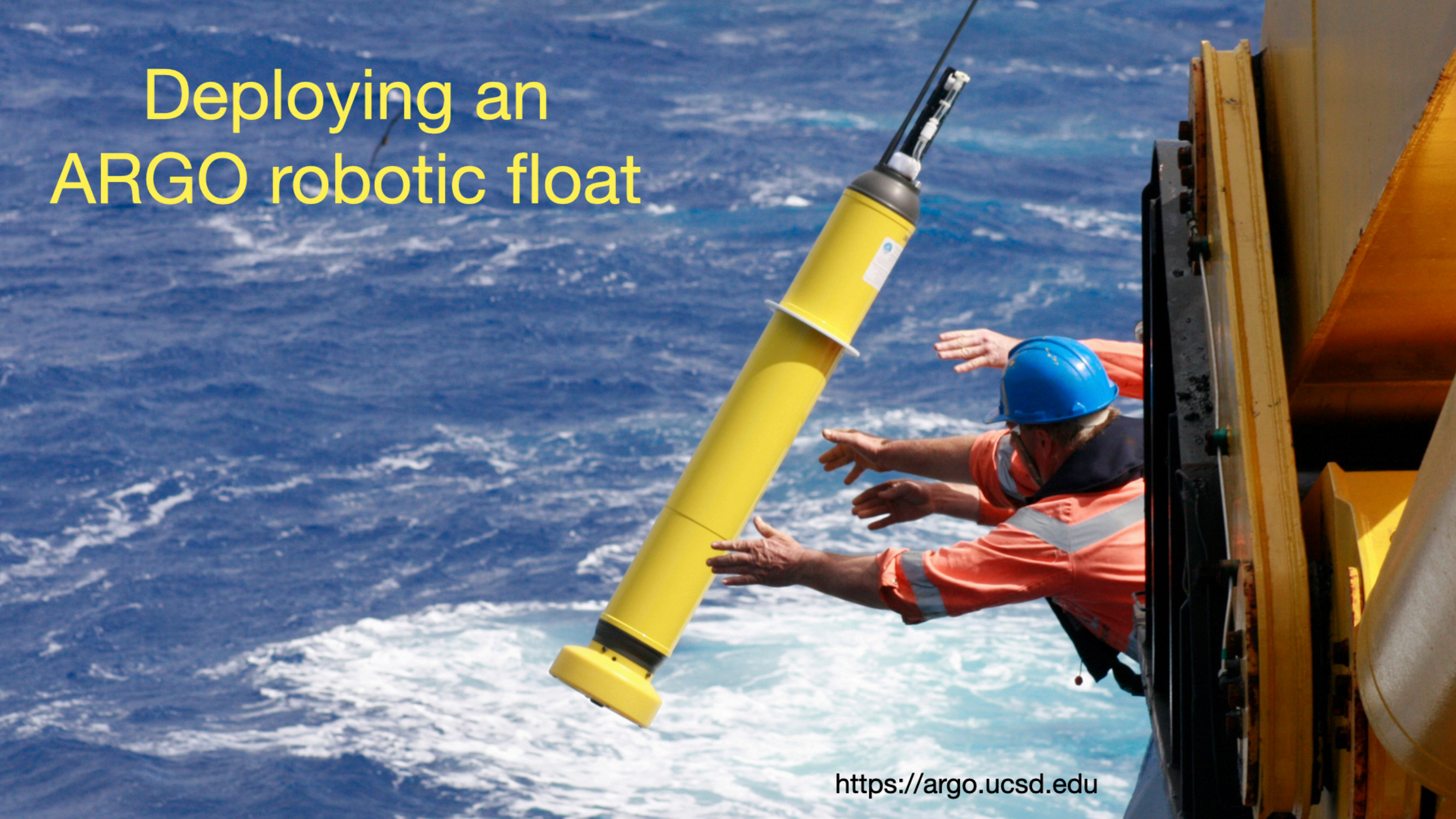
Global Mean Sea Level Rise
1993



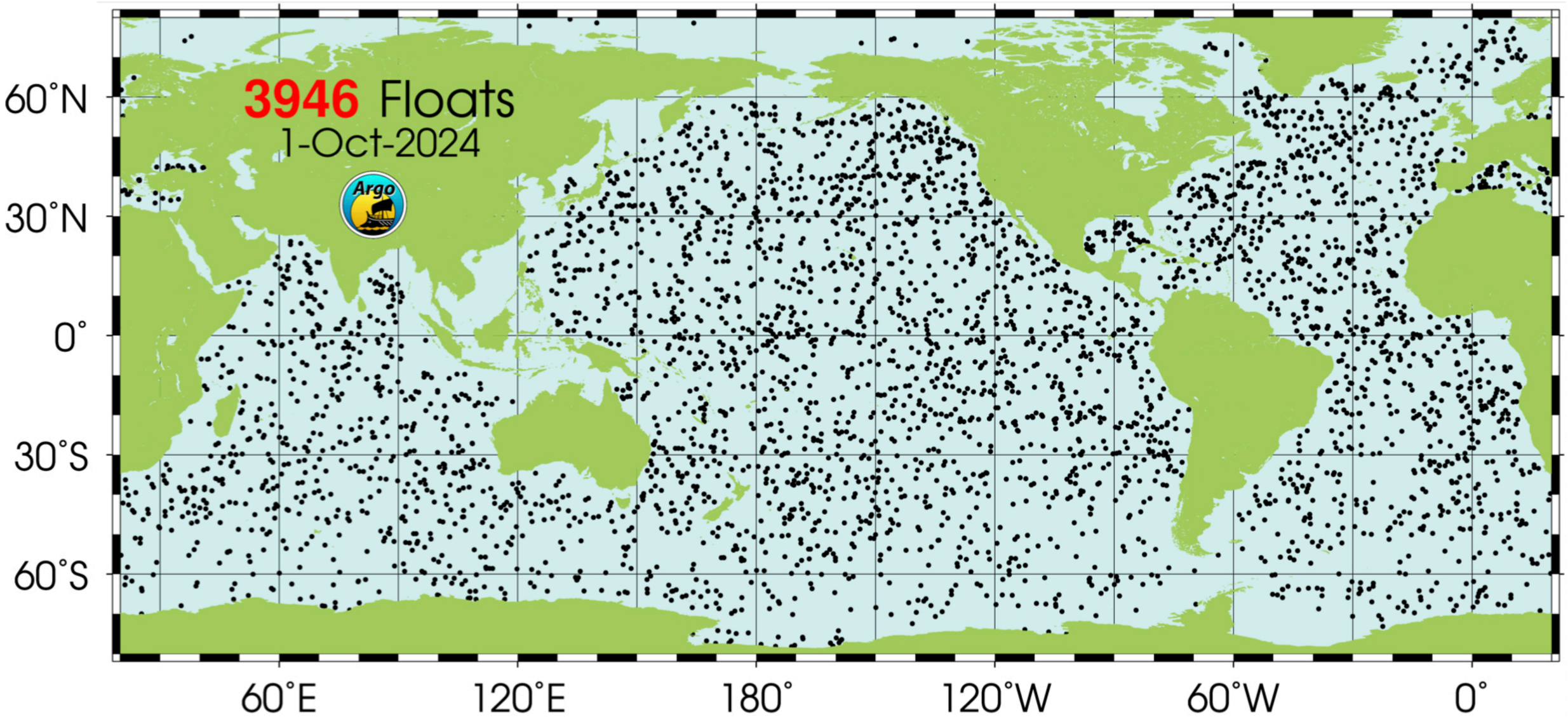
Play Video from
https://svs.gsfc.nasa.gov/5312/

https://svs.gsfc.nasa.gov/5312/

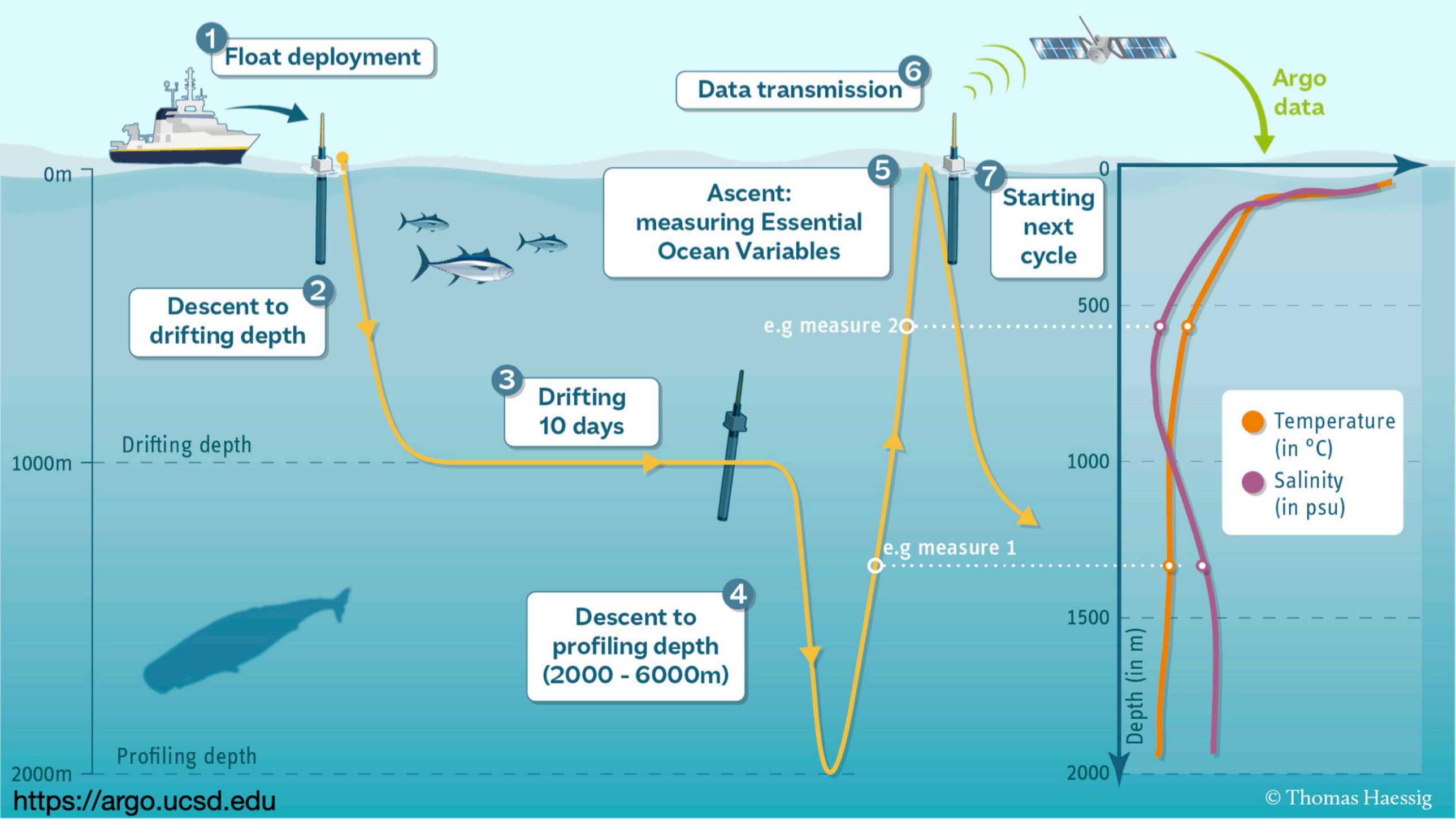
Deploying an ARGO robotic float

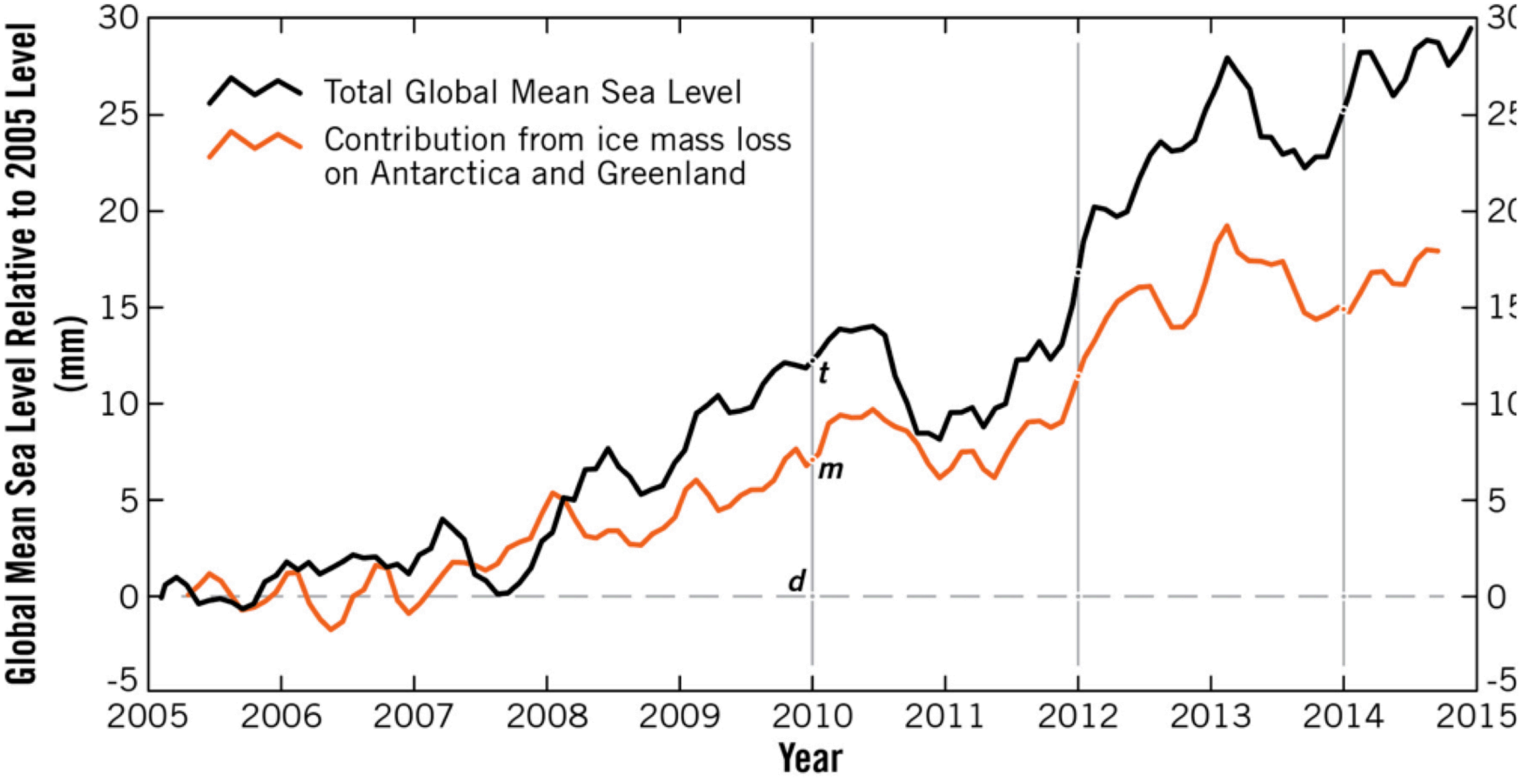


https://argo.ucsd.edu

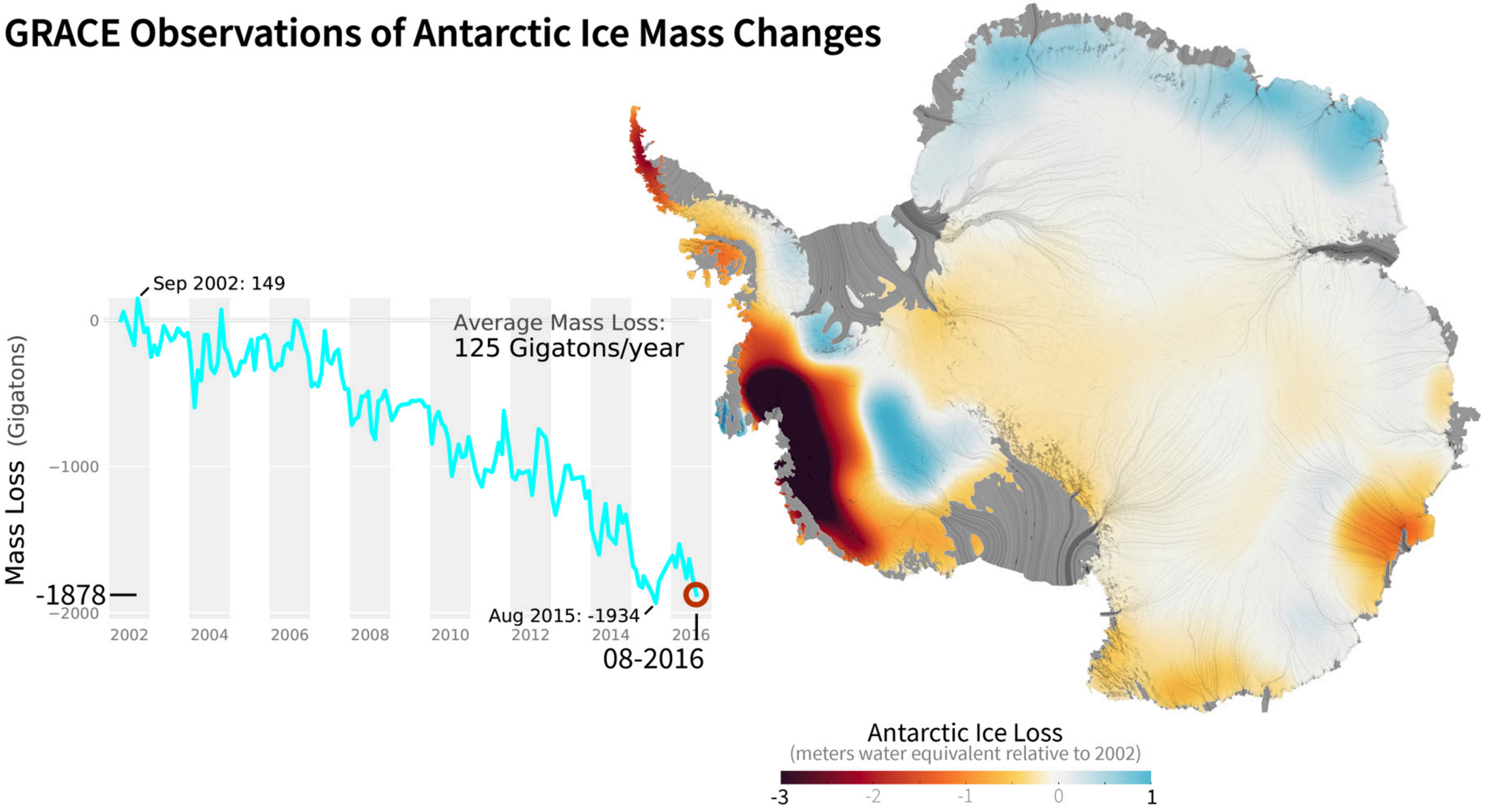


https://argo.ucsd.edu/about/status/

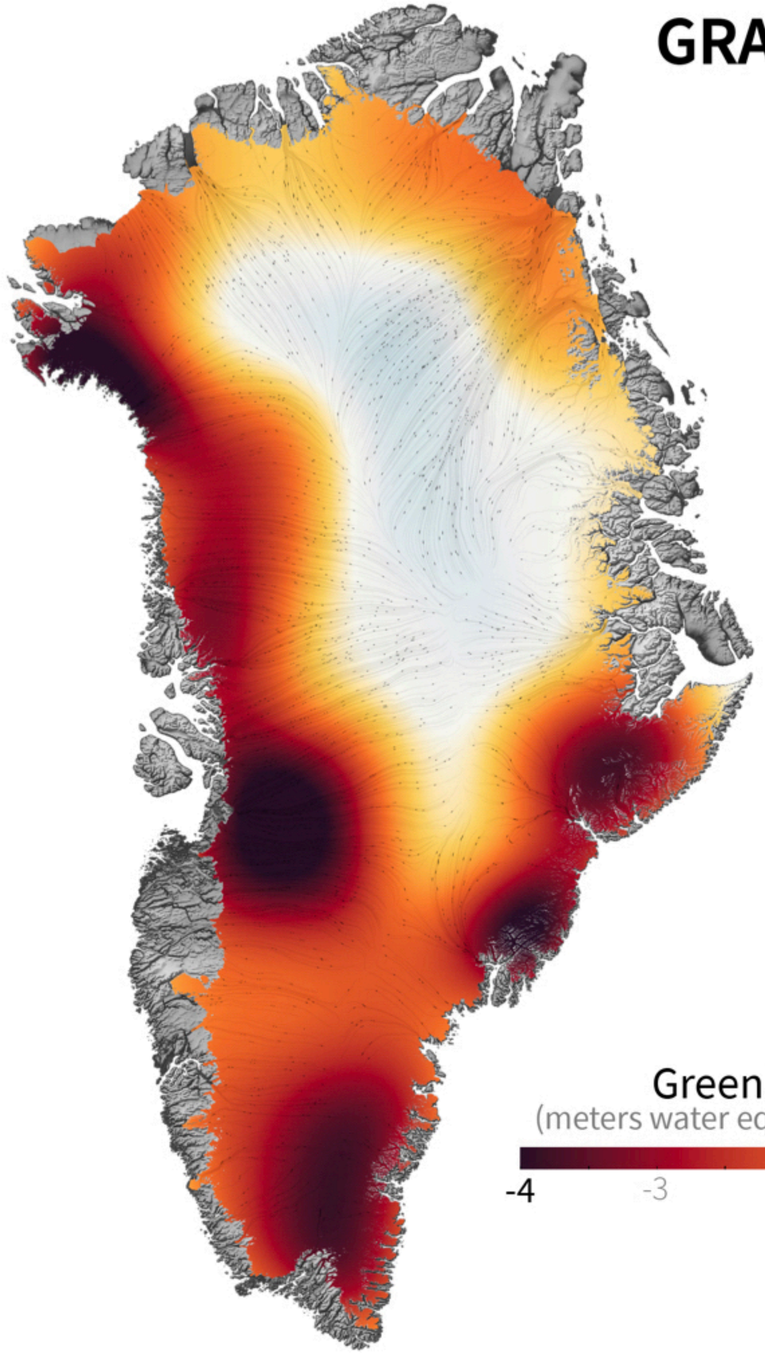

1 Float deployment
2 Descent to drifting depth
3 Drifting 10 days
4 Descent to profiling depth (2000 - 6000m)
5 Ascent: measuring Essential Ocean Variables
6 Data transmission
7 Starting next cycle
Argo data
0m
Drifting depth
1000m
Profiling depth
2000m
e.g measure 2
e.g measure 1
0
500
1000
1500
2000
Depth (in m)
Temperature (in °C)
Salinity (in psu)
https://argo.ucsd.edu
© Thomas Haessig


Global Mean Sea Level Relative to 2005 Level (mm)
Total Global Mean Sea Level
Contribution from ice mass loss on Antarctica and Greenland
t
m
d
30
25
20
15
10
5
0
-5
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year

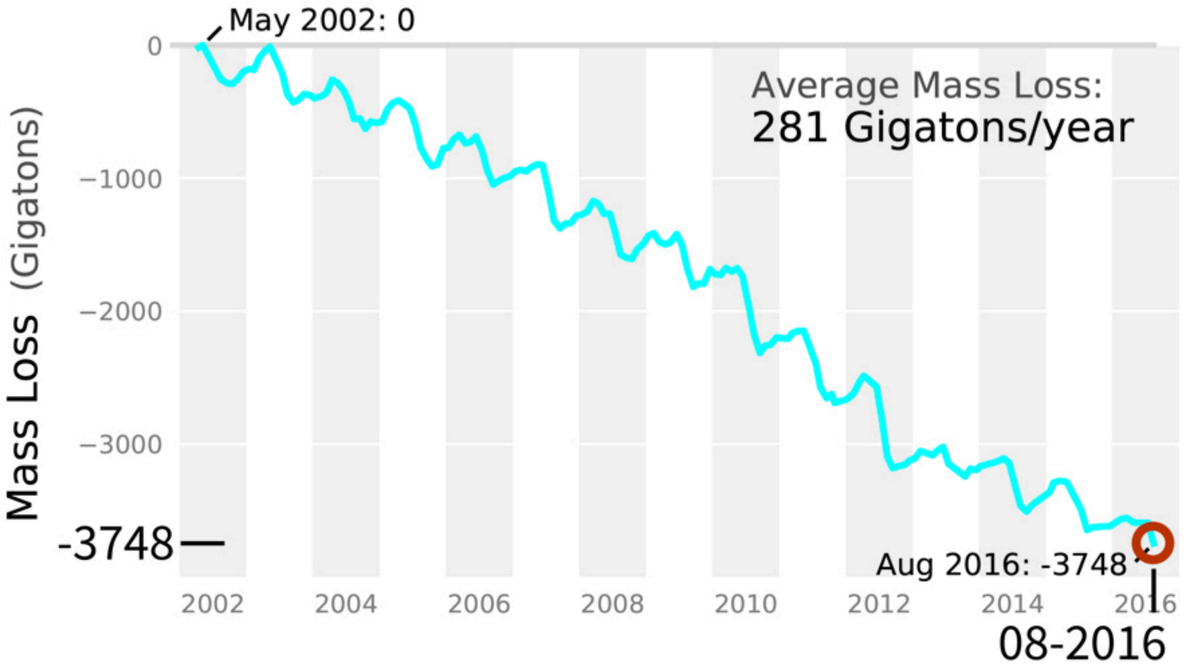
GRACE Observations of Antarctic Ice Mass Changes

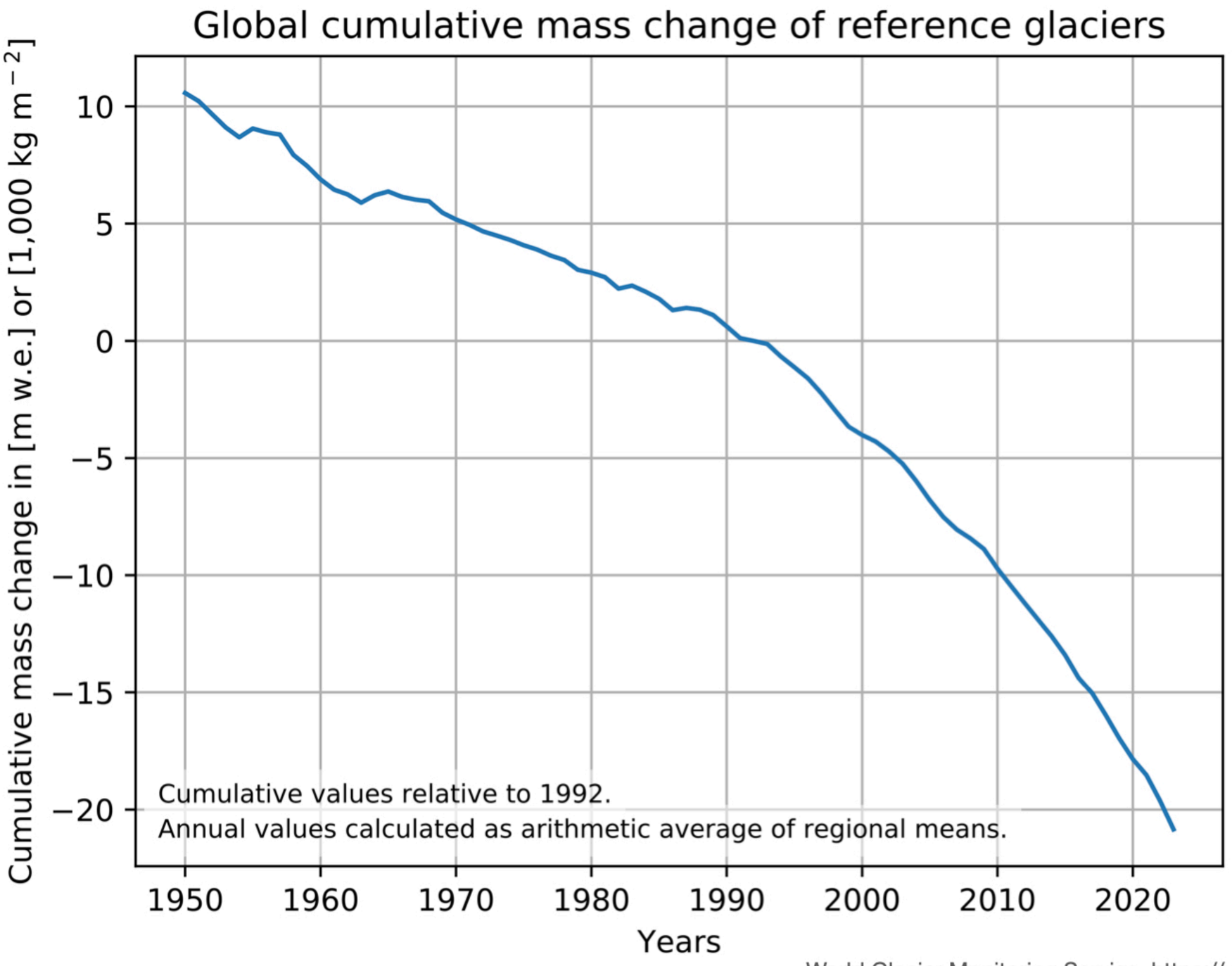


GRACE Observations of Greenland Ice Mass Changes

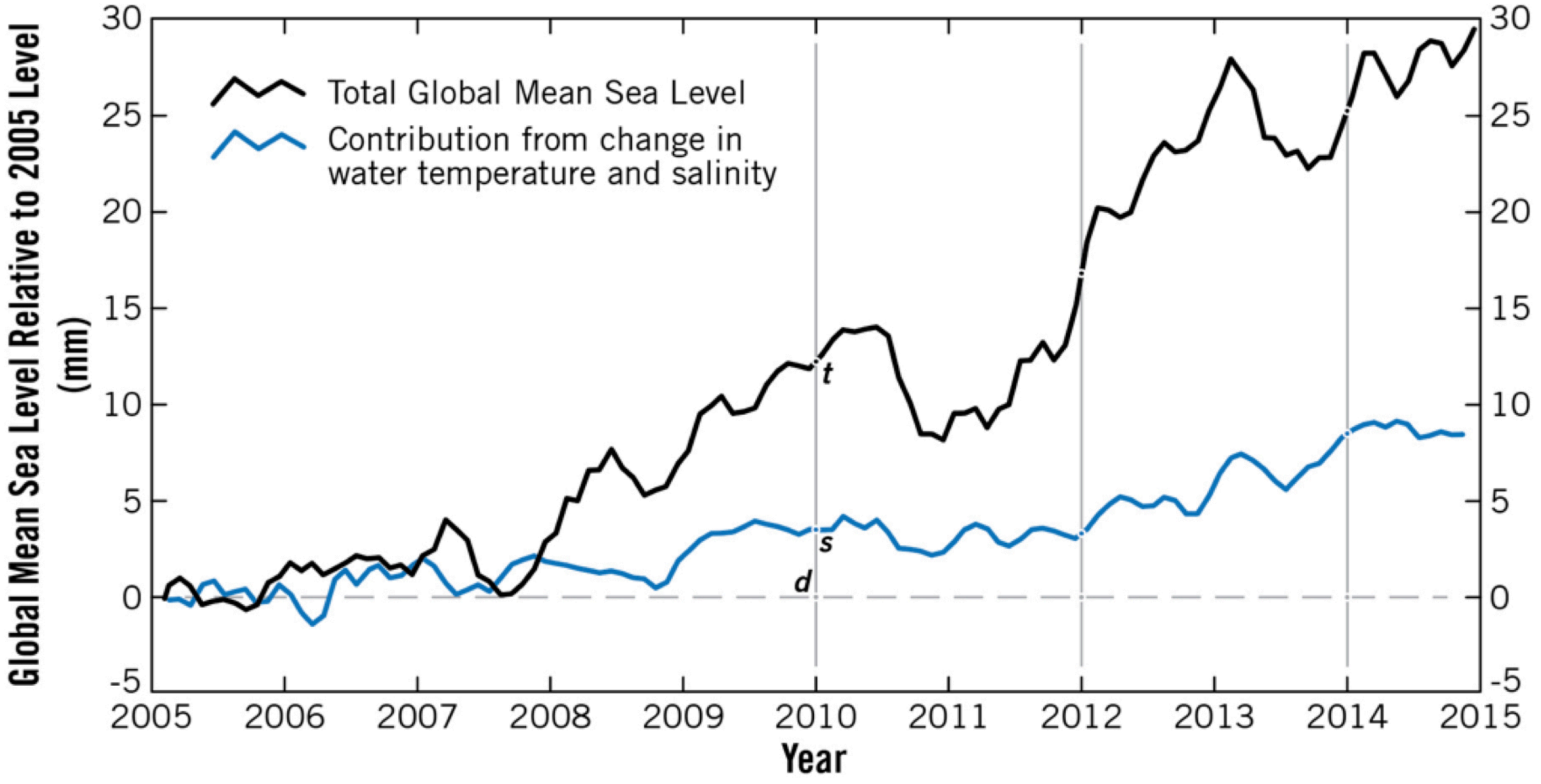


Greenland Ice Loss
(meters water equivalent relative to 2002)
-4 -3 -2 -1 0 0.5

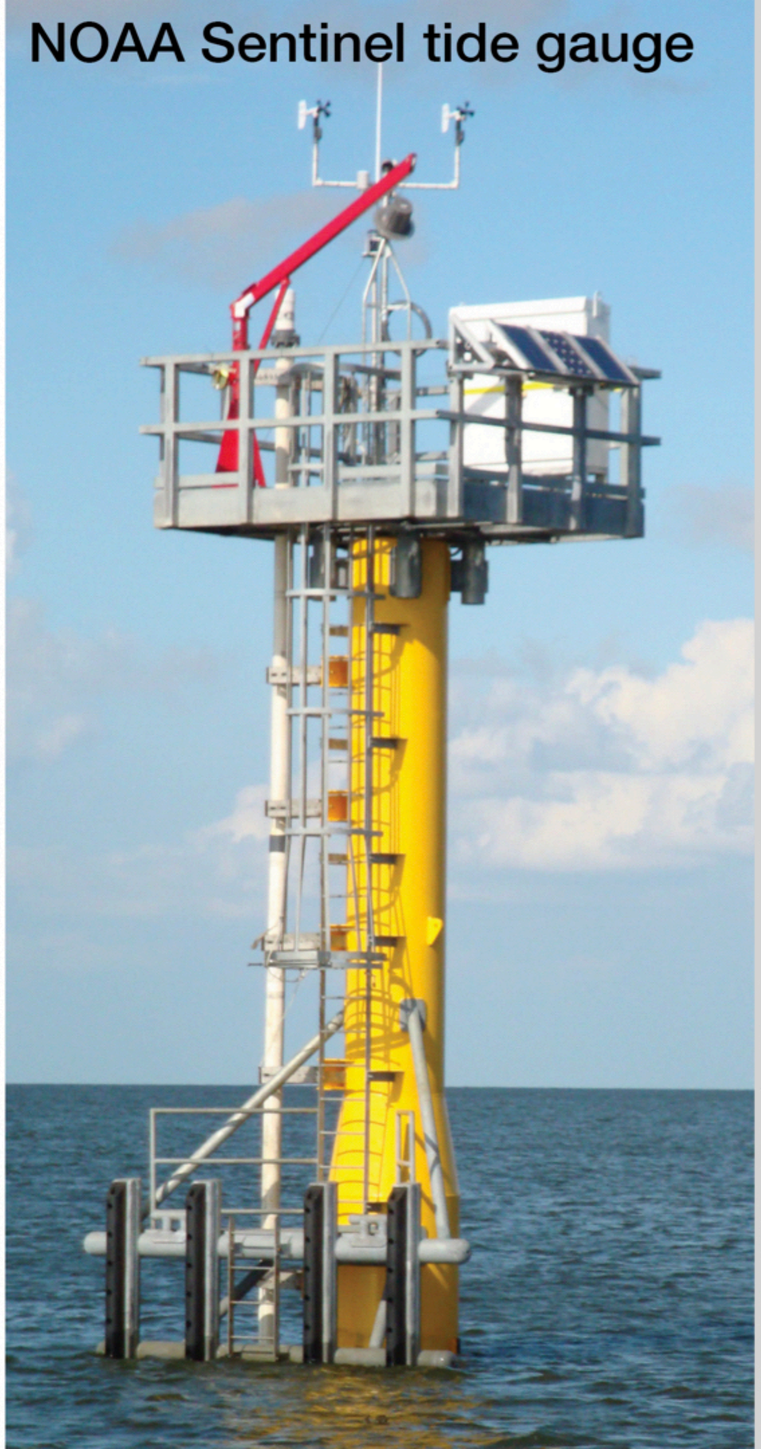


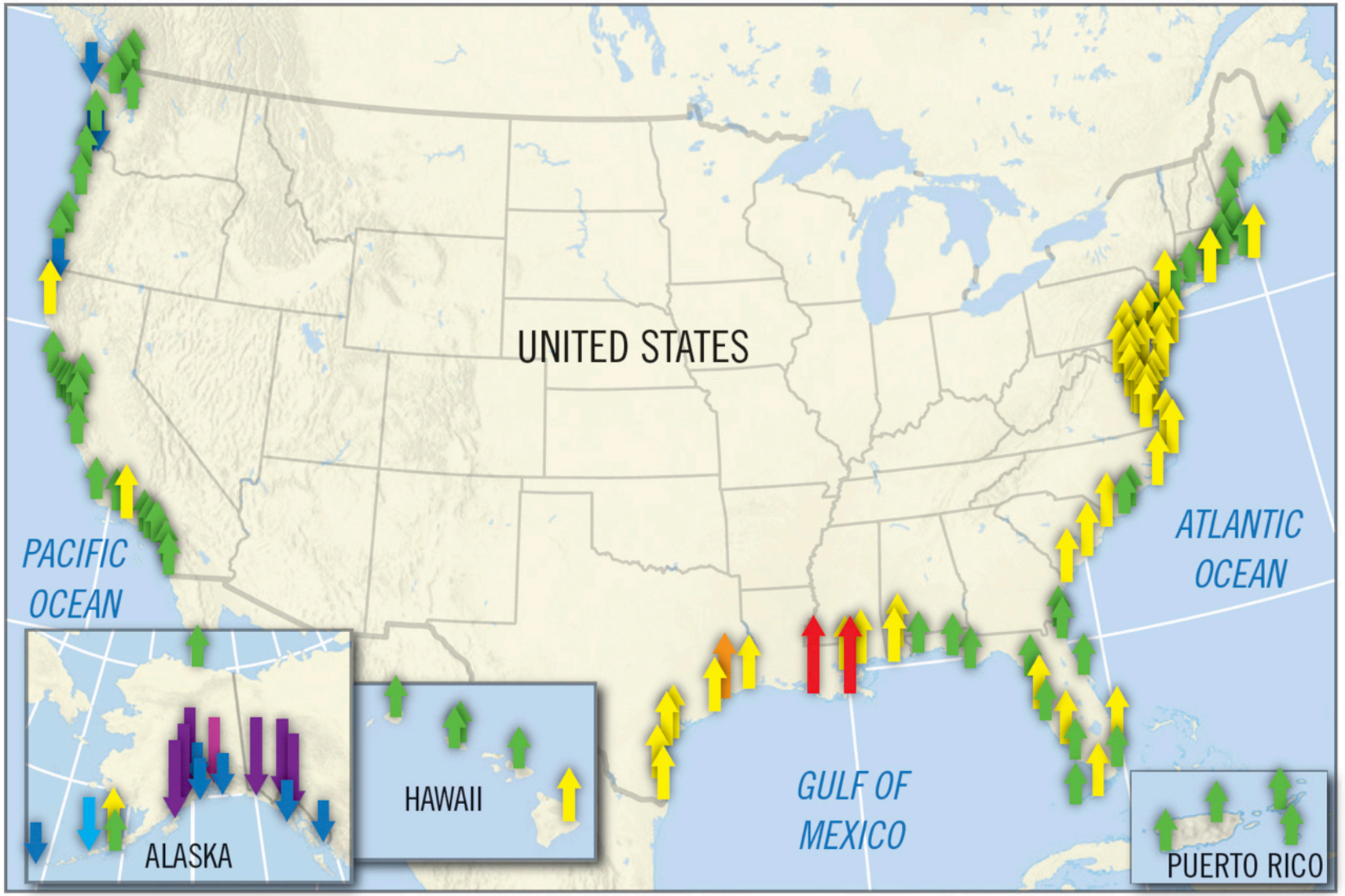


World Glacier Monitoring Service, https://wgms.ch/global-glacier-state/


Global Mean Sea Level Relative to 2005 Level (mm)
Total Global Mean Sea Level
Contribution from change in water temperature and salinity
t
s
d
30
25
20
15
10
5
0
-5
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year


Typical NOAA tide gauge
2006


NOAA Sentinel tide gauge



Relative Sea Level Trends

mm/yr (feet/century)

above 9 (above 3) | 6 to 9 (2 to 3) | 3 to 6 (1 to 2) | >0 to 3 (0 to 1) | –3 to 0 (–1 to 0) | –6 to –3 (–2 to –1) | –9 to –6 (–3 to –2) | below –9 (below –3)

Relative sea level recorded locally at NOAA tide-gauge stations

Freely accessible via NOAA Sea Level Trends website

https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

Relative Sea Level Trends

mm/yr (feet/century)

Above 9 (Above 3)	6 to 9 (2 to 3)	3 to 6 (1 to 2)	>0 to 3 (0 to 1)	-3 to 0 (-1 to 0)	-6 to -3 (-2 to -1)	-9 to -6 (-3 to -2)	Below -9 (Below -3)

https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

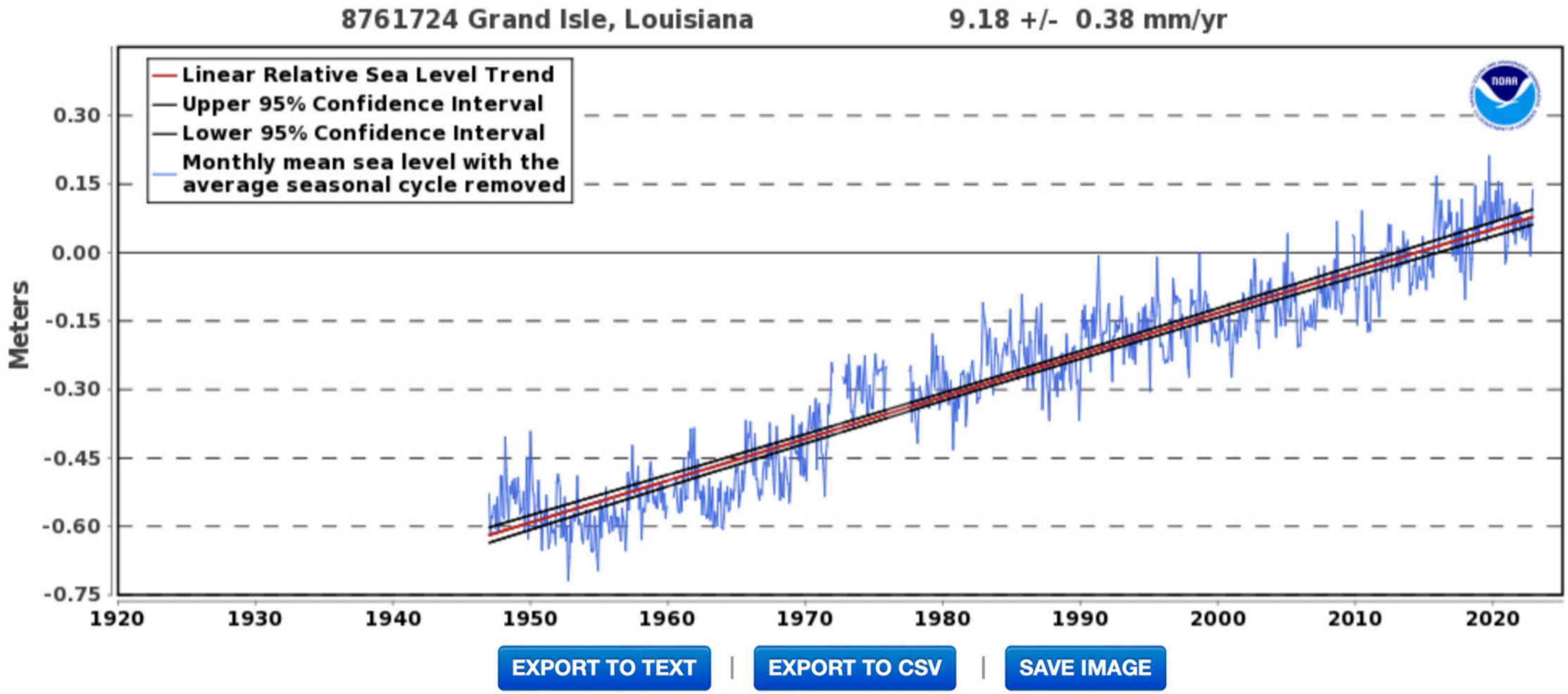
Grand Isle, LA
8761724

The relative sea level trend is 9.18 mm/year with a 95% confidence interval of +/- 0.38 mm/year based on monthly mean sea level data from 1947 to 2021 which is equivalent to a change of 3.01 feet in 100 years.

Choose plot:

Linear Trend
Regional Scenarios
Interannual Variation
Average Seasonal Cycle
Landsat Imagery

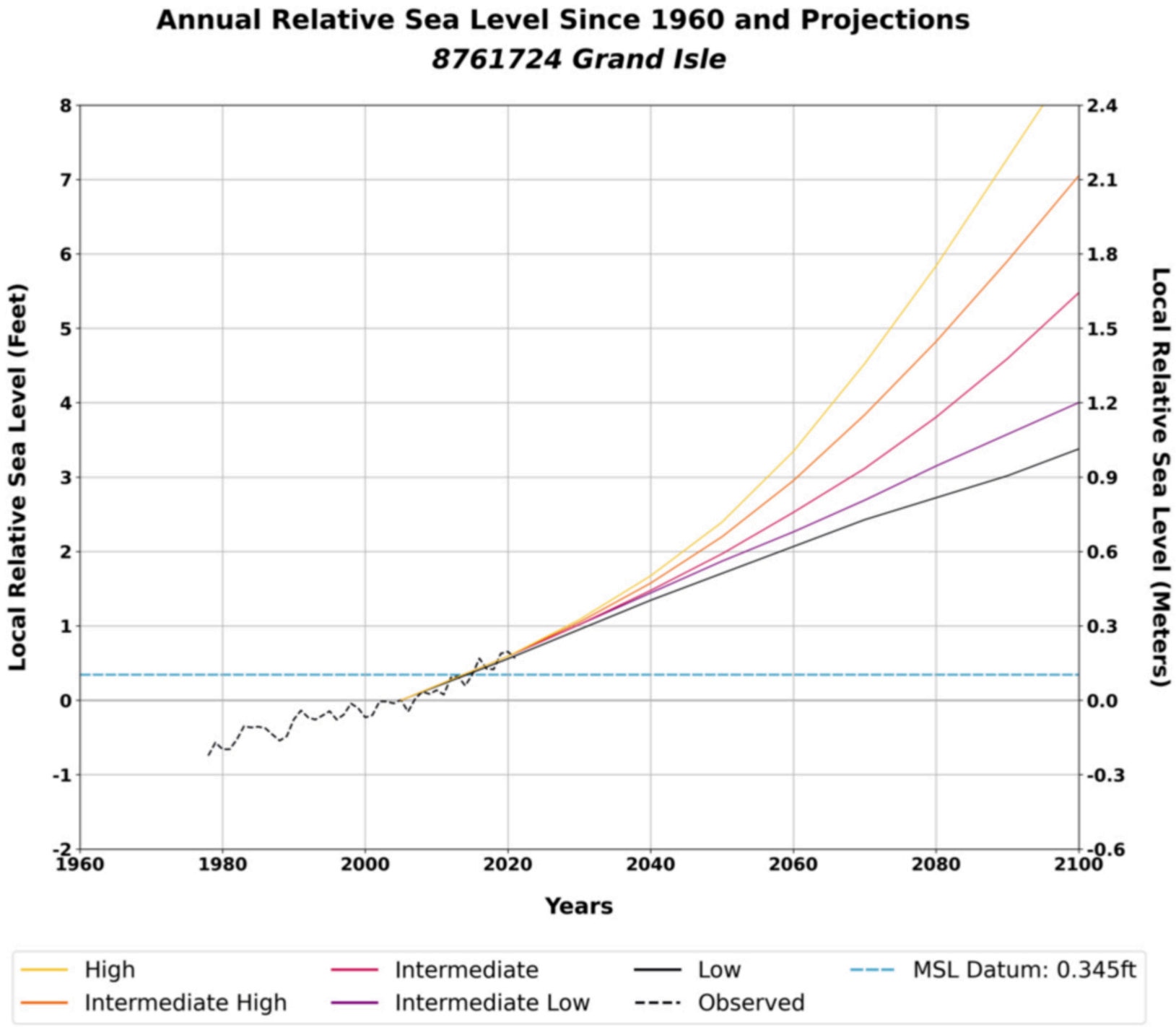
Relative Sea Level Trend
8761724 Grand Isle, Louisiana



EXPORT TO TEXT | EXPORT TO CSV | SAVE IMAGE

The relative sea level trend is 9.18 millimeters/year with a 95% confidence interval of +/- 0.38 mm/yr based on monthly mean sea level data from 1947 to 2021 which is equivalent to a change of 3.01 feet in 100 years.

Earlier data stored in database as station 8761720


Annual Relative Sea Level Since 1960 and Projections
8761724 Grand Isle
Local Relative Sea Level (Feet)
Local Relative Sea Level (Meters)
Years
8
7
6
5
4
3
2
1
0
-1
-2
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
1960
1980
2000
2020
2040
2060
2080
2100
High
Intermediate High
Intermediate
Intermediate Low
Low
Observed
MSL Datum: 0.345ft

Global warming affects humans as well as our communities and infrastructure worldwide.

Global warming affects humans as well as our communities and infrastructure worldwide.

Society depends on geoscientists to understand and mitigate the effects of global warming.

How can geoscientists help society meet the challenge of a changing climate?

1. Develop your relevant knowledge and skills.

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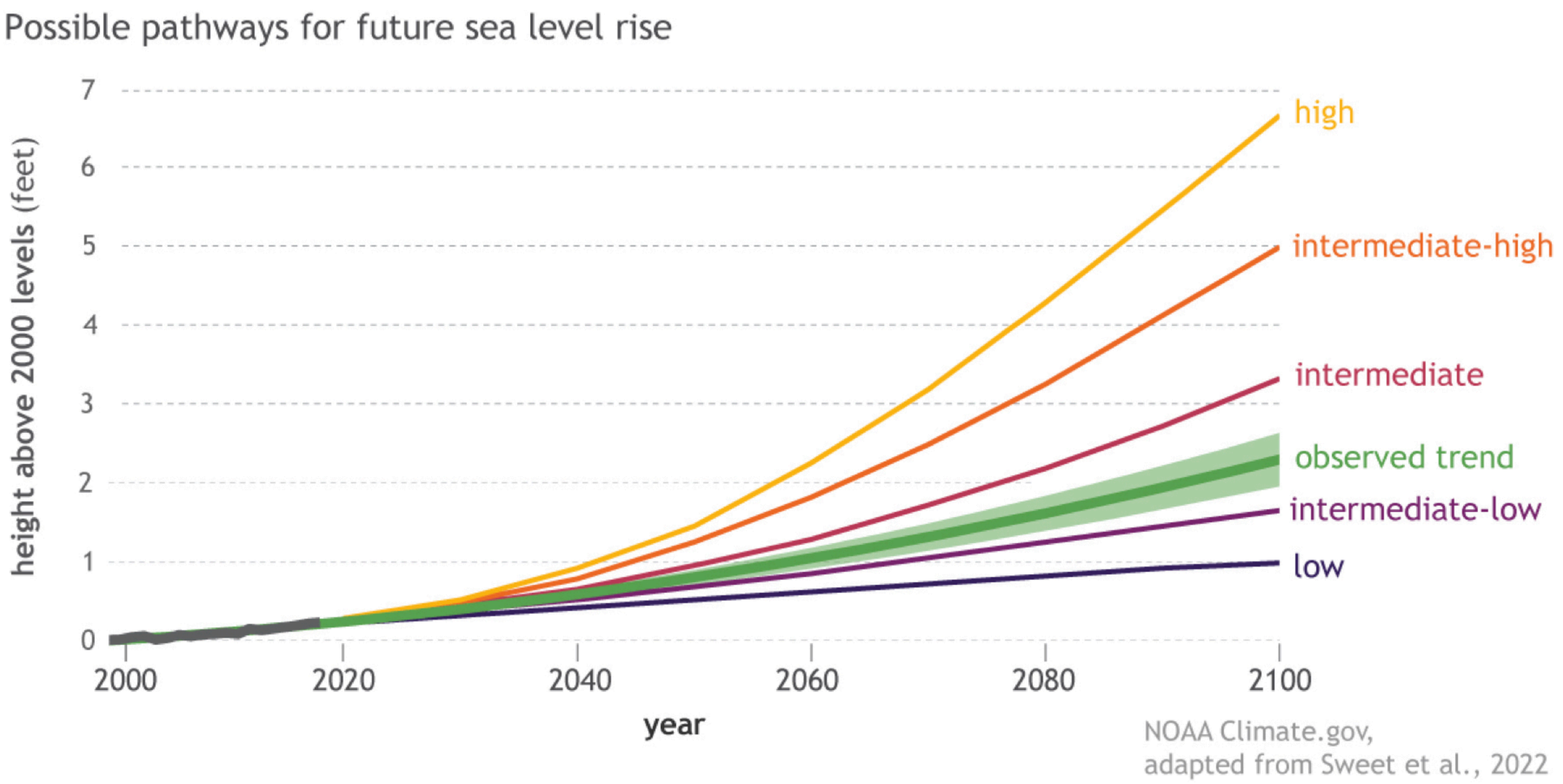
2. Communicate reliable information to help society develop its understanding. Teach through your words and actions.

How can geoscientists help society meet the challenge of a changing climate?

1. Develop your relevant knowledge and skills.
2. Communicate reliable information to help society develop its understanding. Teach through your words and actions.
3. Apply your knowledge and skills to develop, propose, and implement solutions.


Possible pathways for future sea level rise
height above 2000 levels (feet)
7
6
5
4
3
2
1
0
2000
2020
2040
2060
2080
2100
year
high
intermediate-high
intermediate
observed trend
intermediate-low
low
NOAA Climate.gov,
adapted from Sweet et al., 2022

For more information about this topic, visit

https://croninprojects.org/Oct2024/Climate/