Climate and the Oceans Chapter 7 – Global Warming and the Ocean

Presented by Emily Wisinski

10/31/2024

AOSC 680 Vallis Chapter 7: Global Warming and the Ocean

Learning Outcomes

 \checkmark Discuss sources of error in the global surface temperature records

- ✓The modern thermometer
- How satellites collect temperature measurements
- ✓ How proxy data is used for temperature reconstructions
- ✓ Human fingerprints of carbon dioxide
- ✓ How ocean heat content is measured
- \checkmark How the deep ocean will equilibrate
- ✓ Fingerprint of AMOC weakening
- \checkmark Sea level rise by thermal expansion and melting of ice sheets
- ✓ How we track sea ice extent and concentration

Selected Significant Climate Anomalies and Events: Annual 2023

"The name "global warming" is useful...No where will be unaffected, nothing will be impervious, no one will be immune." -Vallis

GLOBAL AVERAGE TEMPERATURE

NORTH AMERICA

vear on record.

Nine back-to-back atmospheric rivers pummeled

California in Jan 2023, which brought a total of

32 trillion gallons of rain and snow to the state.

EASTERN NORTH PACIFIC

Above-average activity: 17 storms,

On Aug 8, winds from Hurricane Dora

wildfire in the U.S. in over a century.

exacerbated a wildfire on the island of

Maui in Hawaii that destroyed the historic

town of Lahaina and became the deadliest

HURRICANE OTIS

million people.

On Oct 25. Hurricane Otis made landfall as a

southern Pacific coast after increasing wind

catastrophic damage to a city of nearly one

Category 5 hurricane near Acapulco on Mexico's

speed by 115 mph within 24 hours and bringing

HURRICANE SEASON

including 10 hurricanes

2023 was North America's warmest

CANADA

CALIFORNIA

HAWAI

The Jan–Dec 2023 average global surface temperature was the highest since global records began in 1850.

over) for the most acres burned in Canadian and North American history. These fires caused

widespread air quality deterioration across much of Canada and the U.S.



Wildfires across Canada burned more than 45.7 million acres, shattering a record (2.6 times **ARCTIC SEA ICE EXTENT**

The 2023 Arctic maximum and minimum extents were third- and sixthsmallest on record, respectively.

EUROPE ASIA Europe had its second-2023 was Asia's second-warmest warmest year on record.

CYCLONE DANIEL On Sep 10, Storm Daniel brought strong

winds and an unprecedented amount of rain to eastern Libya, which caused massive destruction-dams burst across many towns and led to the death of more than 10,000 people, making it the deadliest and costliest tropical cyclone of 2023.

> **NORTH INDIAN** OCEAN CYCLONE SEASON

four cyclones

GLOBAL TROPICAL CYCLONES Above-average activity: 78 storms, including 45 hurricanes/cyclones/

typhoons

GLOBAL OCEAN

2023 was Africa's warmest

South America had its warmest

ATLANTIC HURRICANE

including seven hurricanes

Above-average activity: 20 storms,

AFRICA

year on record.

vear on record.

SOUTH AMERICA

SEASON

For nine consecutive months (Apr-Dec), global ocean surface temperatures were record warm.

year on record.

Above-average activity: eight storms, including

Cyclone Mocha was the North Indian Ocean's first named storm of 2023, and made a devastating SOUTH INDIAN OCEAN landfall as a Category 4 cyclone in Myanmar on May 14.

CYCLONE SEASON* Above-average activity: nine storms, including seven cyclones

OCEANIA

Oceania had its 10thwarmest year on record.

WESTERN NORTH PACIFIC

Below-average activity: 17 storms,

SUPER TYPHOON MAWAR

Super Typhoon Mawar passed

within 100 miles of Guam in the

Western Pacific on May 24 as a

Category 4 storm. Mawar resulted

in heavy rainfall and widespread

power outages on Guam.

TYPHOON SEASON

including 12 typhoons

AUSTRALIA CYCLONE SEASON*

Above-average activity: nine storms, including five cyclones

SOUTHWEST PACIFIC CYCLONE SEASON*

Below-average activity: six storms, including three cyclones

ANTARCTIC SEA ICE EXTENT

The Antarctic had record-low annual maximum and minimum sea ice extents during 2023.

*Cyclone season runs from June 2022–July 2023

TROPICAL CYCLONE MOCHA

Please note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/

Updated Figure 7.1 from Vallis Ch 7. (1850-2023) NOAA climate.gov, based on data from NCEI

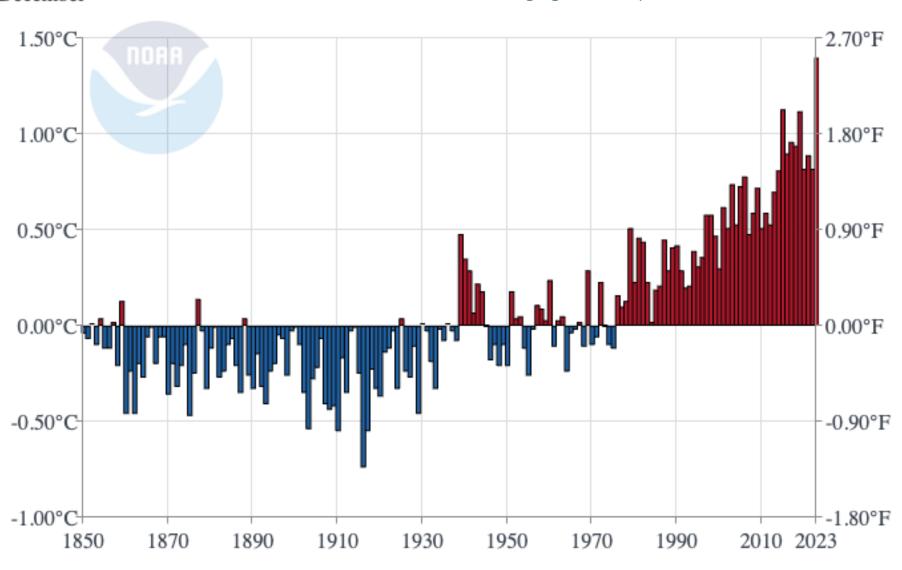
Observed **Global Average** Surface Temperature

December

What overall trend do we see here?

Global Avg Temp Anom https://www.climate.gov/news-features/understanding-climate/climate-

change-global-temperature

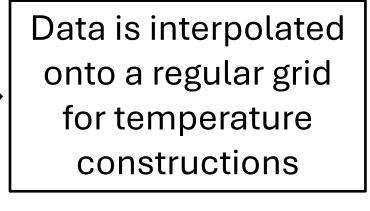


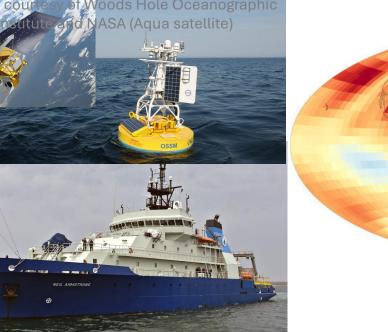
Observed Global Average Surface Temperature

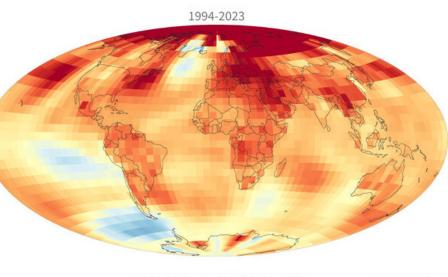
Weather stations collect data 1-2x daily across the globe

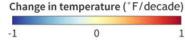


Ocean data comes from in-situ observations (e.g., ships, buoys, & satellites) esy of Woods Hole Oceanographic and NASA (Aqua satellite)









NOAA Climate.gov Data: NCEI

Sources of Error

What are three potential sources of error Vallis discusses?

Examples of artifacts in temperature data Normal Spike Flatliner Outlier **Excessive Range Change Points** MMMMMMM MMMMMM MM Splat a de aler a a a aleradore

NOAA Climate.gov

Measurements and models of the temperature change of water samples in Systematic sea-surface temperature buckets Temperature

G. Carella, A. K. R. Morris, R. W. Pascal, M. J. Yelland, D. I. Berry, S. Morak-Bozzo, C. J. Merchant, E. C. Kent 🗙

First published: 23 May 2017 https://doi.org/10.1002/qj.3078 Citations: 8 Systematic Differences in Bucket Sea Surface Temperatures Caused by Misclassification of Engine Room Intake Measurements

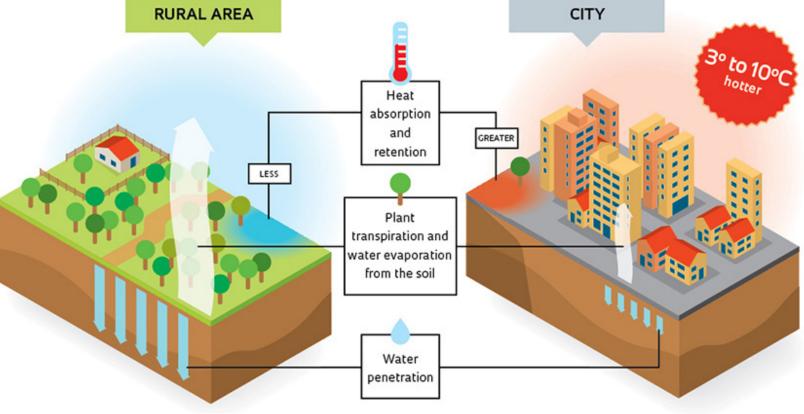
Duo Chan and Peter Huybers

Online Publication: 06 Aug 2020 Print Publication: 15 Sep 2020

Urbanization / The Urban Heat Island Effect

Urban Heat Island Effect graphic, Alexandre Affonso

How do scientists disentangle the actual warming of a localized region impacted by urbanization?



Research Article 🔂 Open Access 🛛 😨 🔅 😂

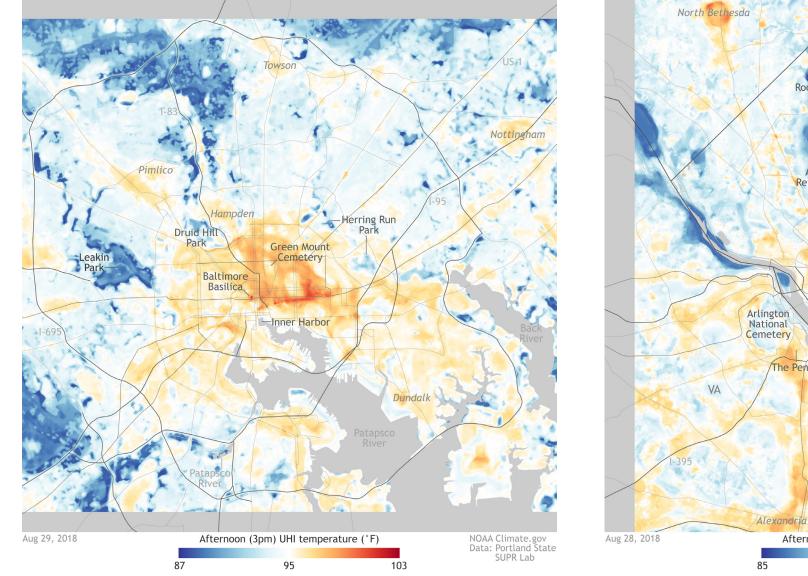
Urbanization Contributes Little to Global Warming but Substantially Intensifies Local and Regional Land Surface Warming

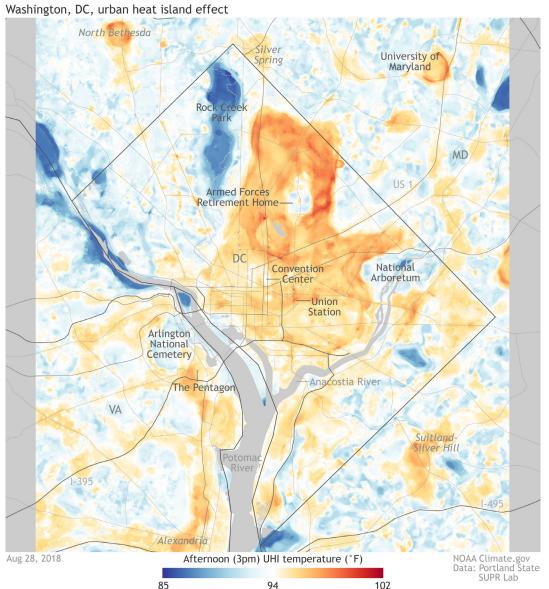
Decheng Zhou, Jingfeng Xiao 💌, Steve Frolking, Liangxia Zhang, Guoyi Zhou 💌

First published: 04 May 2022 | https://doi.org/10.1029/2021EF002401 | Citations: 15

Urbanization / The Urban Heat Island Effect

Baltimore, MD, urban heat island effect

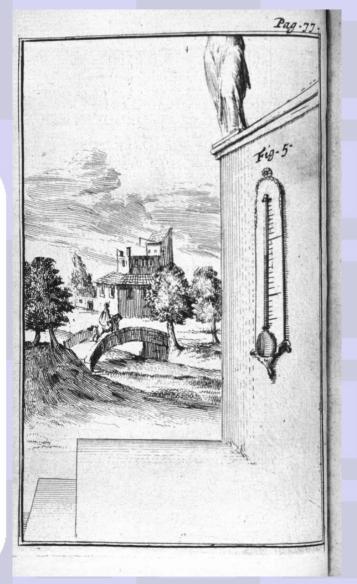




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The Thermometer

- Who invented the first thermometer with a scale? What year?
- Who invented the first thermometer calibrated to the freezing and boiling points of water? What year?
- Who invented the thermometer design with mercury? What year?
- Lastly, who invented the thermometer calibrated to the freezing and boiling points of water at sea level? What year?



Thermometer on an outside wall in 1688, Joachim d'Alence https://time.com/6053214/th ermometer-history?

10/31/2024

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The Modern Thermometer

- Invented by Daniel Gabriel Fahrenheit in 1714, mercury glass tube with a standardized scale running up the side
- The thermometer, barometer, and hygrometer were key parts of the formal weather station (Stevenson screens), first installed in Europe and the US in the 1800s
- Our temperature record begins in 1850

A Stevenson screen, containing meteorological instruments. Credit: Universal Images Group North America LLC / DeAgostini / Alamy Stock Photo.



Satellite Measurements

What are some pros and cons of satellite measurements?

Pros	Cons		

How Do Satellites Measure Temperature?

 → Measurements taken with a microwave and infrared sounder

- → The brightness in each band is sensitive to temperature and water vapor
- → Multiple bands creates a temperature profile

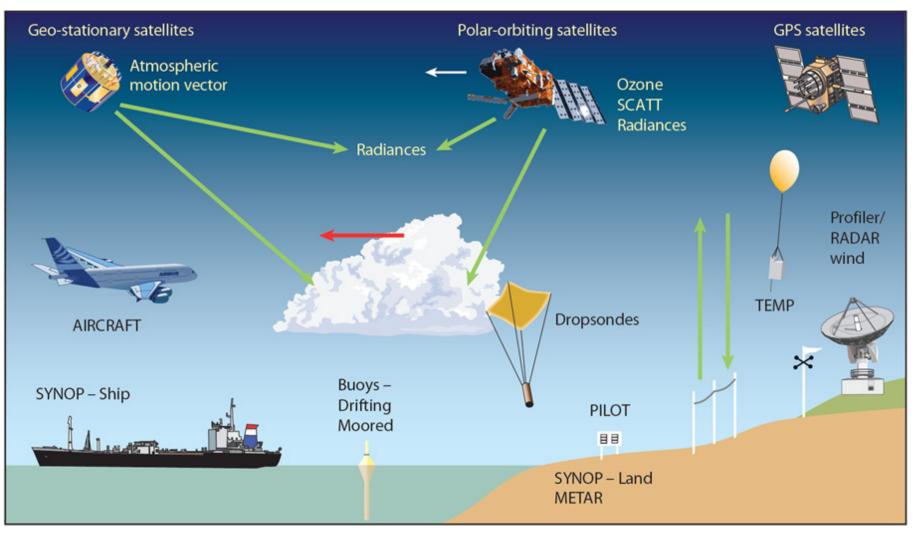


Figure courtesy of ECMWF

Satellite Measurements

What trends do you notice?

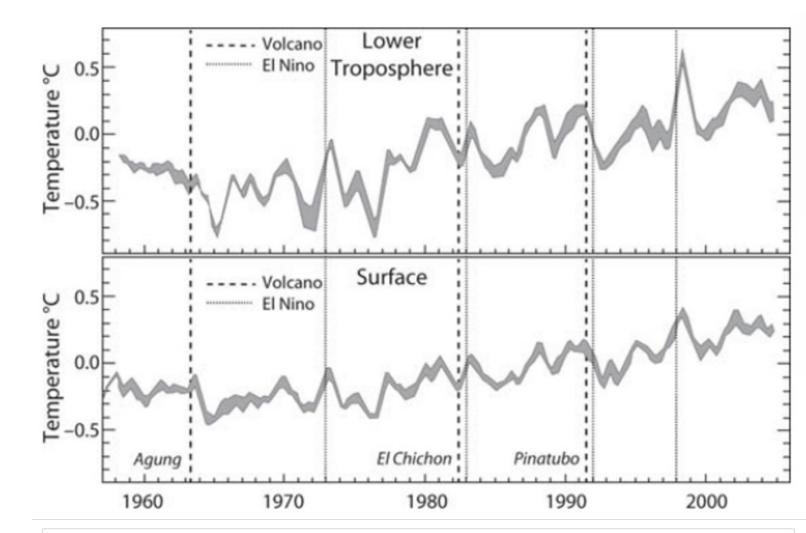


Figure 7.2. Top: Lower troposphere temperature as measured by various satellites and by radiosondes; the gray shading indicates the spread between all measurements. Bottom: Surface temperature records from NOAA, NASA, and UKMO, with gray shading again indicating the spread. Records are monthly means, smoothed with a seven-month running mean filter, and are relative to 1979–1997 mean. Adapted from Solomon et al., 2007.

Proxy Data

What sources are used for reconstruction?

https://www.ncei.noaa.gov/products/paleoclimatology Global view All proxy data Boreholes Marine sediments Climate forcing From 54,416BC to 41,781BC Climate reconstructions MD95-2006 Coral and sponges Study link MD95-2006 Dust deposition North Atlantic Ocean Fire history Year from: 54,416BC Year to: 41,781BC Historical documents Ice cores Centennial-scale evolution of Dansgaard-Insects Oeschger events in the northeast Atlantic Lake levels Ocean between 39.5... Dickson, A.J. et al. (2008) Lake sediments Marine sediments Marine sediments Plant fossils Marine sediments accumulate on the Pollen beds of seas and oceans around the world. The properties and contents of Speleothems the sediment provide clues to the past 8 climate. Tree rinas 888 8 Other collections Total number of marine sediments studies: 8 88 870 8 mapbox © geoBoundaries © Mapbox © OpenStreetMap Improve this map

Amazing interactive tool to learn about proxy data! https://interactive.carbonbrief.org/how-proxy-data-

reveals-climate-of-earths-distant-past/ NCEI Paleoclimatology data (10,000 proxy datasets):

'Hockey Stick' Graph

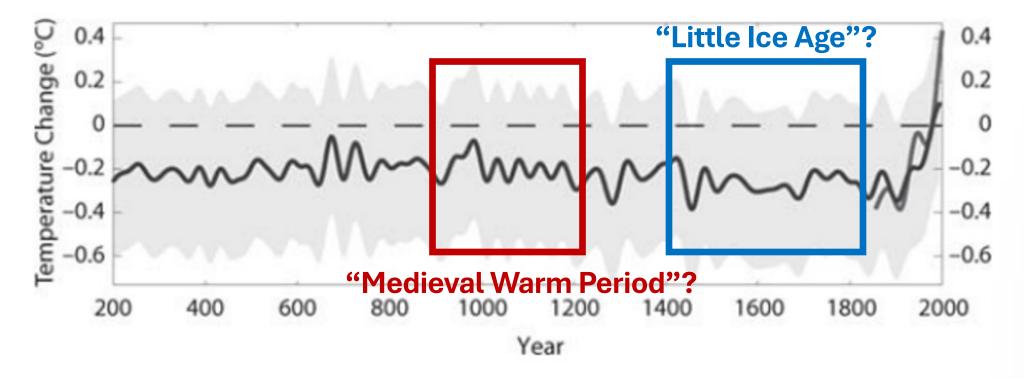
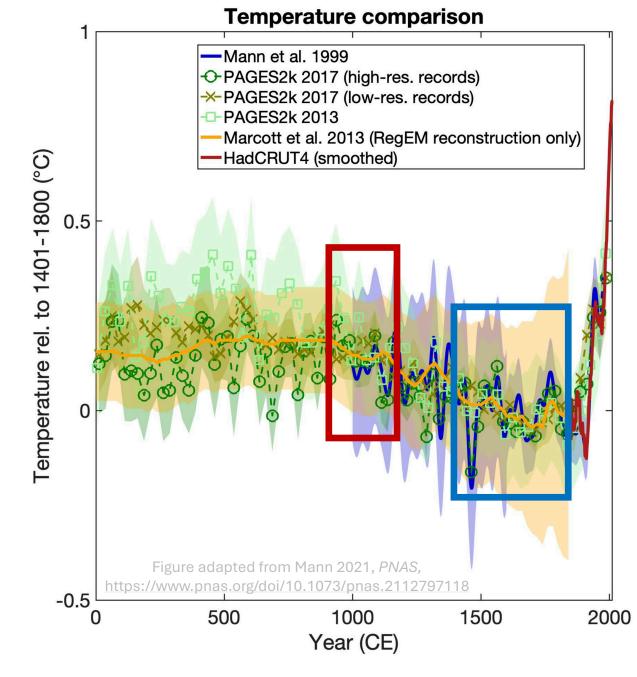


Figure 7.3. Global mean surface temperatures of the past 1,800 years. The lighter solid curve extending from about 1850 to 2000 shows the instrumental record. The longer solid curve is an estimate of temperature over the entire period using proxy reconstructions, and the gray shading is an error estimate (the 95 percent confidence interval). The series are smoothed to remove fluctuations of periods shorter than 40 years, and the temperatures represent anomalies in °C from a late twentieth century value. Source: Adapted from Jones and Mann (2004).

Proxy Data – 'Hockey Stick' Graph

What properties do we assume to be true when using proxy data?



Greenhouse Gases and Global Temperatures

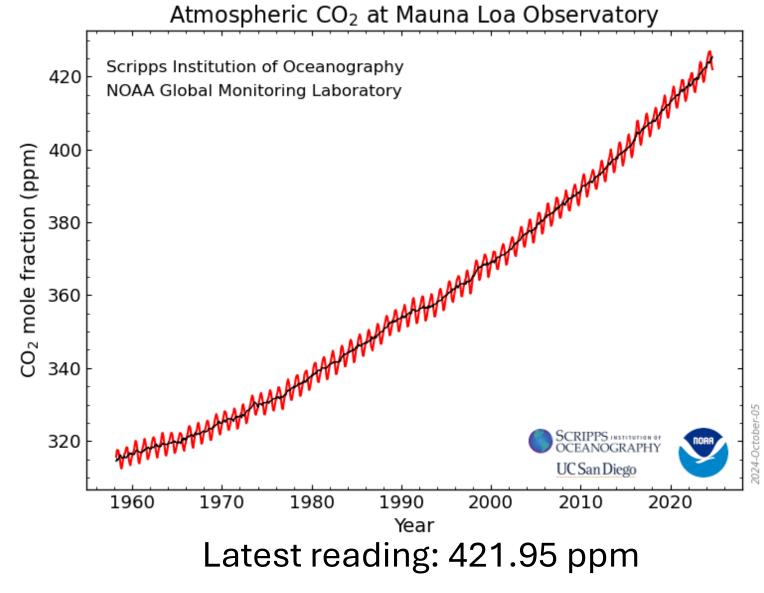
Review:

What is the most important naturally occurring greenhouse gas in Earth's atmosphere?

What is the most important anthropogenic greenhouse gas in Earth's atmosphere?

Greenhouse Gases and Global Temperatures

What are the two distinctive features of the Keeling Curve?



Human Fingerprints of Carbon Dioxide

How do we know the increase in carbon dioxide is caused by the burning of fossil fuels (per Vallis)?

How do we know the increase in carbon dioxide is caused by the burning of fossil fuels (per Beacon of Hope)?

The Likely Culprit of Global Warming

Main Takeaways:

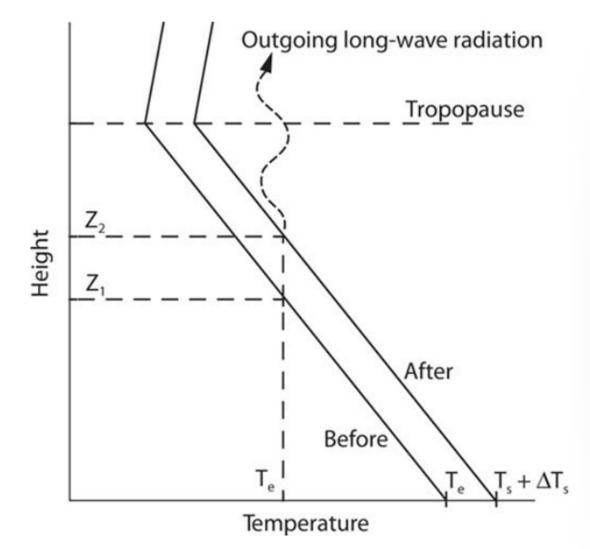


Figure 7.5. Schematic of temperature profiles before and after the addition of greenhouse gases. The total outgoing longwave radiation must remain the same because this radiation balances the incoming solar radiation, and so the emissions temperature, T_{e} , stays the same. However, the emissions height must increase (from Z_1 to Z_2 because of the increased absorptivity of the atmosphere. Hence, if the temperature gradient in the vertical remains similar, the surface temperature must increase.

Has the Ocean Warmed?

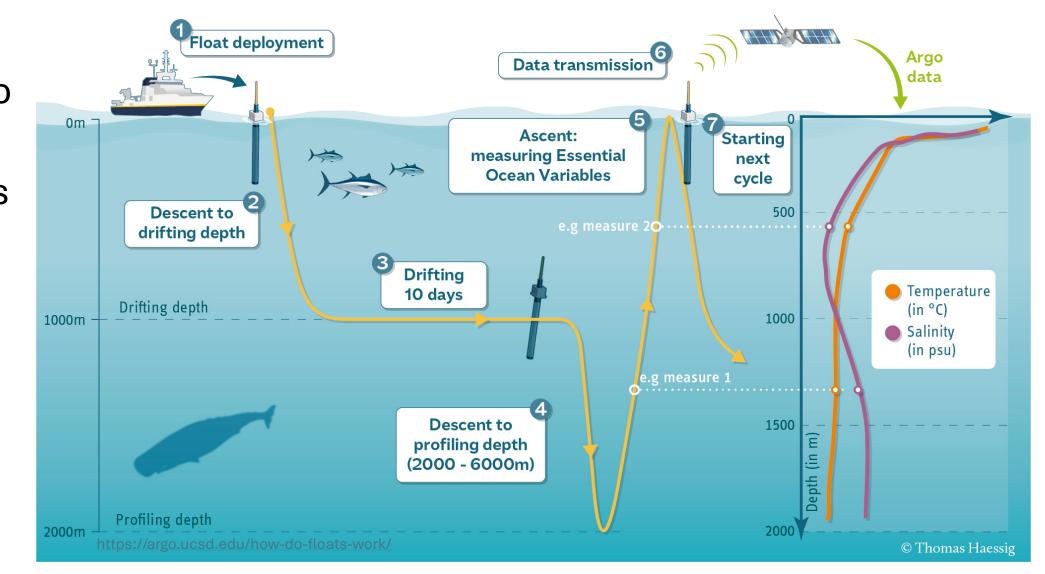
Section 2

What is Ocean Heat Content (OHC)?

"... defined as the heat capacity of seawater multiplied by the change in temperature, integrated over the entire mass of the world's oceans."

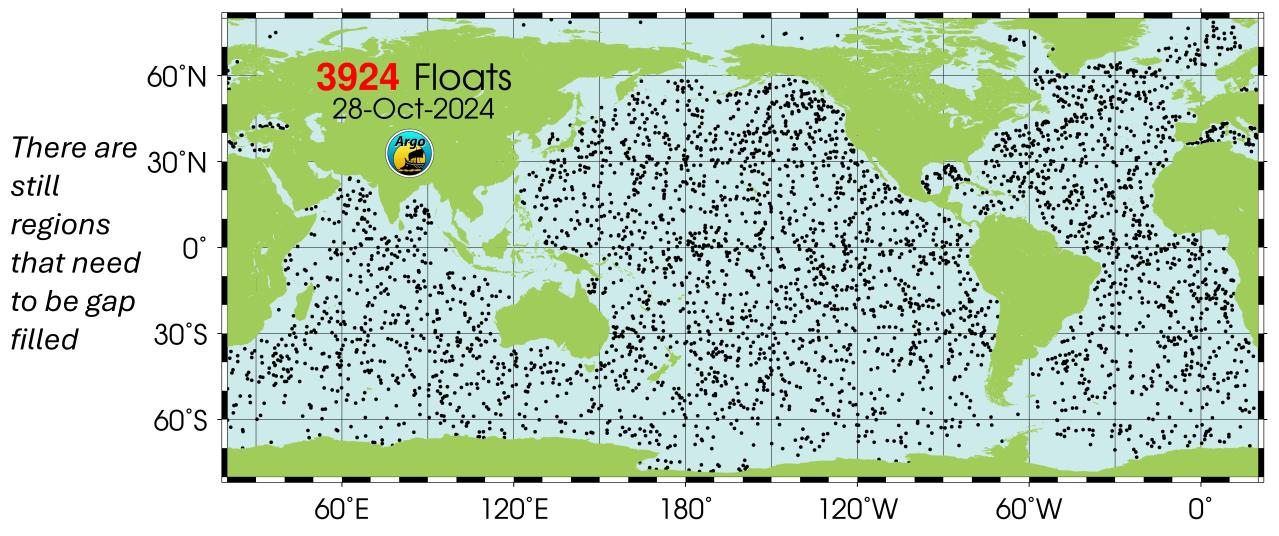
How Do We Measure OHC In-Situ?

Fun fact: Argo was named because of the program's partnership with the Jason earth observing satellites \rightarrow in Greek mythology, Jason sailed on his ship the Argo



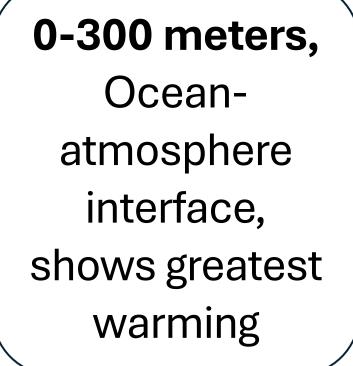
Argo Float Distribution, Oct 2024

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



3 Ocean Heat Content

Indicators



0-700 m, Standard measure of OHC, historical measurements collected here **0-2000 m,** Important for long-term energy imbalance and heat storage

https://marine.copernicus.eu/ocean-climate-portal/ocean-heat-content

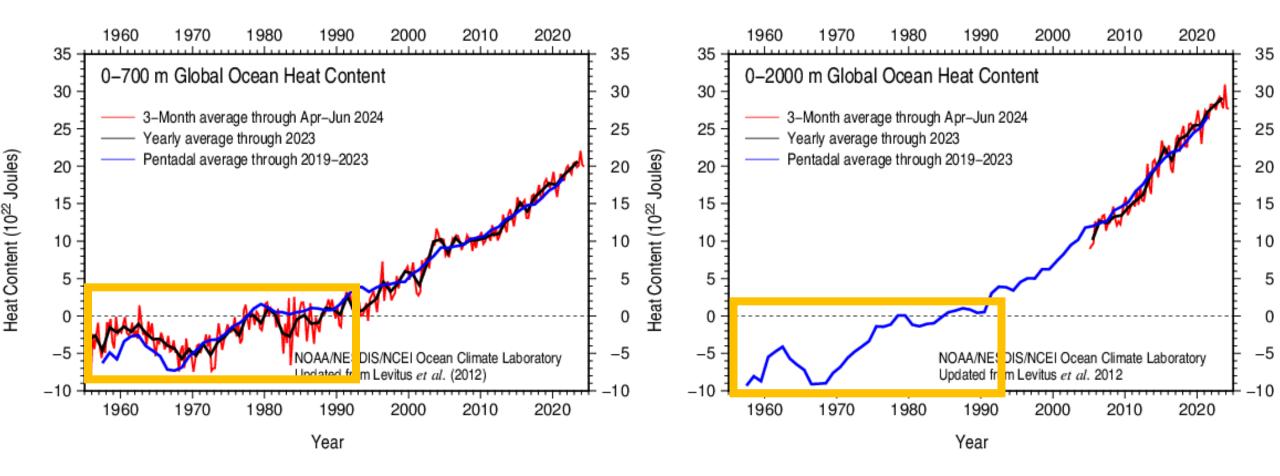
OHC

Where has the ocean experienced the most temperature increase?

What about the negative trend in the Northeastern Atlantic?

Change in ocean heat content from 1993 to 2023 https://climate.copernicus.eu/climate-indicators/ocean-heat-content				
Ocean depth		Global ocean	Northeastern Atlantic	
0–2000 m	W/m²	1.30 ± 0.01 W/m ²	0.22 ± 0.1 W/m ²	
	°C	0.22 ± 0.004°C	0.04 ± 0.01°C	
0–700 m	W/m²	0.83 ± 0.01 W/m ²	0.39 ± 0.04 W/m ²	
	°C	0.40 ± 0.005°C	0.18 ± 0.02°C	
700–2000 m	W/m²	0.47 ± 0.02 W/m ²	-0.16 ± 0.13 W/m ²	
	°C	0.12 ± 0.005°C	-0.04 ± 0.03°C	

OHC Is there anything surprising in these figures?



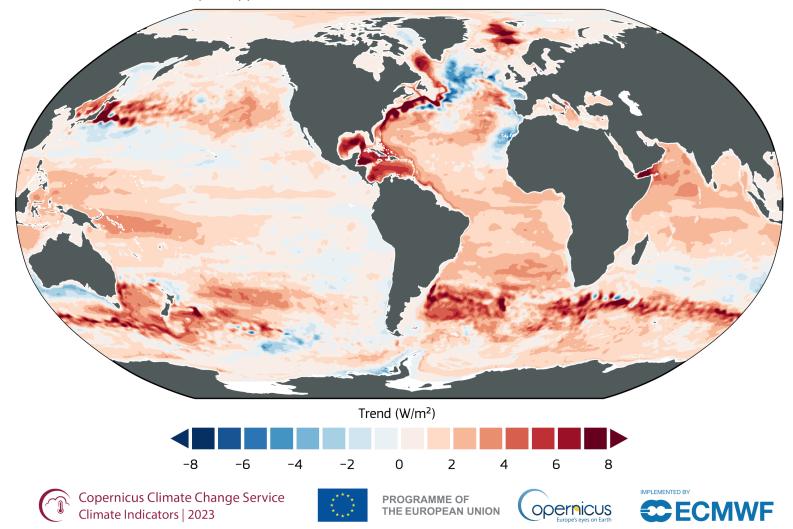
OHC

Why do some regions exhibit cooling trends?

Do you notice anything about the western boundary currents?

Trend in the heat content of the global ocean, for 1993–2023

Depth: upper 2000 m • Data: ORAS5 • Credit: C3S/ECMWF



More Effects of and on the Ocean

The 4 potential effects Vallis includes are:

Effect #1: The Slowing of Global Warming

- There is a slower oceanic response compared to the atmosphere
- The mixed layer is in equilibrium with the forcing levels in the atmosphere about a decade ago

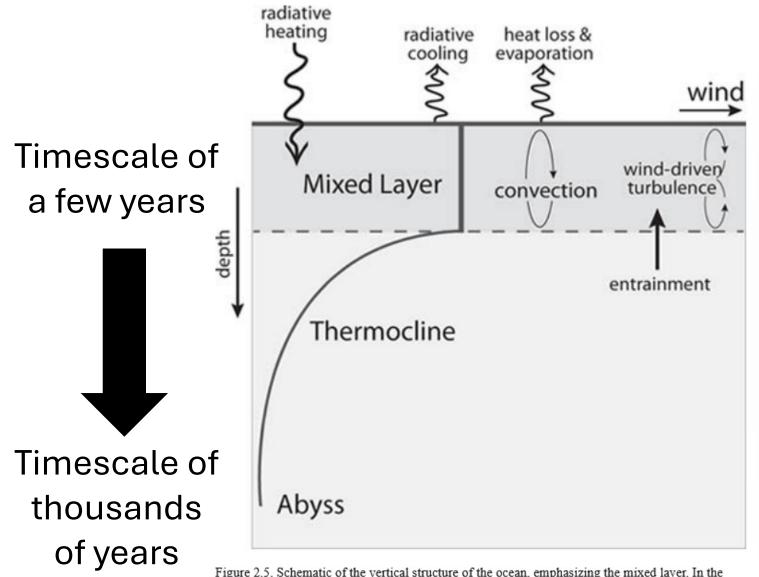
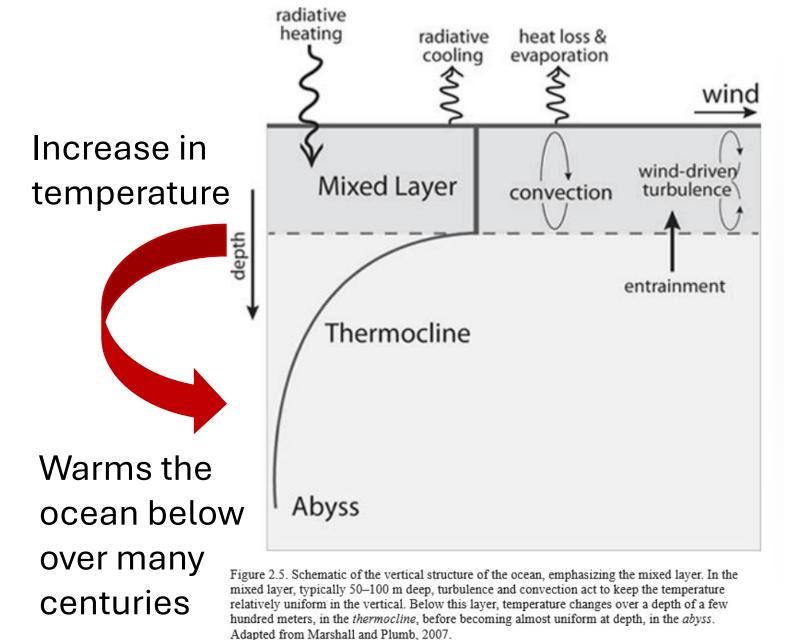


Figure 2.5. Schematic of the vertical structure of the ocean, emphasizing the mixed layer. In the mixed layer, typically 50–100 m deep, turbulence and convection act to keep the temperature relatively uniform in the vertical. Below this layer, temperature changes over a depth of a few hundred meters, in the *thermocline*, before becoming almost uniform at depth, in the *abyss*. Adapted from Marshall and Plumb, 2007.

Effect #1

Main takeaway: "As the deep ocean warms, the mixed layer can give up LESS of its heat to the ocean below, and so can only balance the radiative forcing by further **INCREASING** its temperature, so that it gives its heat BACK to the atmosphere." - Vallis





Is the deep ocean in equilibrium?

Effect #1

What stands out in this figure?

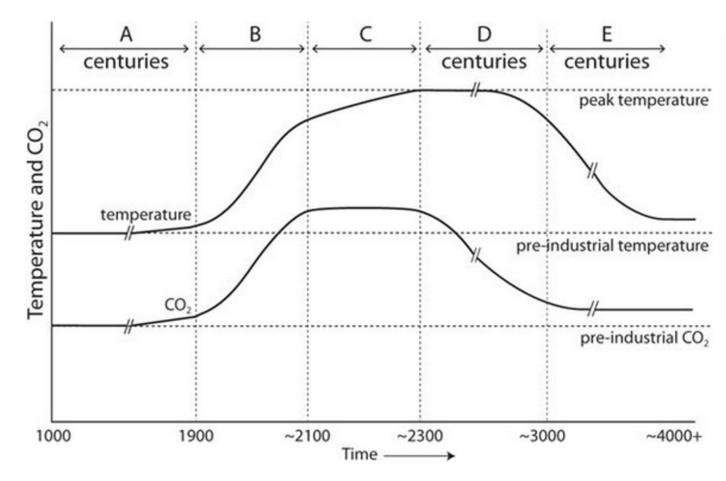


Figure 7.7. Schema of a CO₂-temperature scenario. Carbon dioxide levels increase from 1900 to 2100 (period B) before leveling off (period C) because of controls on emissions. Temperature increases rapidly in period B, then more slowly in period C. At the end of period C (the year 2300 in the figure), anthropogenic emissions go to zero, and the level of CO_2 slowly diminishes through periods D and E back to levels close to, but probably a little above, the

slowly diminishes through periods D and E back to levels close to, but probably a little above, the preindustrial period. In period D, temperature stays roughly constant for centuries before it too eventually falls back to near pre-industrial levels in period E. Many plausible scenarios can be adapted from this plot by changing 2100 and 2300 to other dates and calibrating the y-axis.

Effect #2: Circulation Changes and a Thermohaline Shutdown

Will the winds change their basic structure?

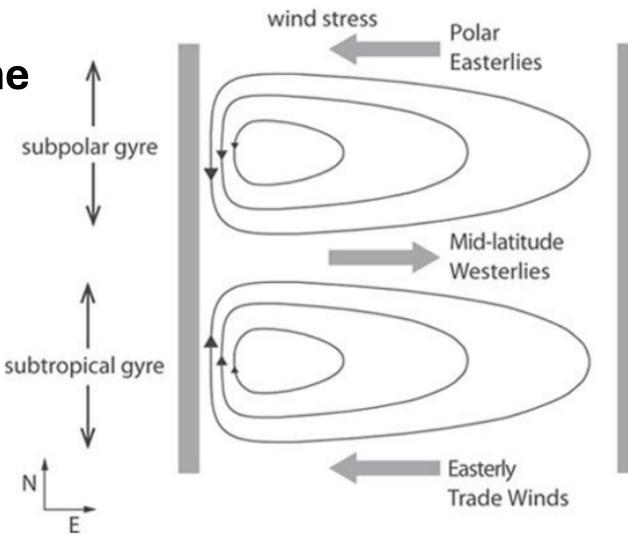
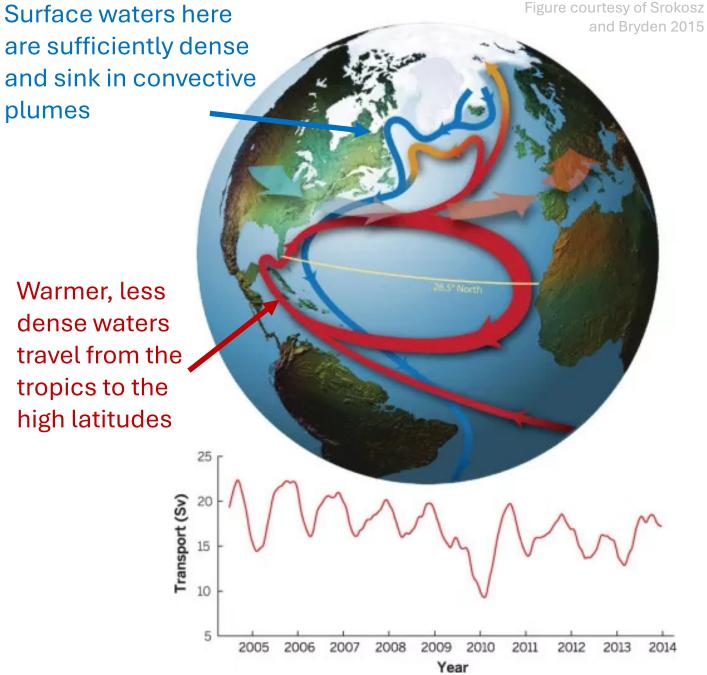


Figure 4.1. An idealized gyre circulation in a rectangular ocean basin in the Northern Hemisphere, showing the subtropical gyre (lower, typically extending from about 15°N to 45°N), the subpolar gyre (upper), and the intense western boundary currents on the left.

Effect #2:

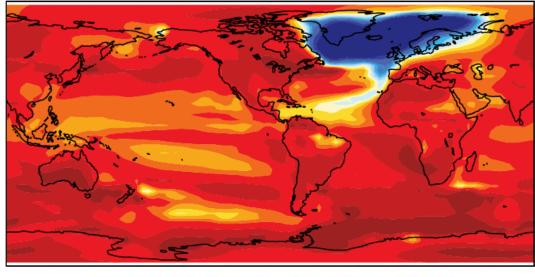
One controlling factor in the intensity of the overturning circulation is the meridional buoyancy gradient at the ocean surface

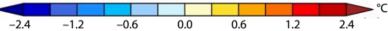


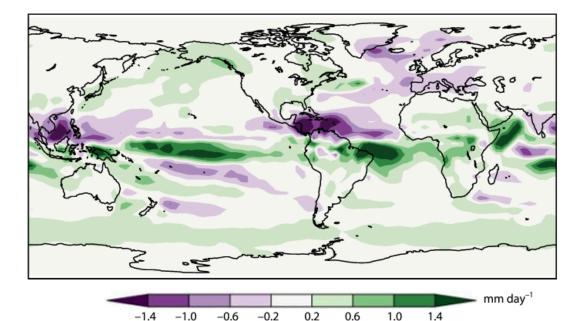
Effect #2:

What 2 things can bring AMOC to a halt?

Figures adapted from Liu et al. 2017 Top figure shows near-surface air temperature change resulting from carbon dioxide doubling and AMOC breakdown. Bottom figure shows the southward shift of the tropical Pacific rainfall belts. https://www.science.org/doi/10.1126/sciadv.1601666

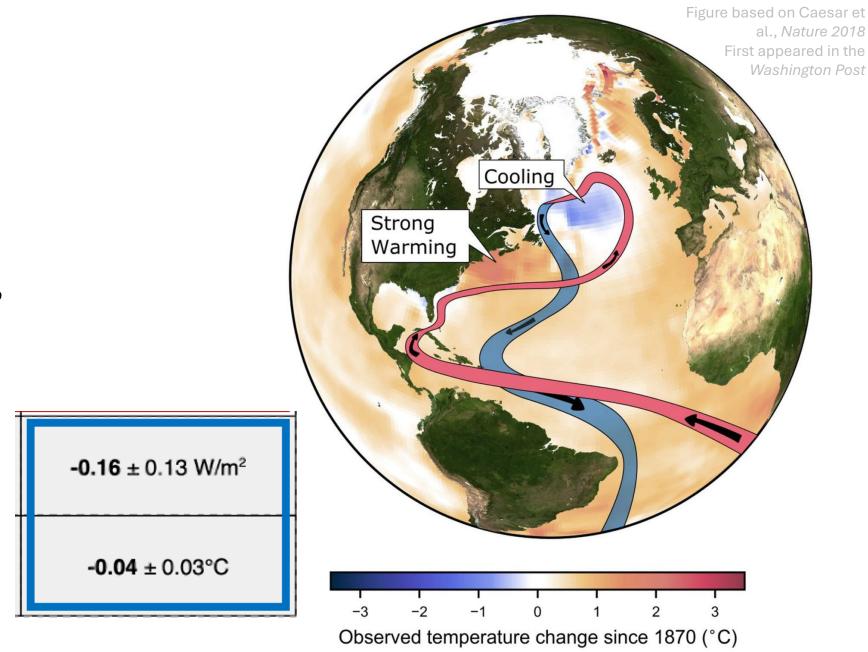






Effect #2:

- Fingerprint of AMOC weakening:
- → Cold blob off the coast of Greenland, warming off the East Coast of the US
- Reminder: OHC and temperature are directly related



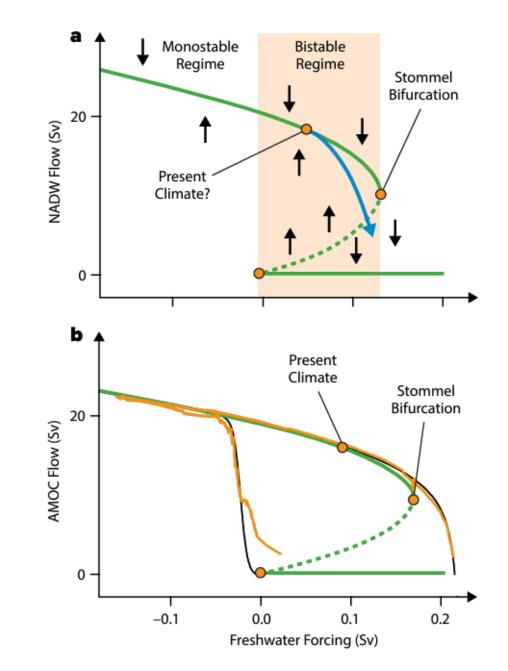
Effect #2:

AMOC has a tipping point:

- Decline of AMOC gets steeper as freshwater forcing increases
- When the green curve bends back on itself, the tipping point has been reached

Top figure displays the stability diagram in Stommel's box model, with the solid green line indicating the stable equilibrium regime and the dashed green line indicating the unstable equilibrium regime. The blue line represents the path leaving the equilibrium state under climate change. The bottom figure displays the AMOC equilibrium in a three-dimensional global ocean circulation model. The top orange line indicate AMOC "on" and the bottom line indicates AMOC "off".

https://link.springer.com/article/10.1007/s003820050144 https://www.nature.com/articles/nature01090



Effect #2

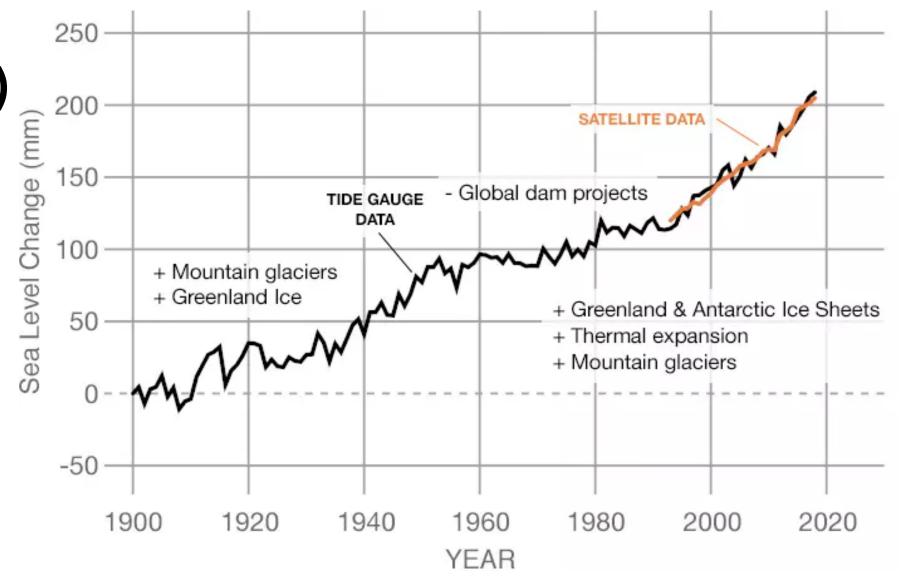
Effect #2

What is the current state of the science? <u>AMOC is weakening,</u> <u>possible collapse</u> <u>around mid-century</u> (dependent on model <u>parameters used)</u>

Top stories : Oceanographic Magazine Live Science 'We don't really consider it Atlantic current collapse 'closer than we think' low probability anymore': Collapse of key Atlantic... 2 days ago 2 days ago 🕞 The Guardian SI BBC Science Focus Magazine 'We don't know where the The Atlantic Ocean's currents tipping point is': climate are on the verge of collapse. Guardian expert on potential collapse... This is what it means for th... 4 days ago 2 weeks ago More news \rightarrow

Data source: Frederikse et al. (2020) Credit: NASA's Goddard Space Flight Center/PO.DAAC Items with (+) indicates contribution to sea level rise while (-) indicates contribution to a decline in sea level rise

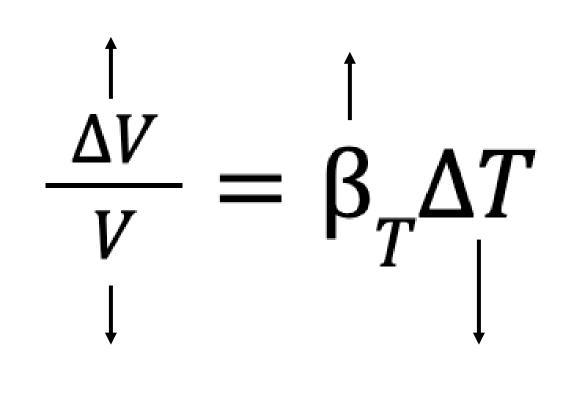
Effect #3: Sea Level Rise (SLR) Since 1993, SLR has risen by 101.9 mm (about 4 inches)



Effect #3: SLR

Based solely on thermal expansion, we find an *increase in temperature of 1 C contributes to* ~ 0.5 m in SLR

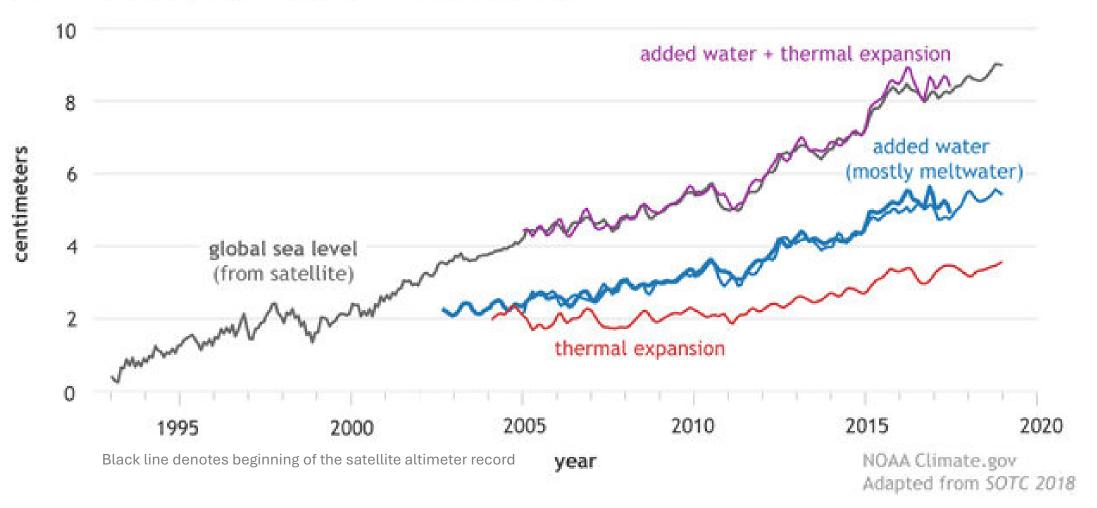
> If temperatures reach 3 C for a prolonged period, an increase of 1.5 m in SLR is likely, purely by thermal expansion (no contribution from melting ice sheets)

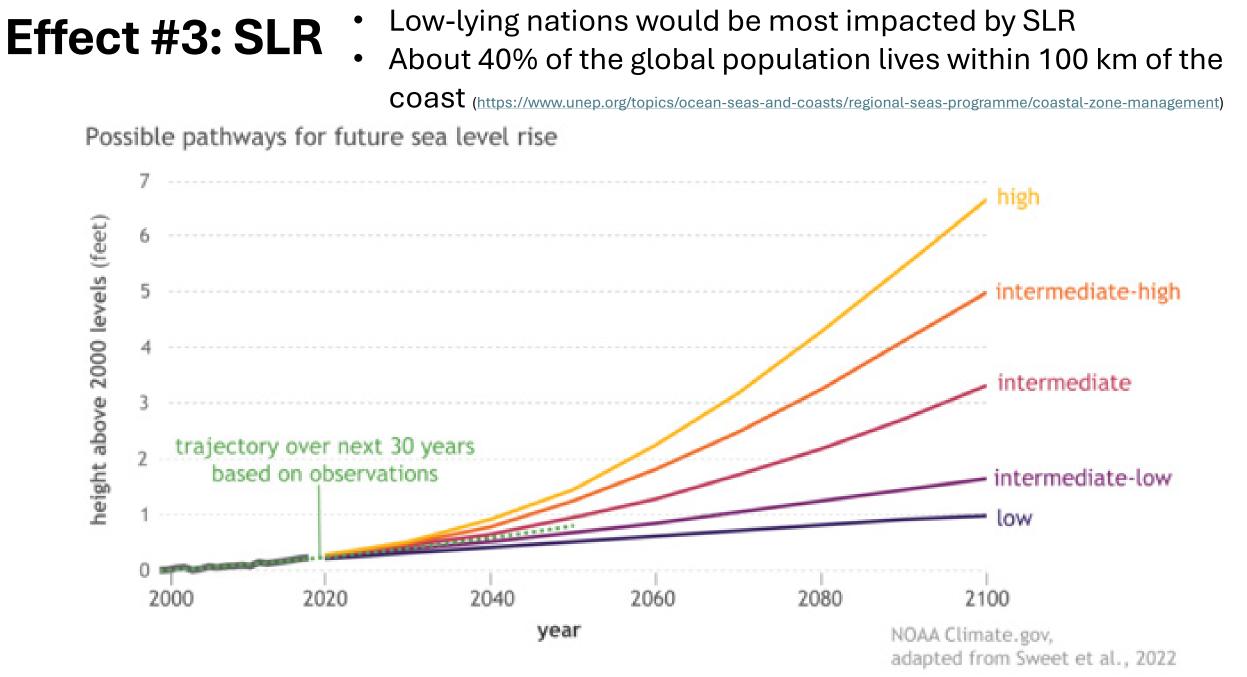


Effect #3: SLR

Vallis states, "thermal expansion of the oceans is estimated to have contributed a little more than half of the total sea-level rise ... climate models project that a global sea-level rise due to mainly thermal expansion..."

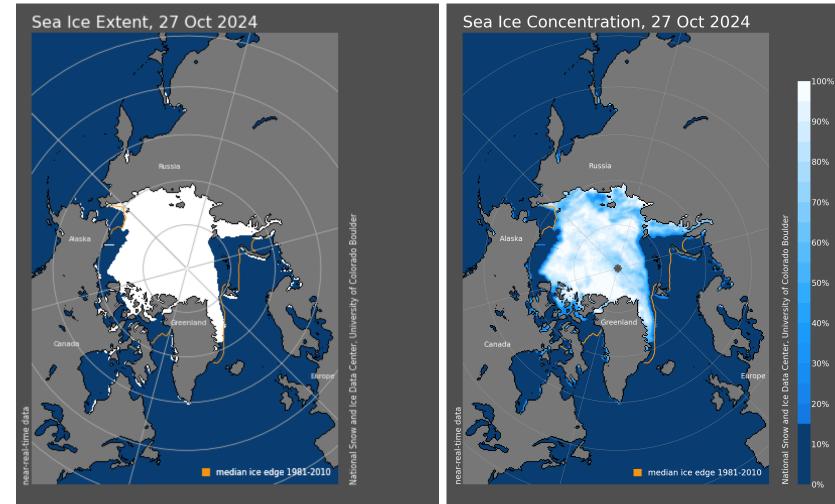
Contributors to global sea sea level rise (1993-2018)





Effect #3: Loss of Sea Ice

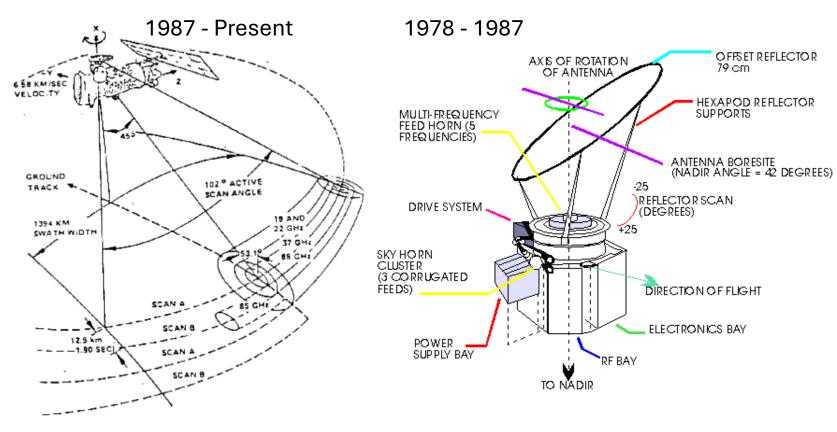
Why is sea ice important?



https://nsidc.org/sea-ice-today

Effect #3: Loss of Sea Ice

Why do we use microwave radiation to monitor sea ice?



The record of sea ice began in 1978 with the the launch of the NASA Scanning Multichannel Microwave Radiometer (SMMR) (right) and then continued with the Special Sensor Microwave Imager/Sounder (SSMI/SSMIS) (left). Other satellites, like AMSR, ICESat/ICESat-2 and CryoSat/CryoSat-2 have continued and enhanced the sea ice record. More information: https://www.remss.com/missions/ssmi/

Additional Readings and Resources

- How do we measure weather and climate? <u>https://www.climate.gov/maps-data/climate-data-primer/how-do-we-observe-todays-climate</u>
- How do weather observations become climate information? <u>https://www.climate.gov/maps-data/climate-data_data-primer/how-do-weather-observations-become-climate-data</u>
- The contribution of the UHI to global warming: <u>https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021EF002401</u>
- Urban heat island effects of Baltimore and Washington D.C: <u>https://www.climate.gov/news-features/features/detailed-maps-urban-heat-island-effects-washington-dc-and-baltimore</u>
- Beyond the Hockey Stick: <u>https://www.pnas.org/doi/10.1073/pnas.2112797118</u>
- Argo Status: <u>https://argo.ucsd.edu/about/status/</u>
- More about ocean heat content: <u>https://climate.copernicus.eu/climate-indicators/ocean-heat-content</u>
- AMOC talk by Stefan Rahmstorf: <u>https://www.youtube.com/watch?v=k0FUZKQhU6U</u>
- The consequences of AMOC shutting down: <u>https://www.germanwatch.org/en/87910</u>
- More about SAR, scatterometers, and radar for sea ice: <u>https://www.meereisportal.de/en/learn-more/sea-ice-measuring-methods/measurements-from-space/active-microwave-sensors-radar</u>
- More about sea ice: <u>https://nsidc.org/sea-ice-today</u>

Learning Outcomes

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