



Sea Level Rise

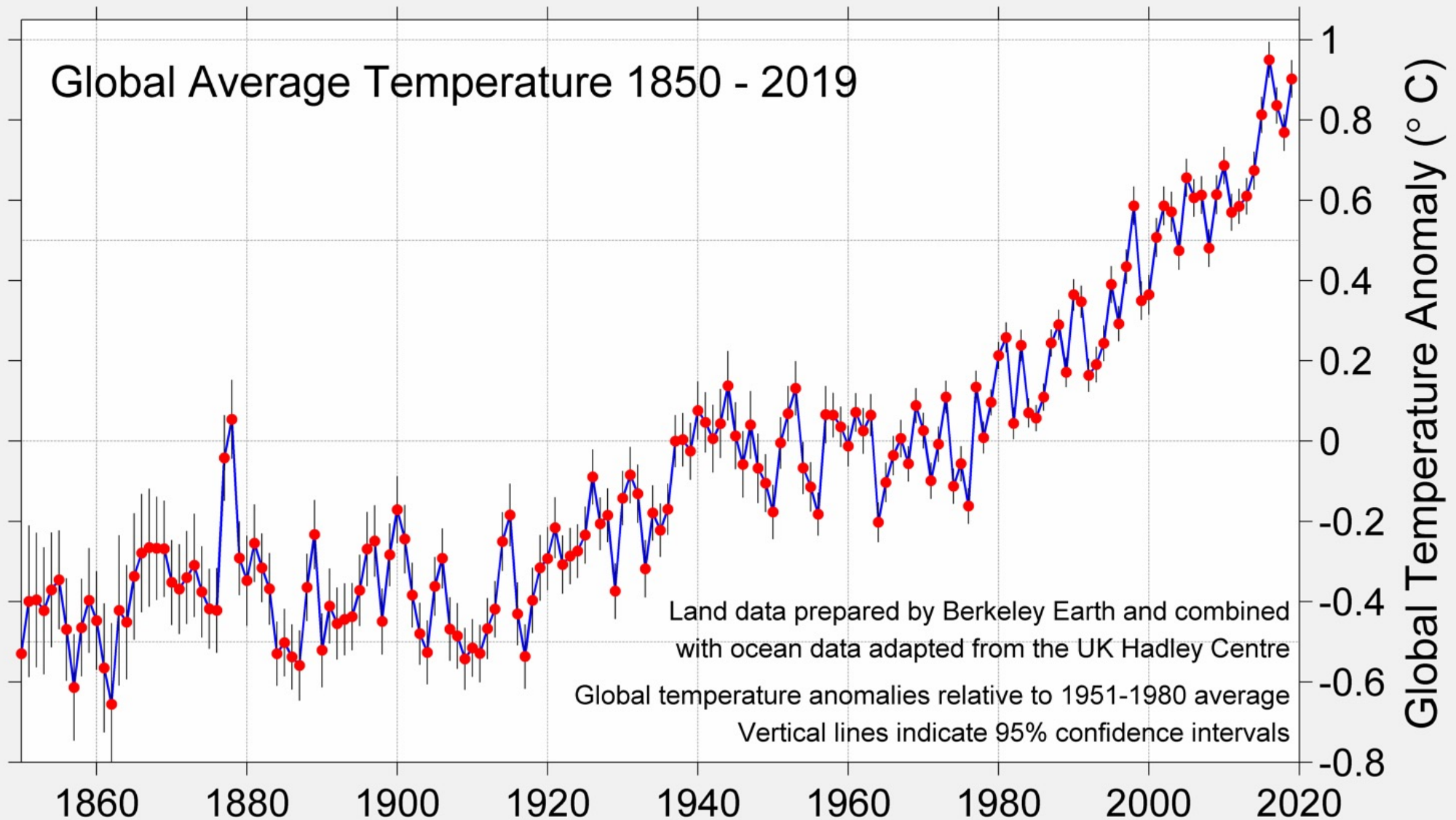
Climate Conversations

June 10 – July 8, 2021

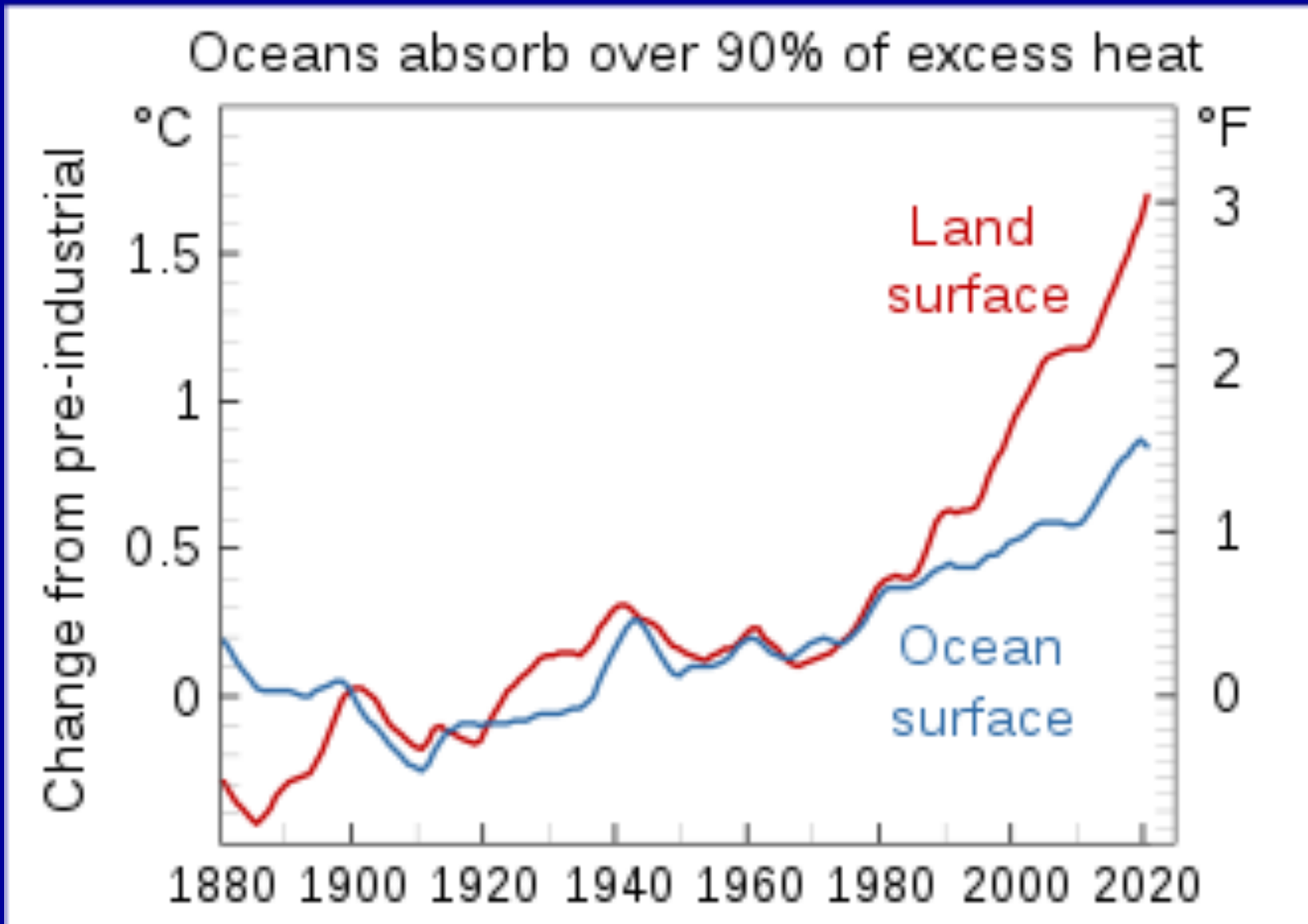
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JFOrmes@gmail.com

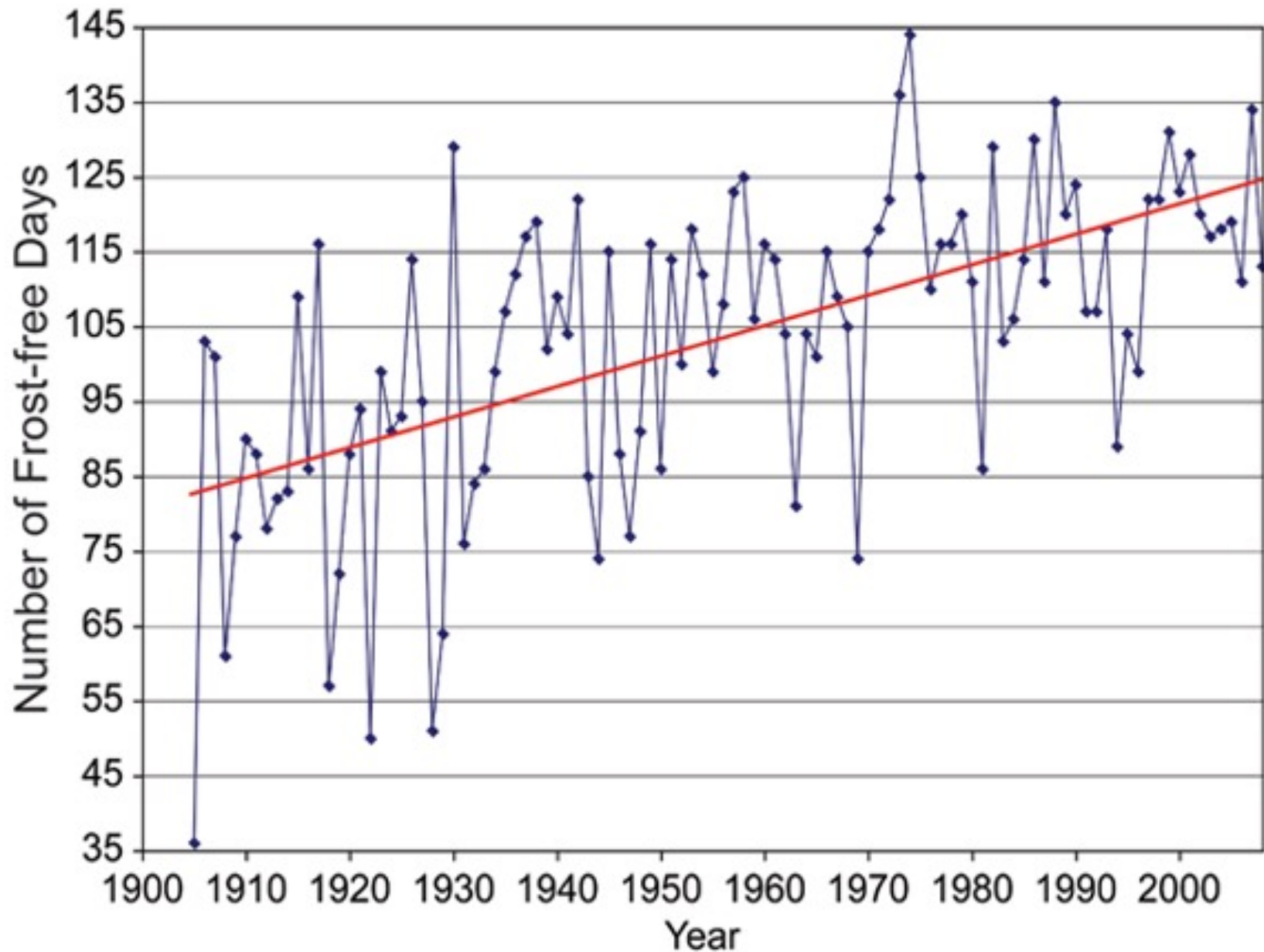
Interesting question



Land vs. Ocean temperature records



Frost-free Fairbanks, Alaska



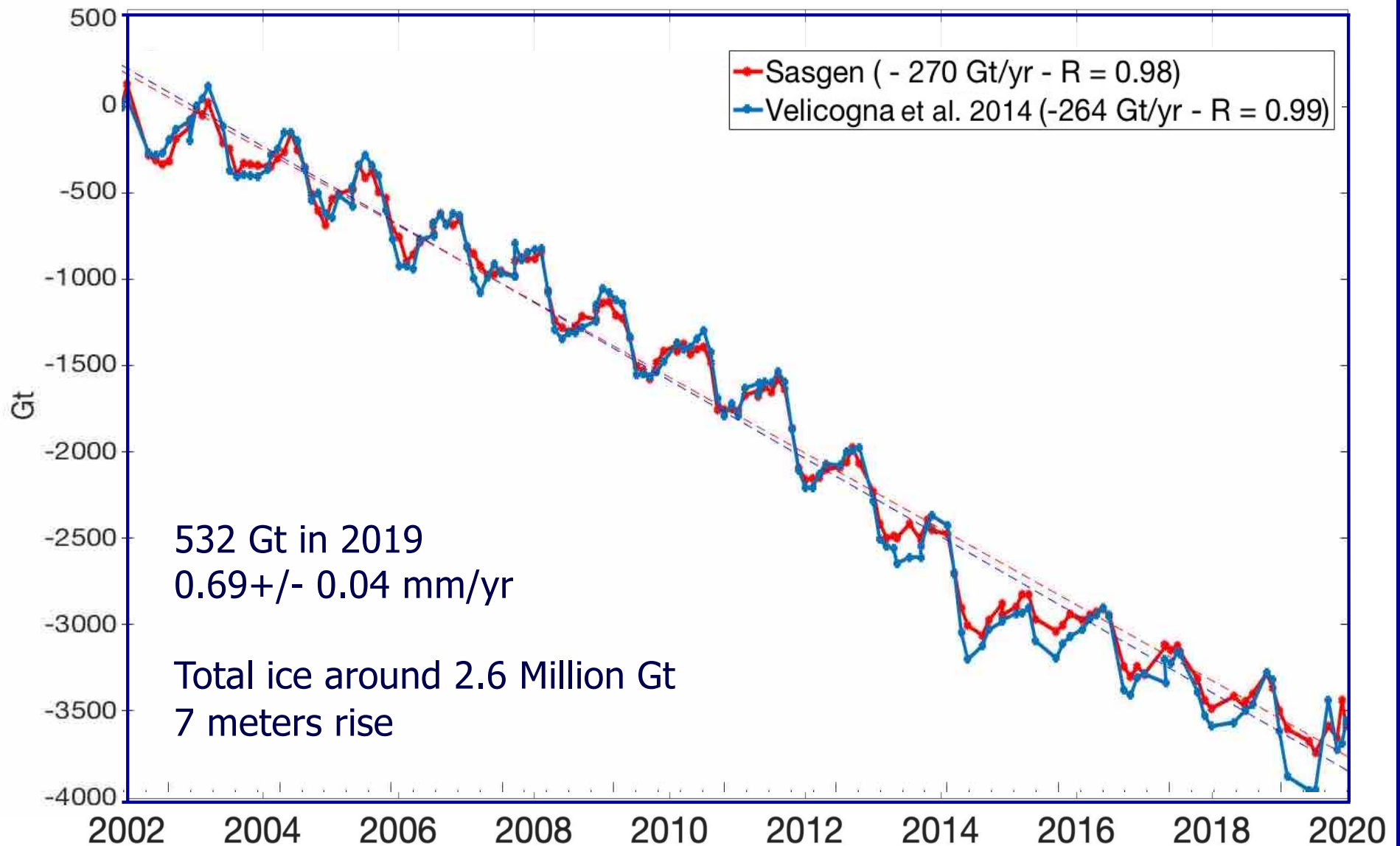
Permafrost thaw



Modeling didn't predict this melting until the end of the century.

An estimated 1,400 gigatons of carbon are frozen in Arctic permafrost, making it one of the world's largest carbon sinks.

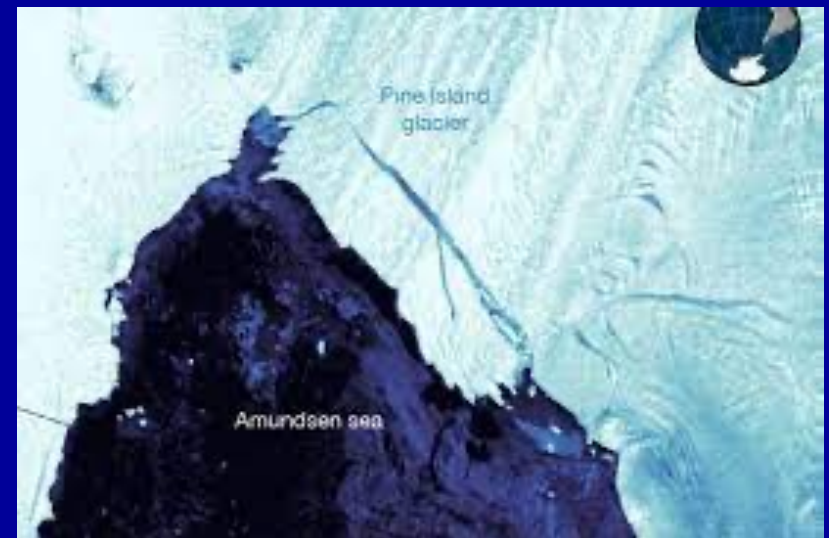
Greenland Ice loss: Grace satellites



Pine Island Glacier: West Antarctica



Mass loss 150 Gt/yr
About $\frac{1}{4}$ - $\frac{1}{2}$ that of Greenland

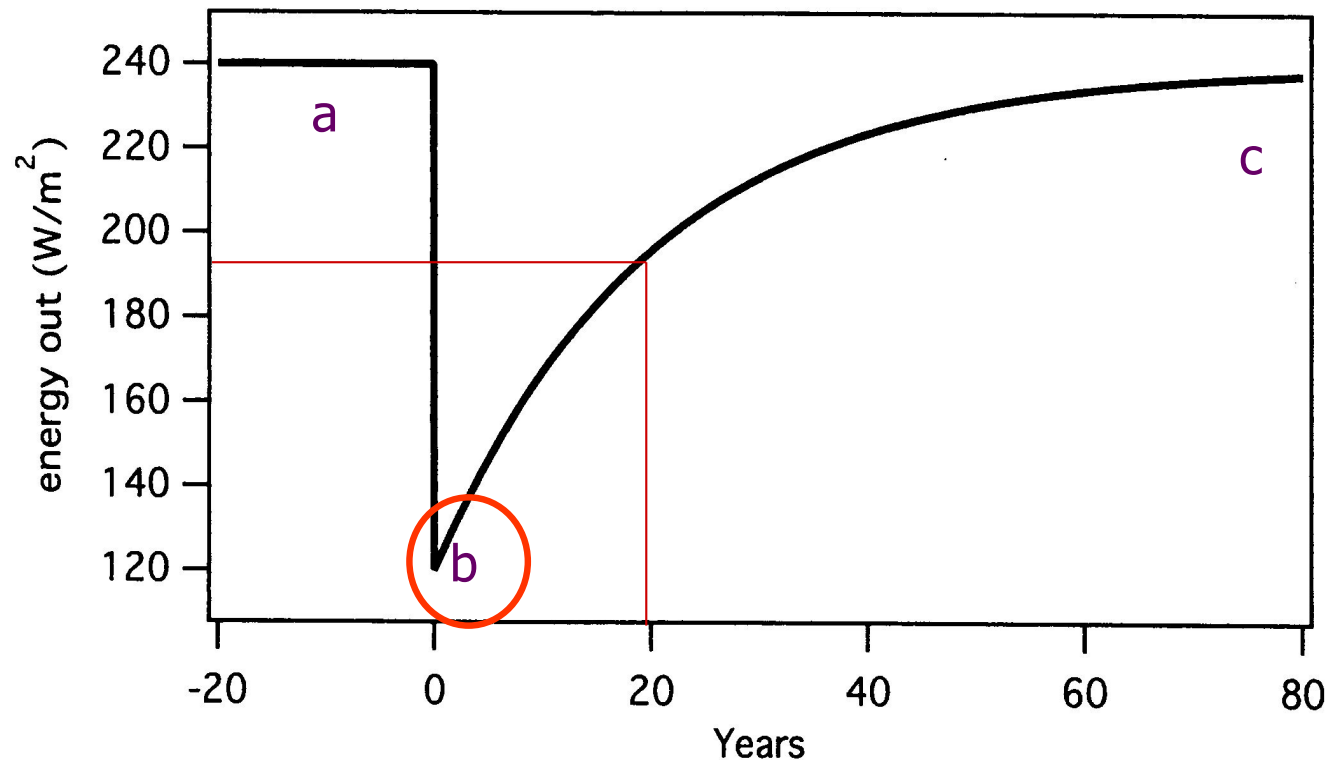


4 x size of Manhattan

<https://www.livescience.com/satellite-images-pine-island-glacier-acceleration.html>

A disequilibrium leads to a "recovery curve" like that shown here.
The recovery follows an exponential.

Where the "recovery" time τ is about 20 years as shown.

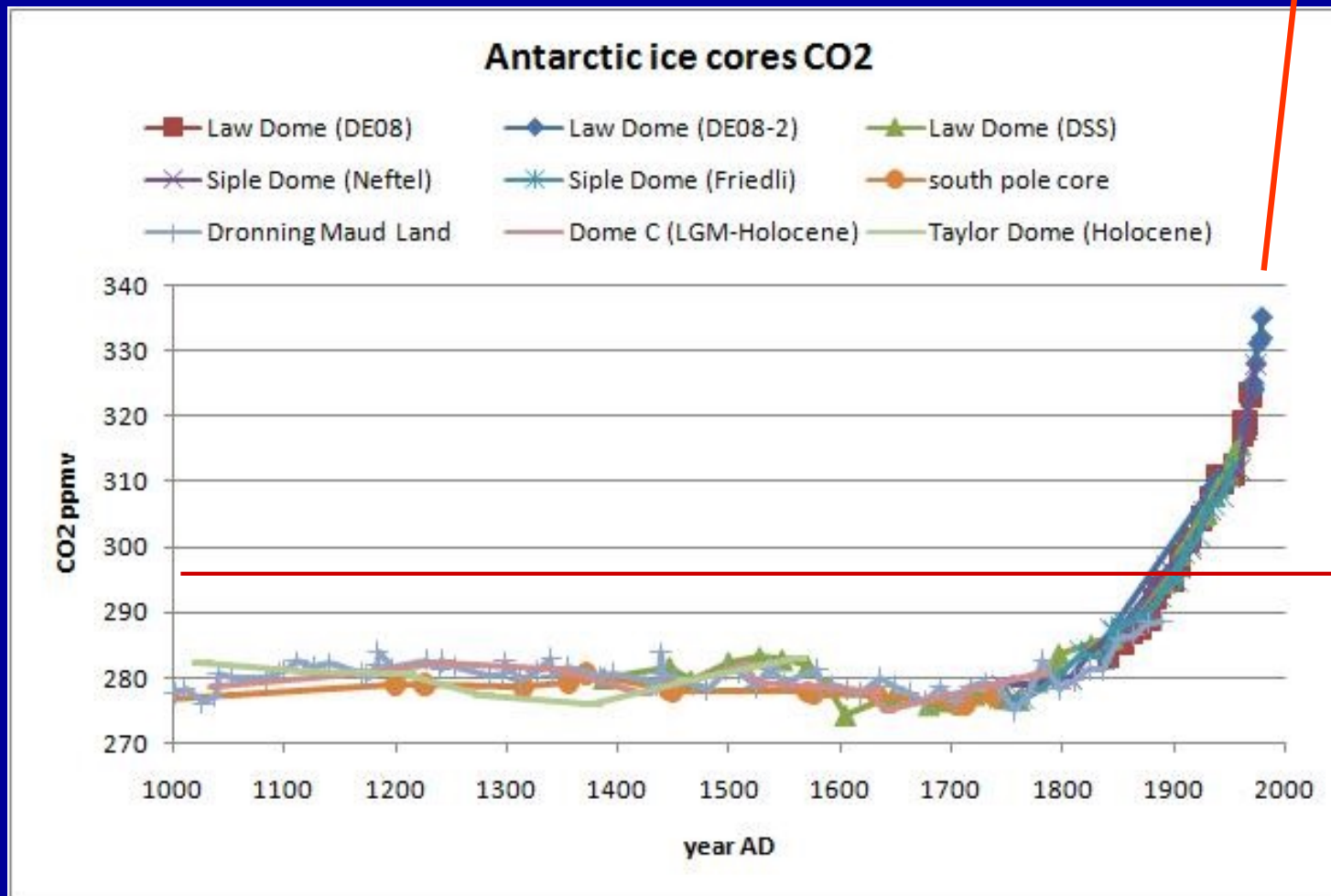


This recovery or equilibration time is not well understood and is the subject of current study. It depends on the heat capacity of the ocean

Atmospheric CO₂ rates

Human activities: 44 billion tons/yr of CO₂ (2020)

The fraction of *new* atmospheric CO₂ is currently 32% of all the CO₂.



red lines indicate maximum for last 0.8 million years



U.S. West prepares for possible 1st water shortage declaration

“The study, while significant, is not a surprise,” said officials from the Arizona Department of Water Resources and Central Arizona Project

By **SAM METZ** | The Associated Press

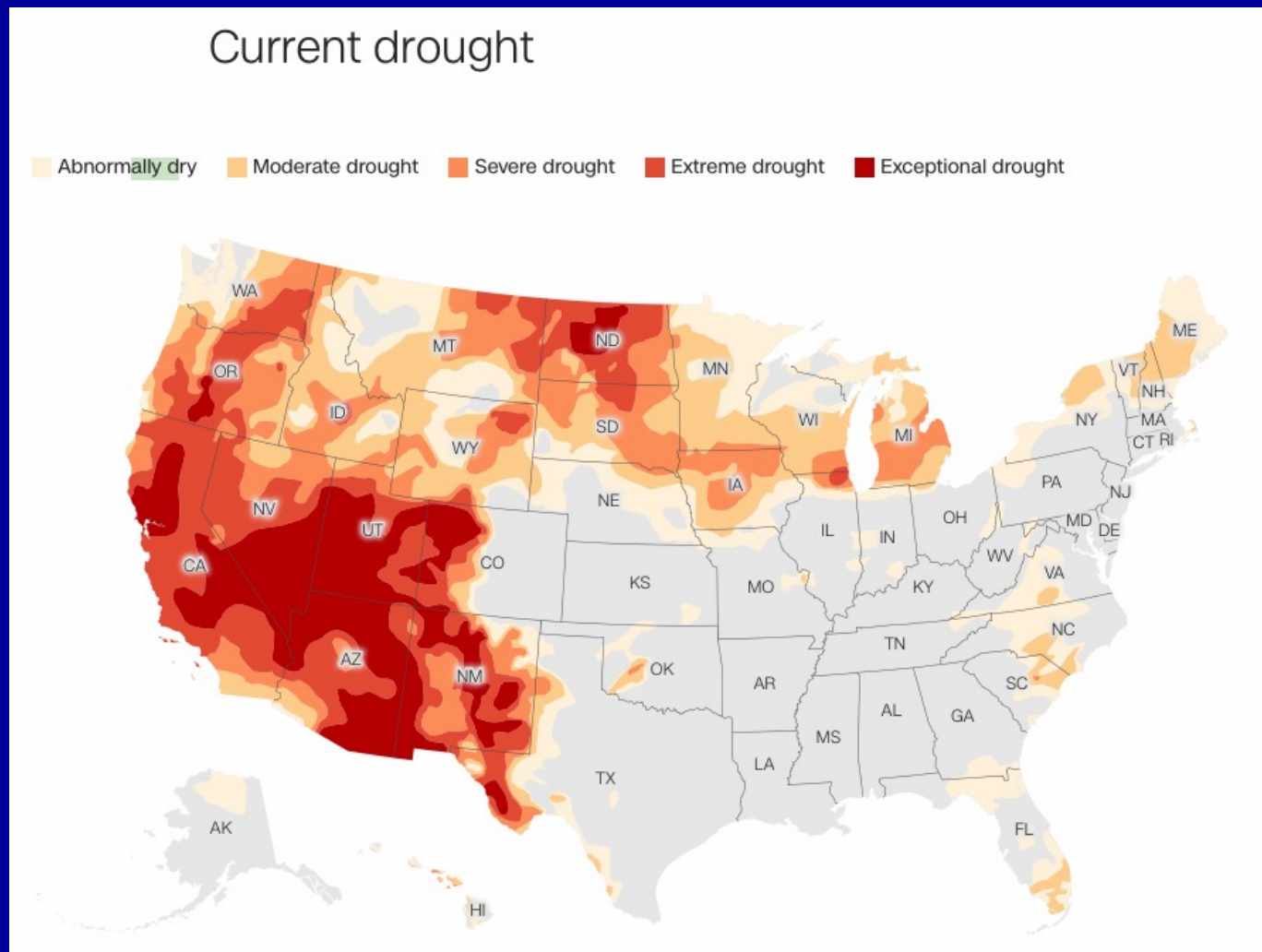
PUBLISHED: April 17, 2021 at 12:26 p.m. | UPDATED: April 17, 2021 at 12:37 p.m.



In this July 28, 2014, file photo, lightning strikes over Lake Mead near Hoover Dam that impounds Colorado River water at the Lake Mead National Recreation Area in Arizona. The Bureau of Reclamation is forecasting first-ever water shortages because of falling levels at Lake Mead and says the reservoir could drop so low that it might not be able to generate electricity at Hoover Dam.

The West's historic drought

By John Keefe and Rachel Ramirez, CNN
Updated 9:53 AM ET, Thu June 17, 2021

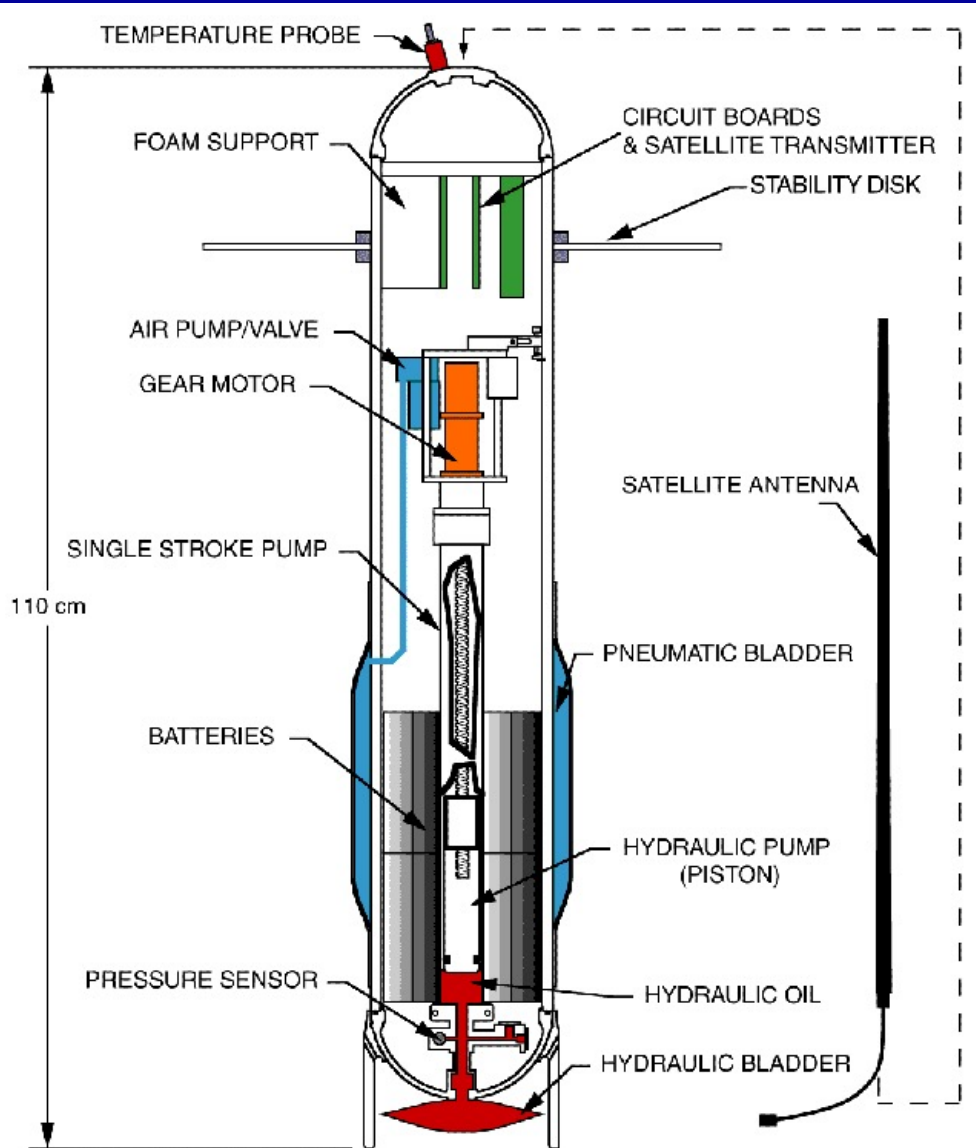
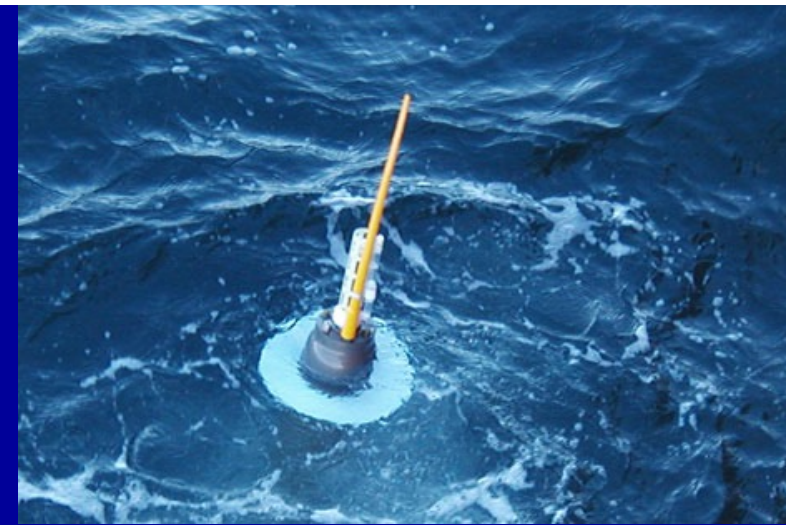


How is ocean surface temperature measured?

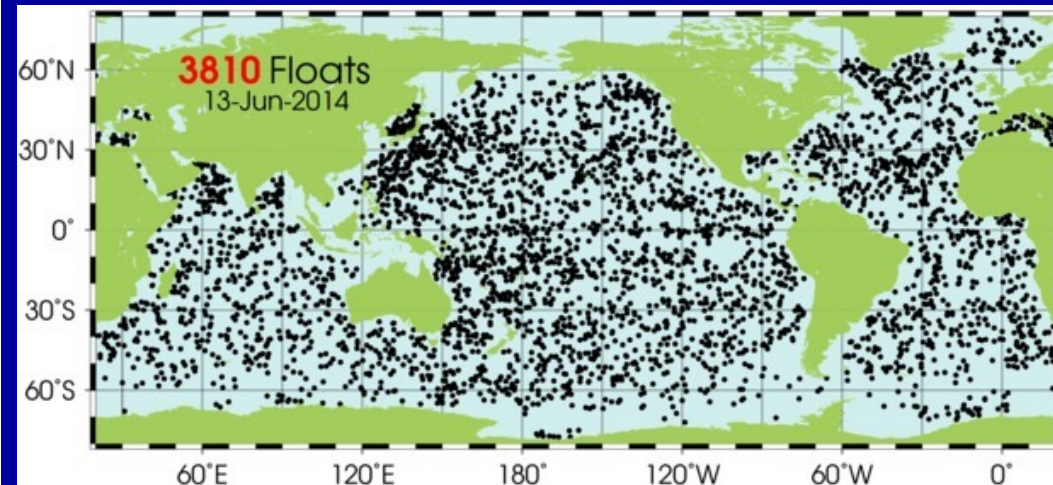
- Satellite microwave radiometers
- Infrared radiometers
- Moored and drifting buoys
- Ship reports
(Benjamin Franklin)



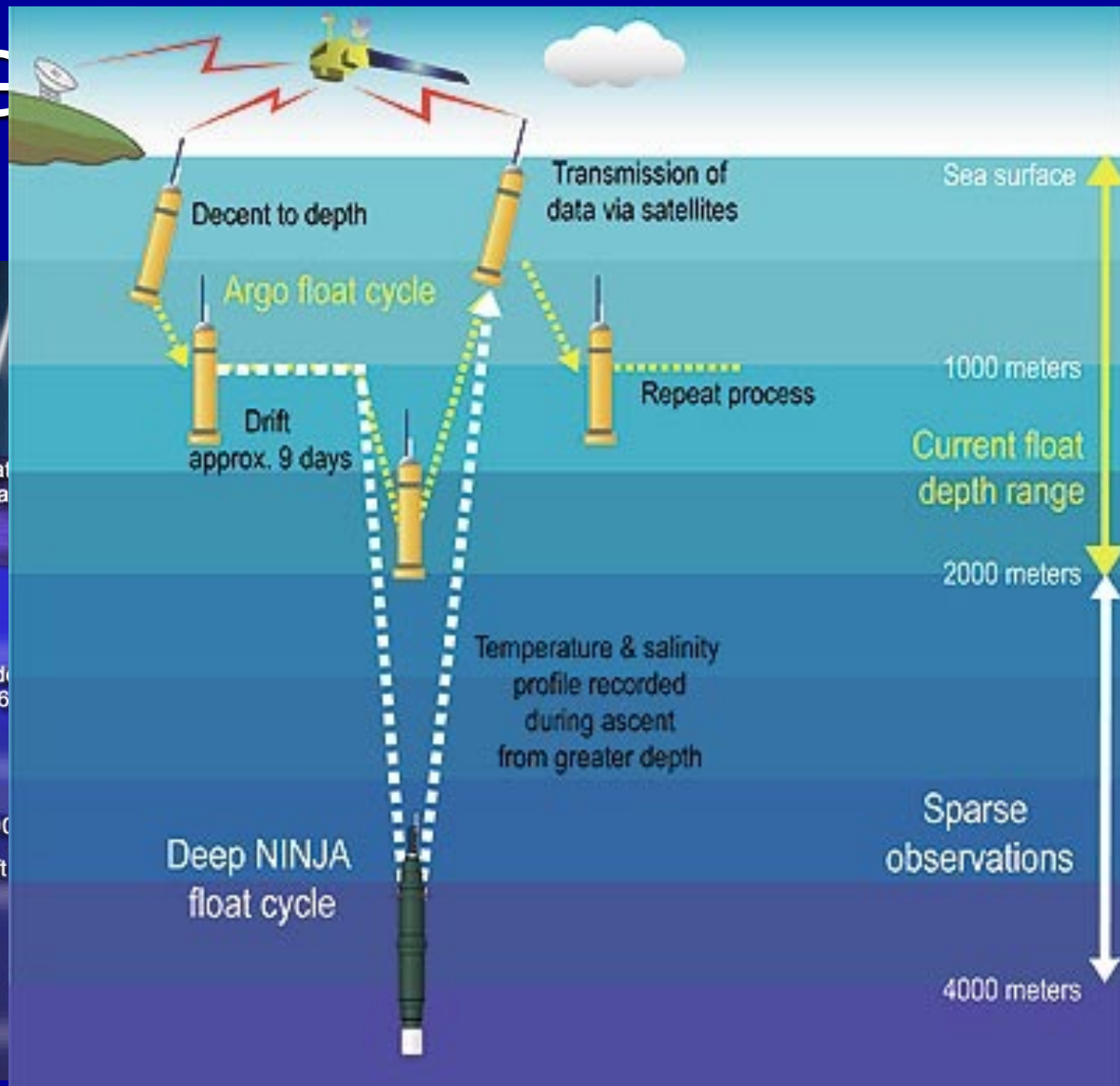
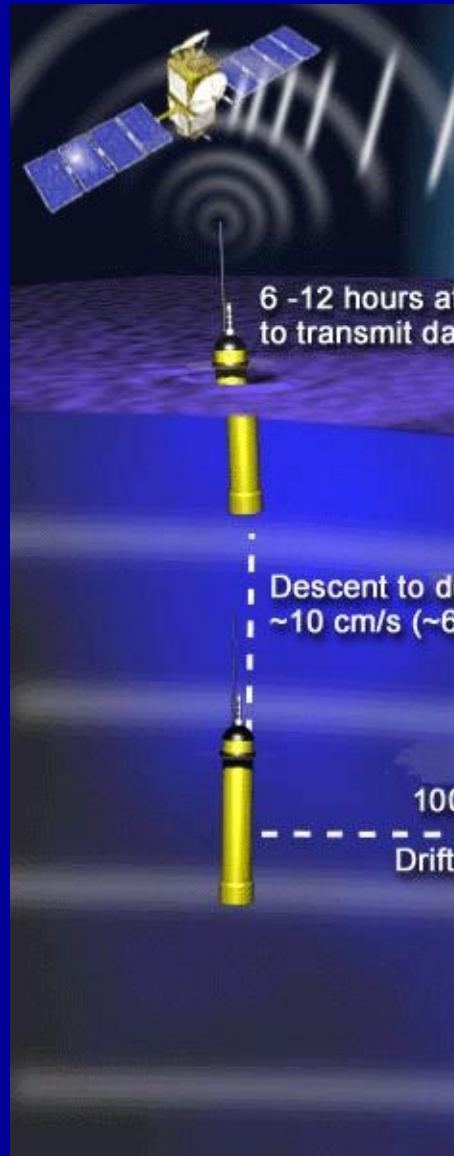
Argo floats



Devices that can change their density and go down into the ocean up to 2 km, measure Temp, pressure, and salinity and come back up and radio their data & location to a satellite going overhead.



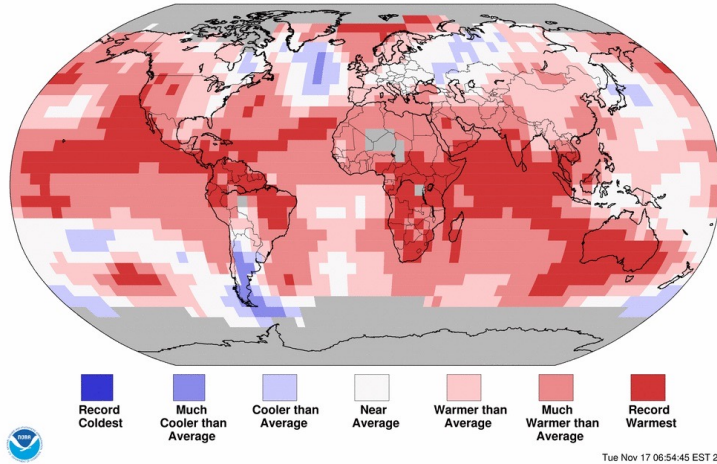
ARGO



Freshwater melt from Greenland and other North Atlantic ice caps is causing a cold spot in the North Atlantic.

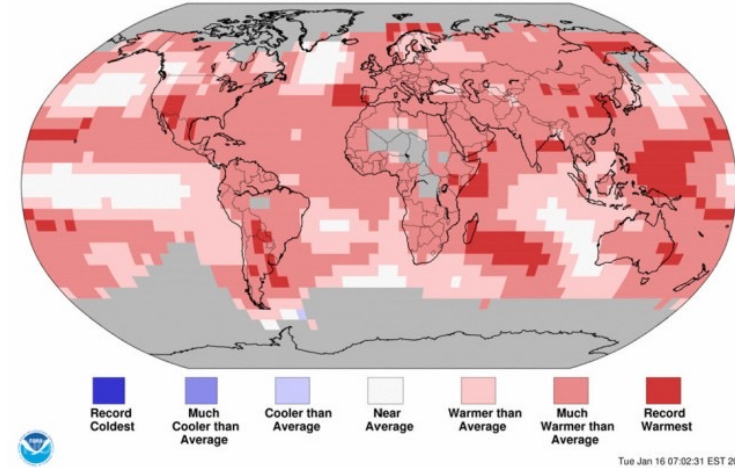
Land & Ocean Temperature Percentiles Oct 2015

NOAA's National Centers for Environmental Information
Data Source: GHCN-M version 3.3.0 & ERSST version 4.0.0



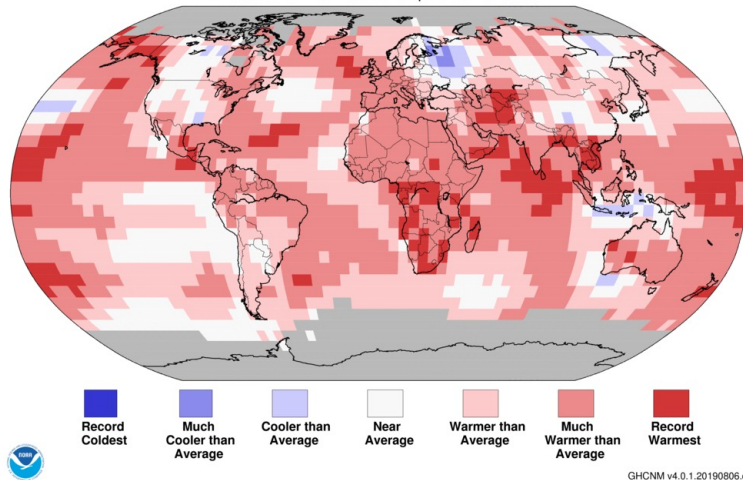
Land & Ocean Temperature Percentiles Jan–Dec 2017

NOAA's National Centers for Environmental Information
Data Source: GHCN-M version 3.3.0 & ERSST version 4.0.0



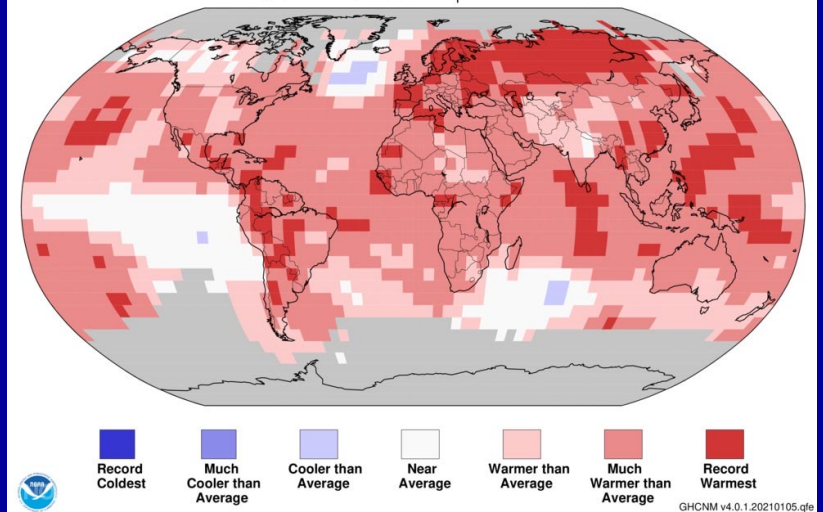
Land & Ocean Temperature Percentiles Jul 2019

NOAA's National Centers for Environmental Information
Data Source: NOAAGlobalTemp v5.0.0–20190808



Land & Ocean Temperature Percentiles Jan–Dec 2020

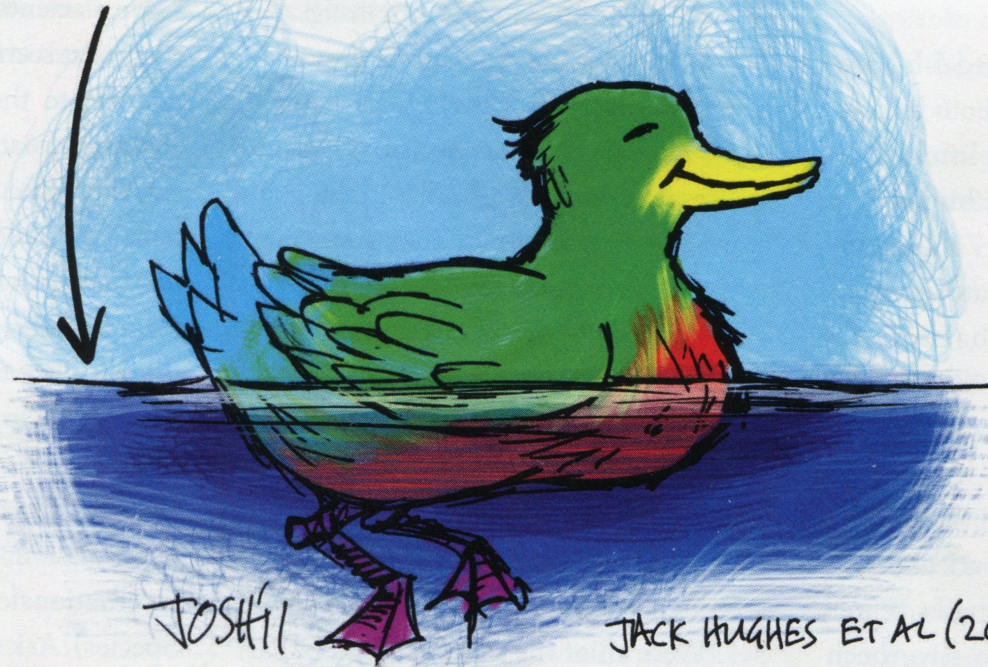
NOAA's National Centers for Environmental Information
Data Source: NOAAGlobalTemp v5.0.0–20210106



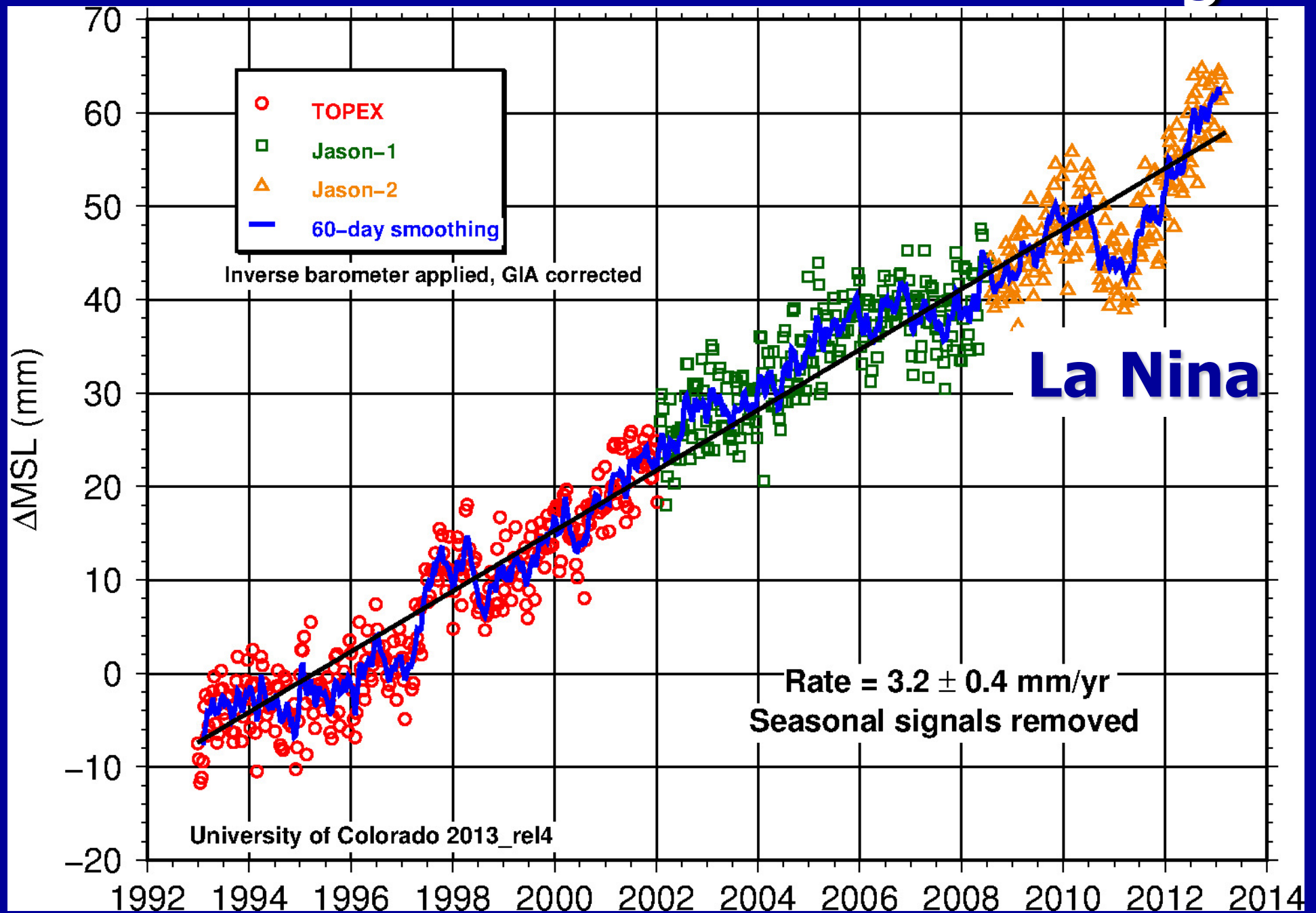
Measuring Sea Level

CONCLUSIVE PROOF OF STABLE SEA LEVELS

STILL ONLY COMES
HALF-WAY UP A DUCK



This measurement is amazing



Where did the water go?



Bangkok, Thailand



Australia

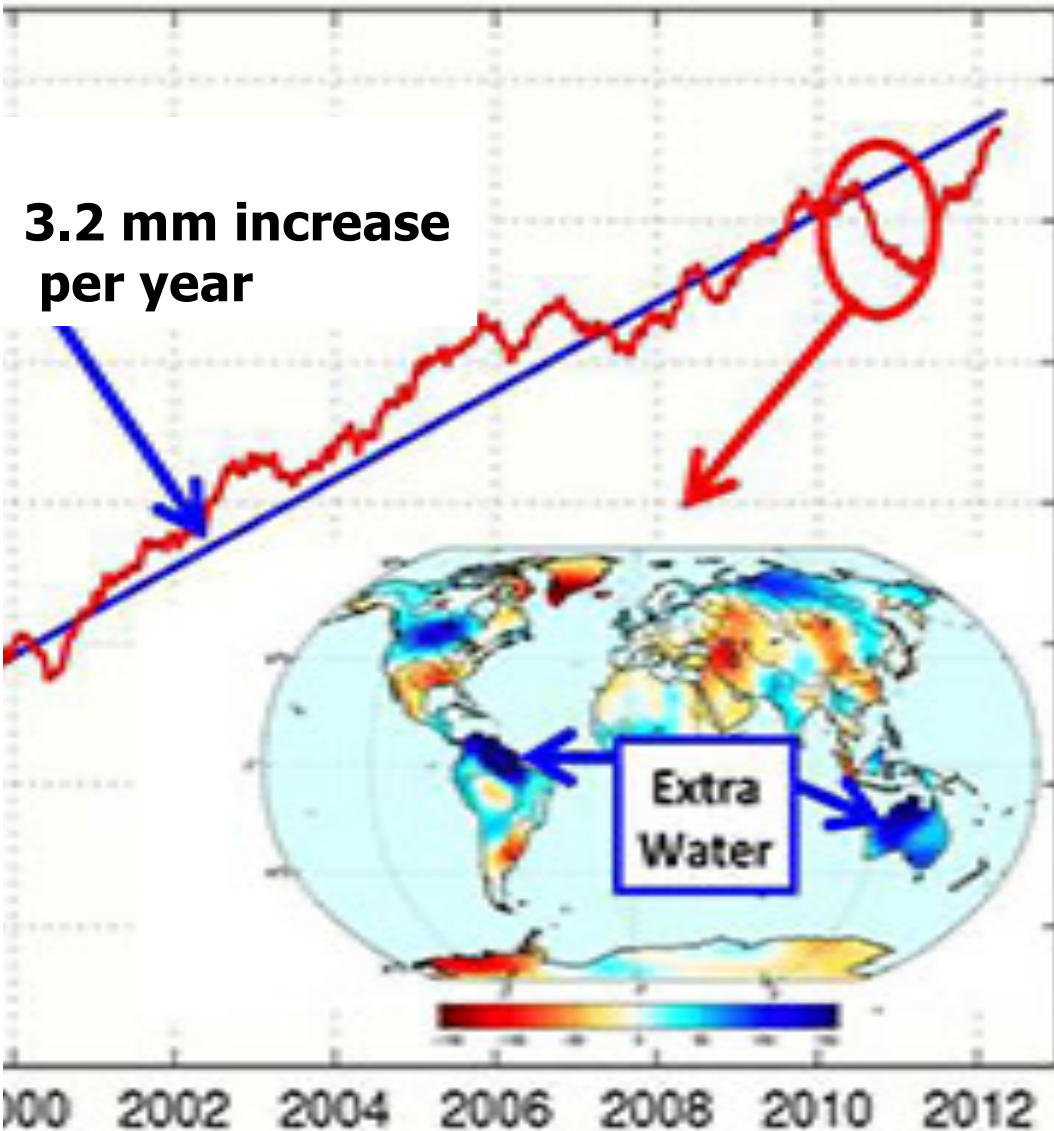


Most recent trend

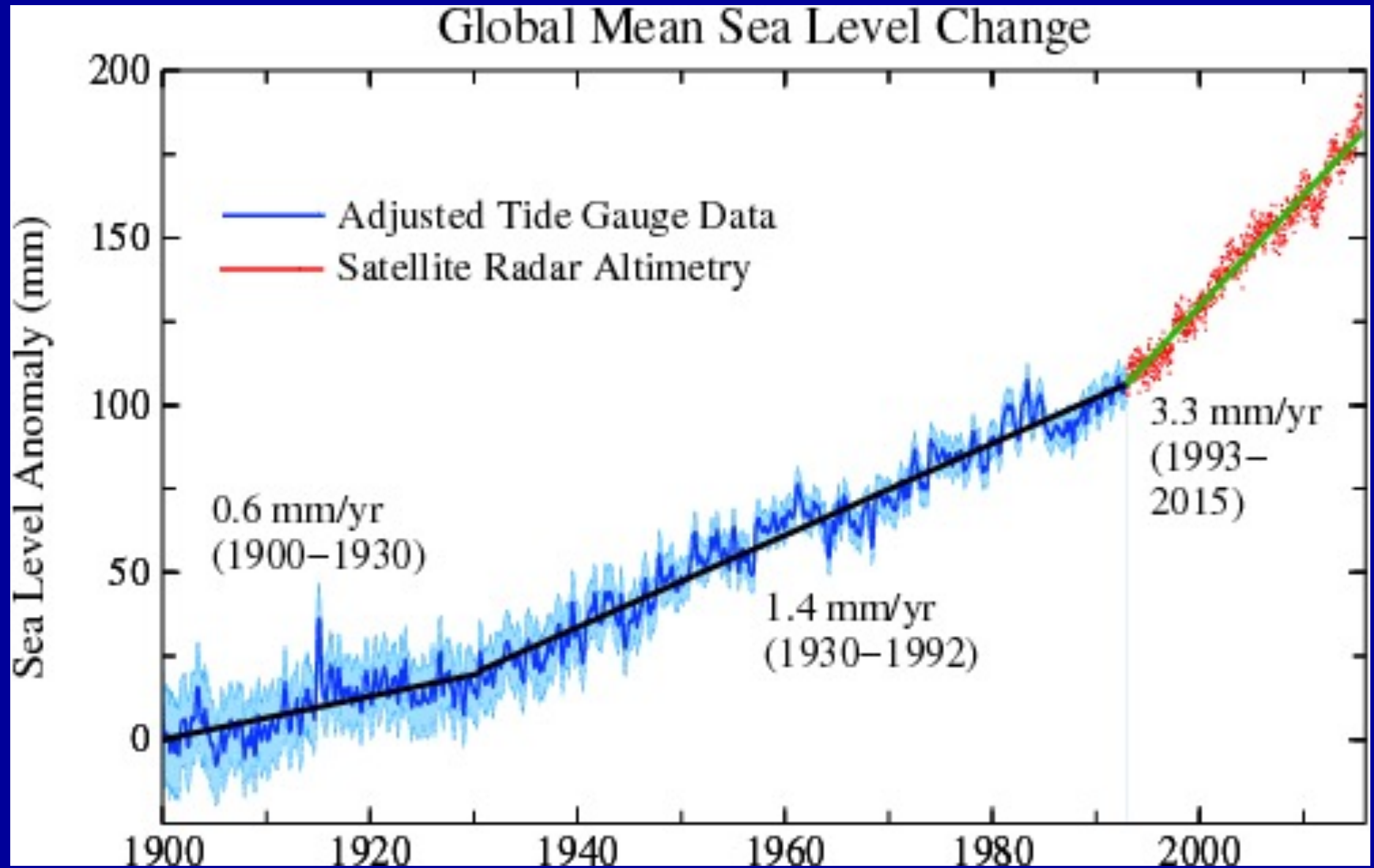
**3.2 mm increase
per year**

Dip in 2010 caused by huge
rains all over the planet.
The water was on the land!

**Cumulative rise since 1880
9.5 inches**



Rate of change is increasing



Most recent trend

Now 3.3 mm/year. Increased glacial melt.

1.2 \pm 0.6 mm/yr from thermosteric effects
(hotter water is less dense => more volume)

0.25 \pm 0.09 mm/yr groundwater depletion

0.93 \pm 0.19 mm due to ice sheet melt.

Greenland = 0.56 \pm 0.13

Antarctic = 0.37 \pm 0.14

0.92 \pm 0.05 mm glacial and ice cap melt

Floods are getting more common

- Underreported
 - Flood in Ohio didn't make news
 - 28 serious floods worldwide to June 18
 - <http://floodlist.com/news>
- Disaster fatigue
- Sea level rise
 - Miami considering a 20 ft high sea wall
 - There goes the ocean view.

June 17th 2021



Melek-Chesme river
parts of City of Kerch in Crimea
under 1.7m of water

Sea level rise: Maldives, Miami and me



Better build some sea walls.

All this is happening far far away
to people we don't know.

Why should a Coloradan be concerned?
Climate refugees?

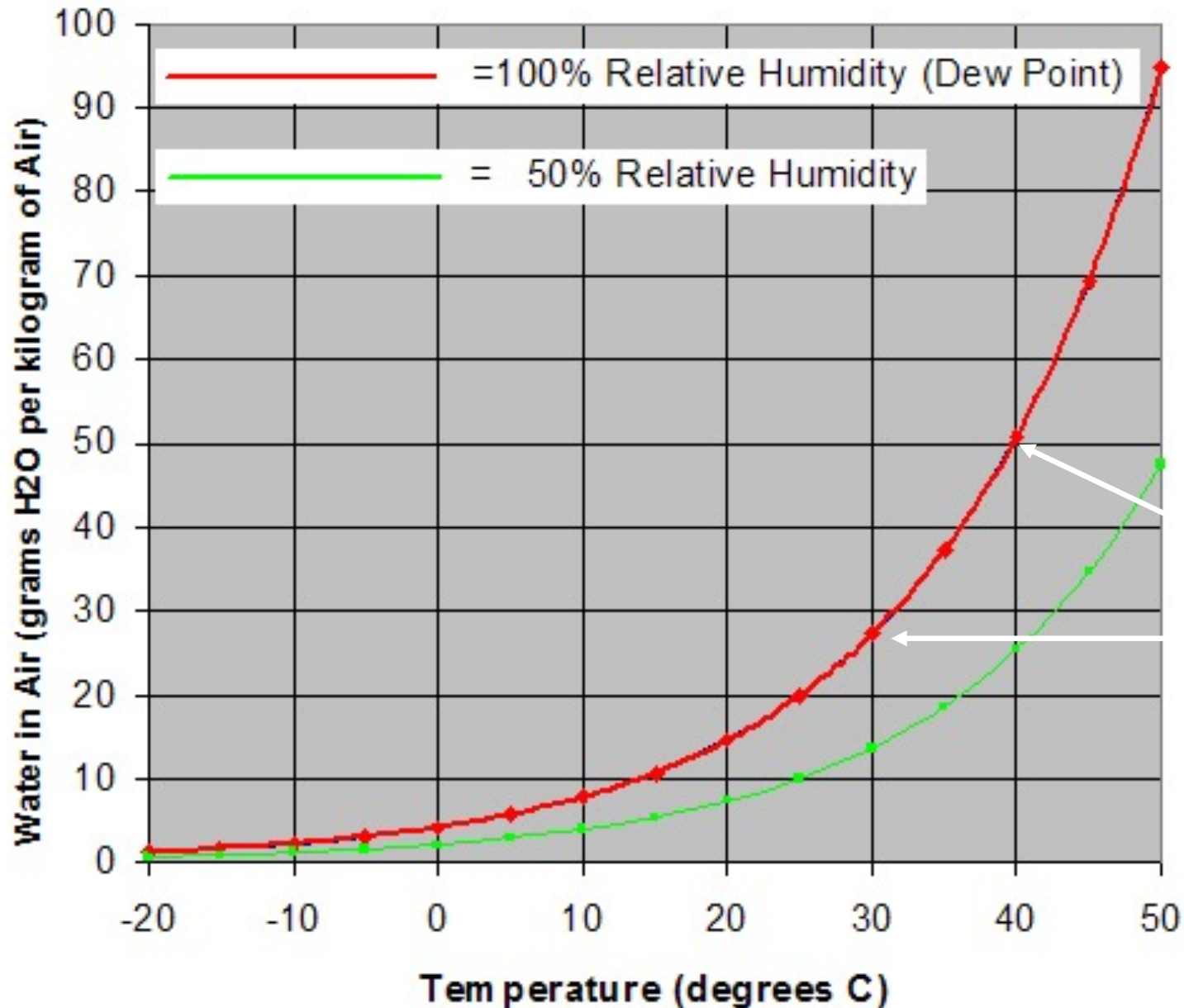
Conclusion

Sea level rise is probably the most immediate nearterm impact of climate change.

If you live in the
Maldives, move now.
Miami (or New York), get prepared.
– Buy property in Colorado
Me in Colorado, “no worries mate”.

Amount of Water in Air at 100% Relative Humidity Across a Range of Temperatures

Calculated with tool at <http://www.lennetech.com/calculators/relative-humidity.htm>



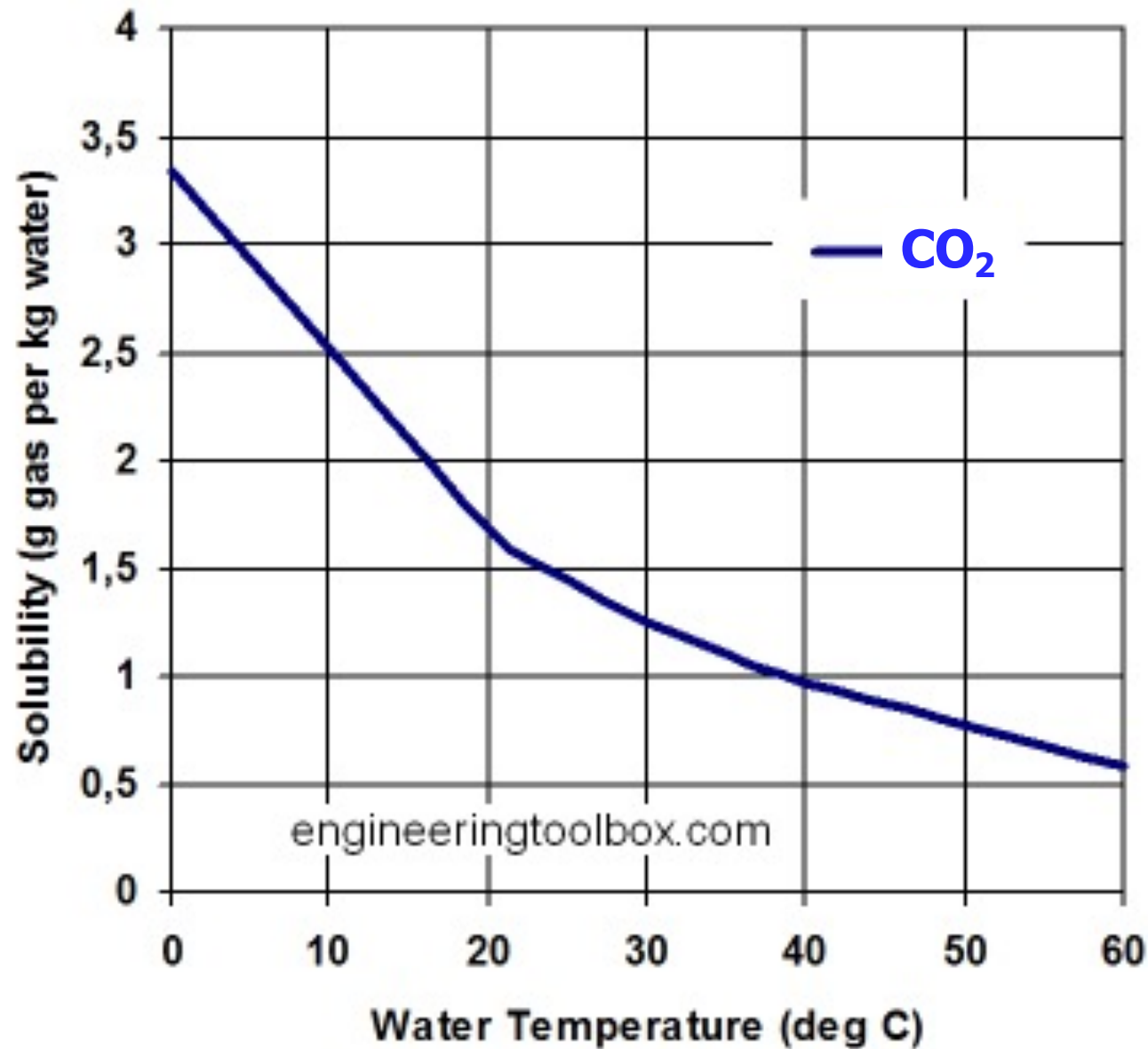
Why are there more severe rainstorms and flooding?

Warmer air holds more H₂O

40°C is 104°F
30°C is 86°F

40°C air holds twice more water vapor than 30°C air

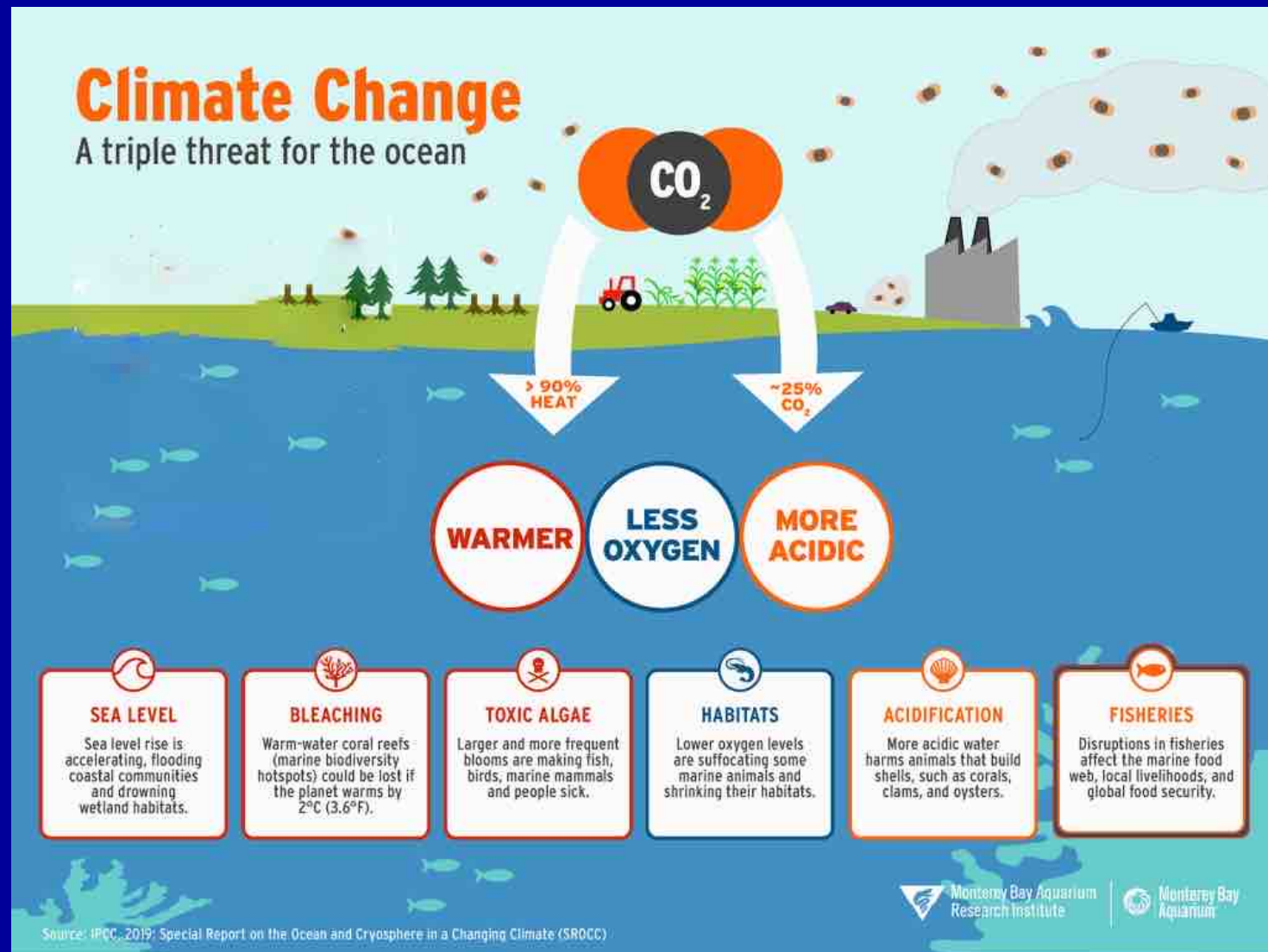
Carbonating our oceans



Chemical
migration to
colder waters:

Poleward
Deeper ocean

Triple threat to ocean



Coral

Healthy coral



Bleached coral



Dead coral covered
in tufting algae

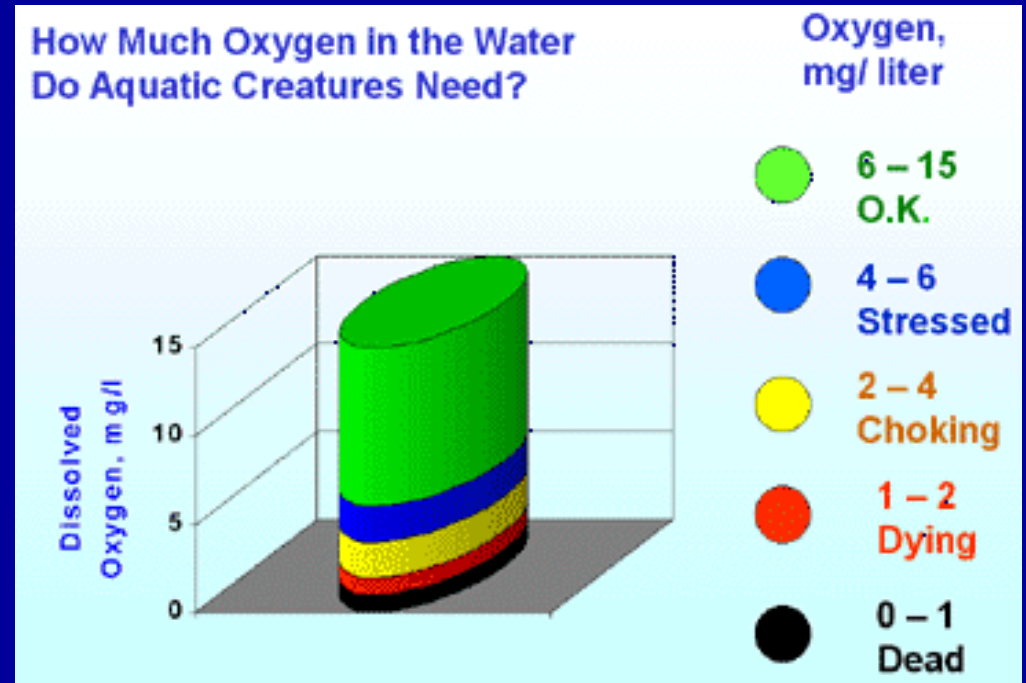
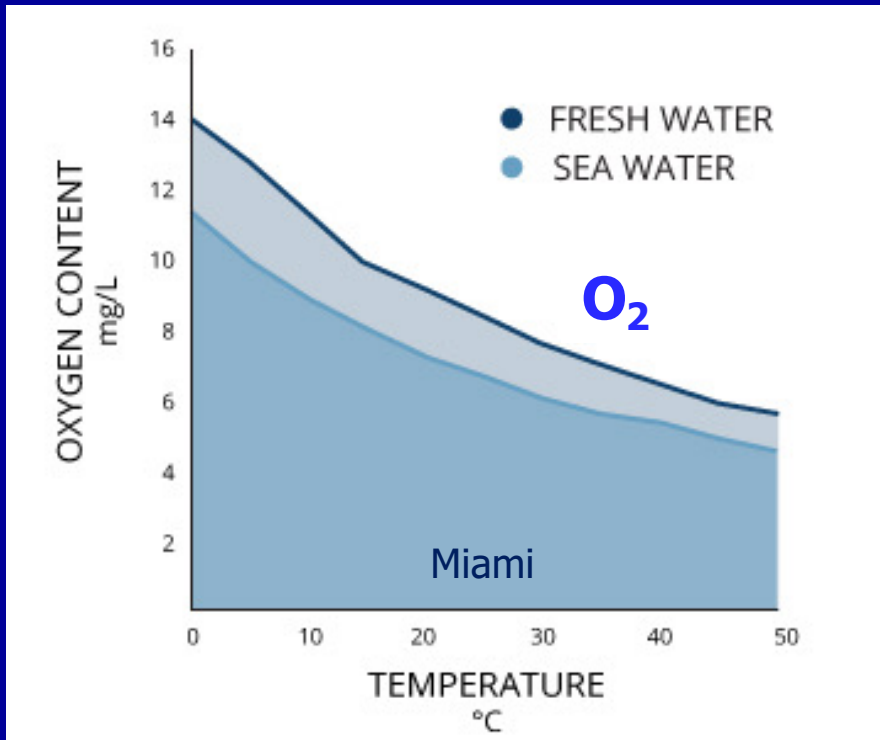


**Coral can recover
from bleaching, but
it can take years.**

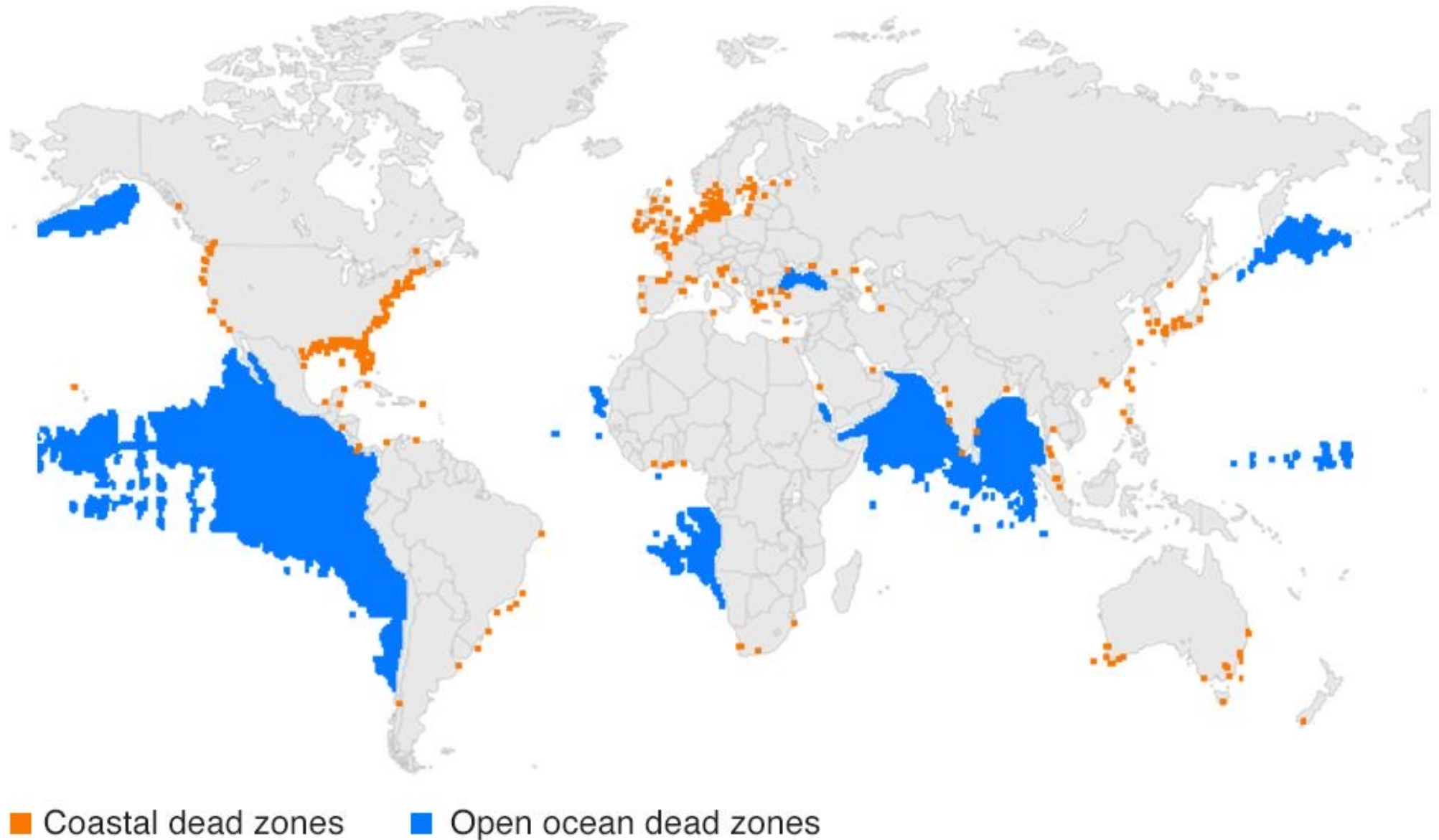
How many of you had a fish tank?



Oxygen in our oceans



Ocean dead zones, where oxygen is lower than 2 milligrams per litre



Source: Global Ocean Oxygen Network, Science

Atlantic Ocean Circulation

First, melting ice, mostly from Greenland, dilutes the surface waters where the Gulf Stream reaches its northernmost extent. Since fresh water is less dense than salty water, the water has a more difficult time sinking to begin its journey southward.

Second, the surface water is warmer than it used to be, and since warm water is less dense than cold water, this just adds to the problem.

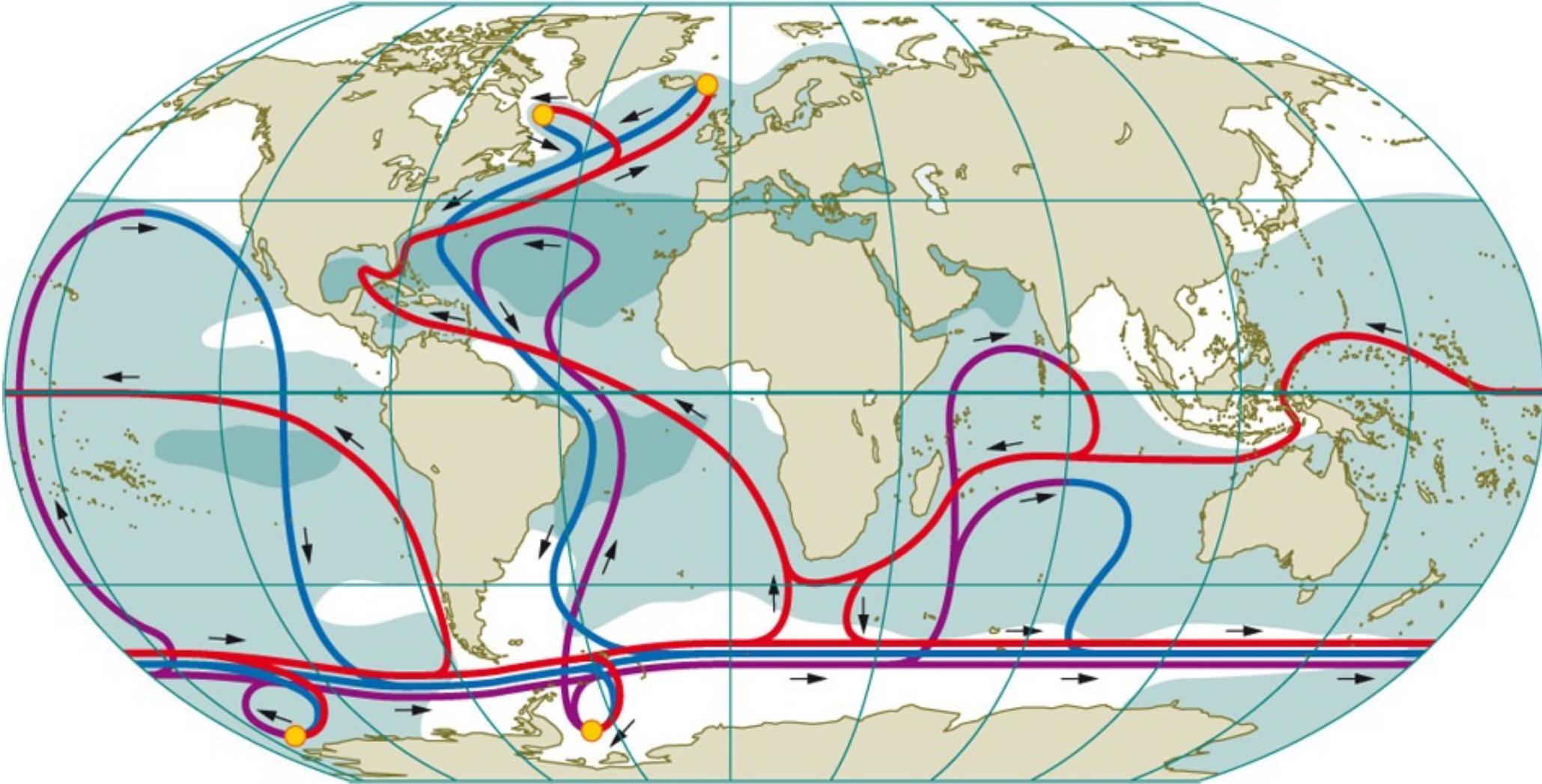
**Slower Gulf Stream -> faster rising sea level on east coast of USA
(faster stream tends to pull water away from the coast
1-1.5 m effect)**

Closely tied to melt water from Greenland: low probability- high impact

<http://www.climatecentral.org/news/east-coast-faces-rising-seas-from-slowing-gulf-stream-15587>

Thermohaline Circulation

It takes water 500 to 1000 years to go around the planet.



What drive ocean currents

- Wind and tides drive surface currents
 - Winds drive upwelling of cold, nutrient filled waters; good fishing off west coast of South America
- Floating ice does not affect sea level
- Frozen water cannot hold salt; freezing squeezes the salt out

Thermohaline pump

- Temperature and salinity drive deep ocean currents; hence “thermohaline”
- Meltwater from glaciers and ice sheets is cold
 - cold water is denser and sinks
 - salt water is denser than fresh
- This combination makes pumps that drive water towards the ocean floor near the cold continents
 - huge underwater “waterfall” off Antarctica

- The cold water flows down in underwater rivers that move around in the deep ocean following the topography of the ocean floor
- The water near the equator rises slowly over a larger area in the tropical and sub tropical zones
- This flow carries warmer surface water towards the poles, carrying heat to where climate change is most pronounced.



Gulf Stream

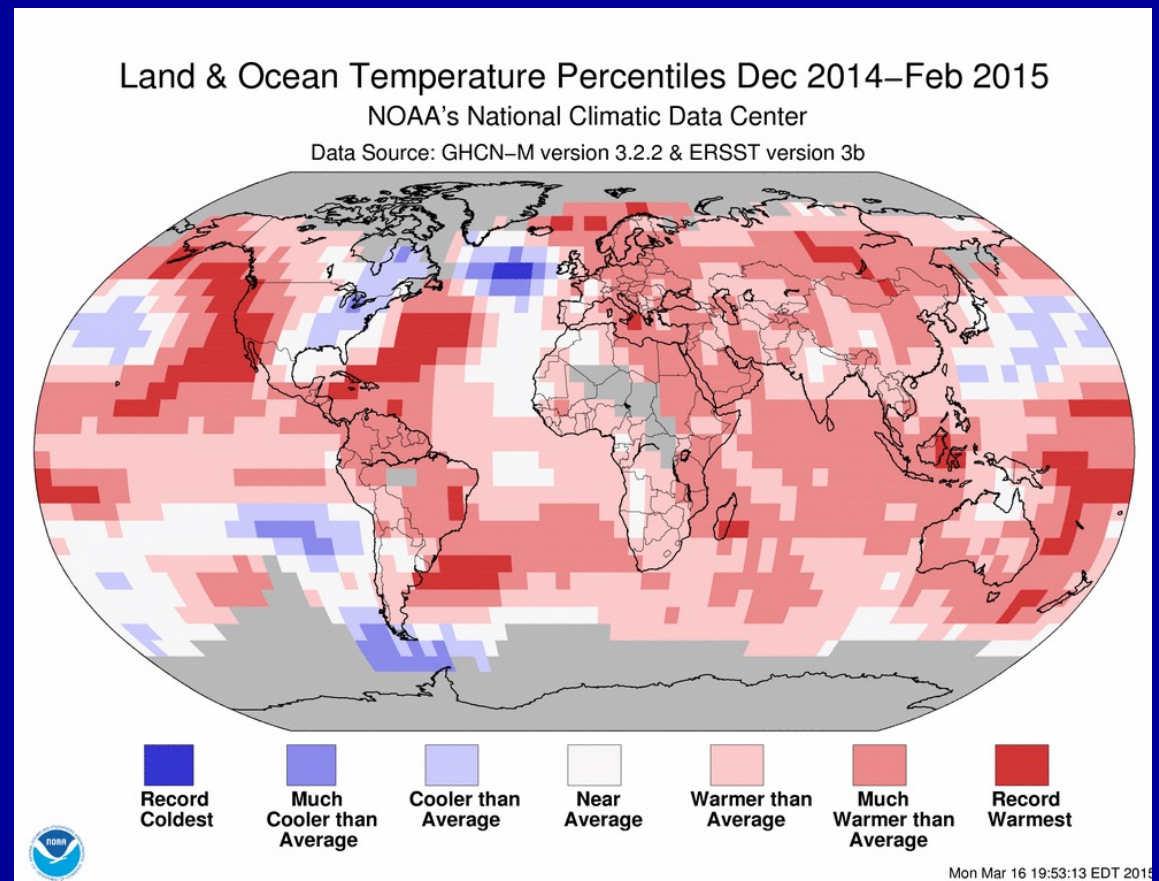


- Discovery credit goes to Anton de Alaminos, a pilot for Ponce de Leon (both sailed with Columbus) 1519
- Northern leg was charted by Benjamin Franklin and his cousin Folger in the 18th century; Spanish treasure ships used the stream to return to Europe throughout the 16th century.
- British Admiralty wanted to know why American ships sailed to England 2 weeks faster than theirs. Franklin was called to testify. They ignored his testimony.
- One hundred thousand million (10^{11}) tons of warm saltwater flow between Florida and the Bahamas every hour. At 235 gallons per ton, we have 235×10^{11} gallons per hour flowing between two and five miles per hour northward.

Slowing of the Ocean currents

Freshwater melt from Greenland and other North Atlantic ice caps is causing a cold spot in the North Atlantic which has slowed the Gulf Stream by 15-20%.

Exceptional twentieth-Century slowdown in Atlantic Ocean overturning circulation.
(2015): Nature Climate Change (online), Rahmstorf, et al.

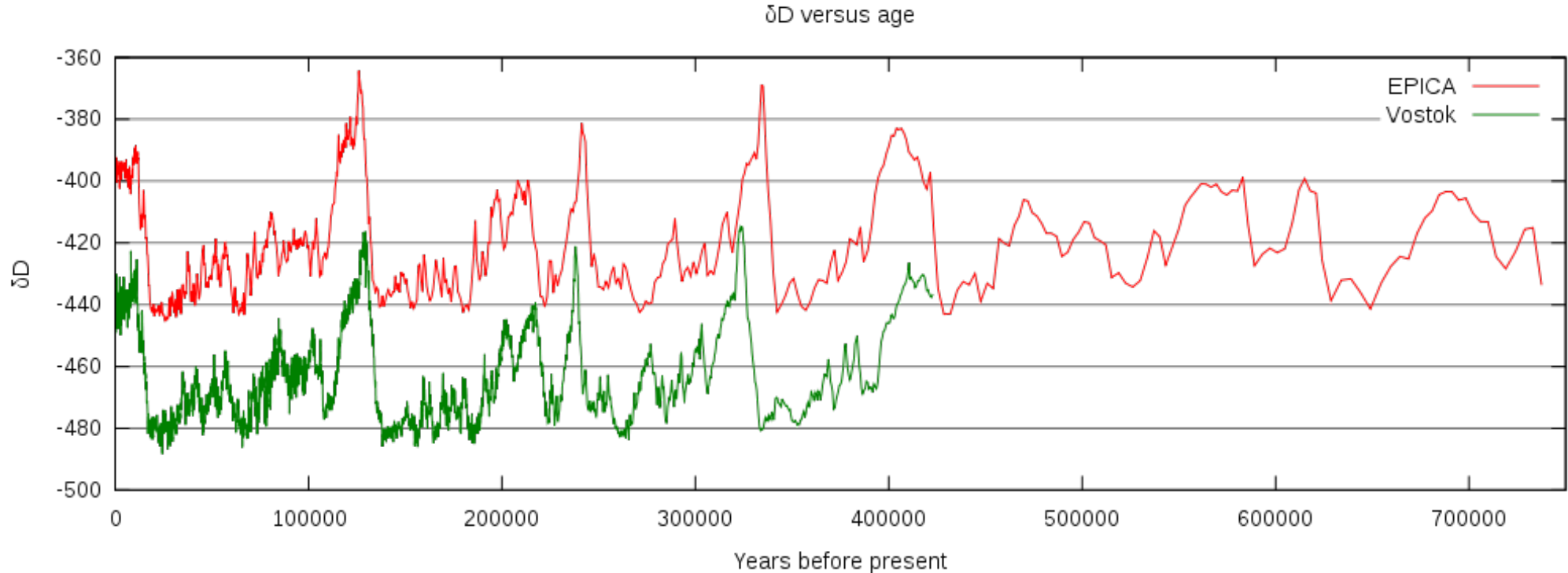
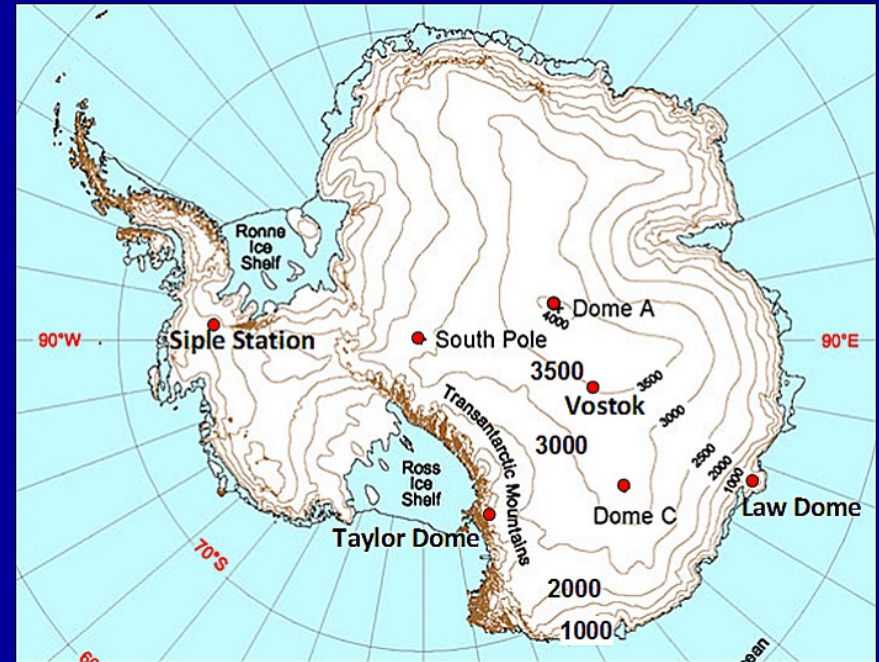


Affects sea level on the east coast

- Gulf stream draws water away from the coastal areas; faster stream, more draw.
- Sea level there has been about 1 meter lower than average sea level due to this effect.
- As the Gulf stream slows, this trough is filling, so sea level is rising faster there than the global average rise.

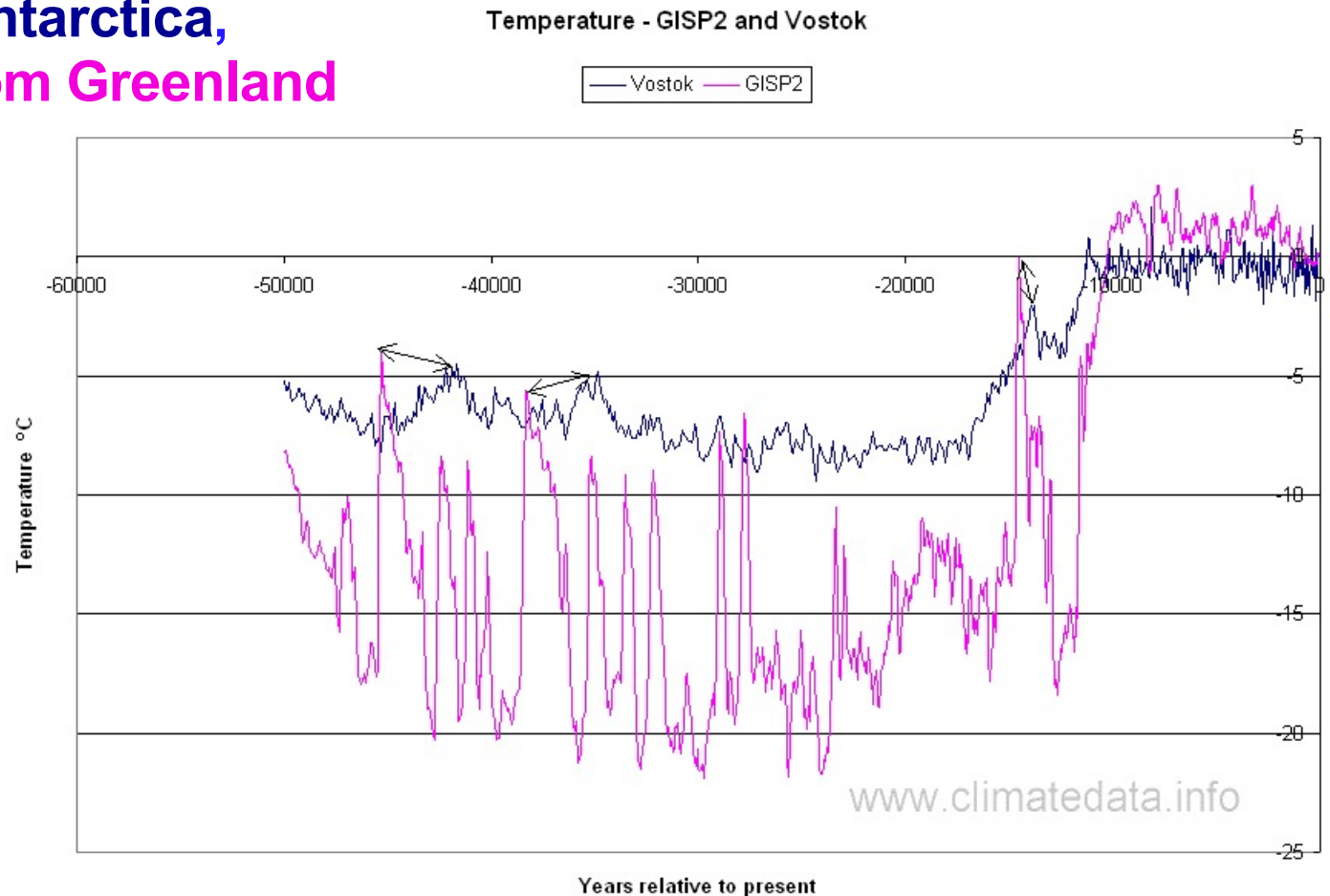
Compare two Antarctic Ice cores

Red is EPICA (Dome C)
Green is Vostok



Compare Greenland and Antarctic Ice cores

Vostok is Antarctica,
GISP2 is from Greenland



Conclusions:

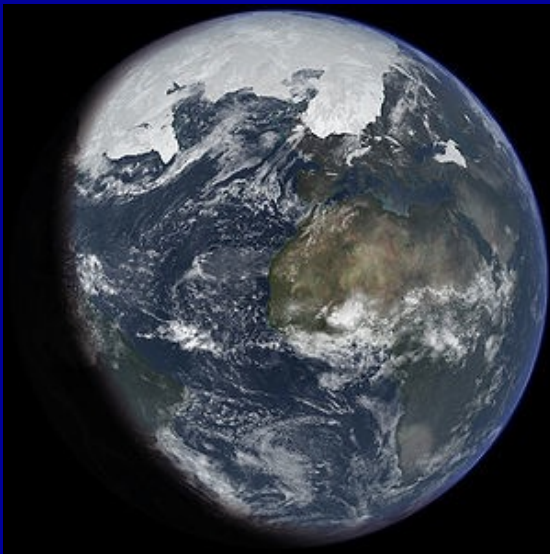
1. General trends are consistent
2. Significant variation N-S hemispheres and regions of Antarctica
3. Greenland shows lots of variations (Northern hemisphere is more complex)

Ice age natural cycles

- When less sunlight reaches the northern latitudes, temperatures drop and more water freezes into **ice**, starting an **ice age**.
- When more sunlight reaches the northern latitudes, temperatures rise, **ice** sheets melt, and the **ice age ends**.

Ending the last Ice Age

- The Earth's orbital cycles trigger the initial warming (starting approximately 19,000 years ago), which is first reflected in the Arctic.
- An influx of fresh water disrupted the Atlantic Ocean circulation, in turn causing a seesawing of heat between the hemispheres. The Southern Hemisphere and its oceans warmed, starting about 18,000 years ago.
- The warming Southern Ocean then released CO₂ into the atmosphere starting around 17,500 years ago, which in turn caused the entire planet to warm via the increased greenhouse effect.



"Changes in the CO₂ and CH₄ content have played a significant part in the glacial-interglacial climate changes by amplifying, together with the growth and decay of the Northern Hemisphere ice sheets, the relatively weak orbital forcing."

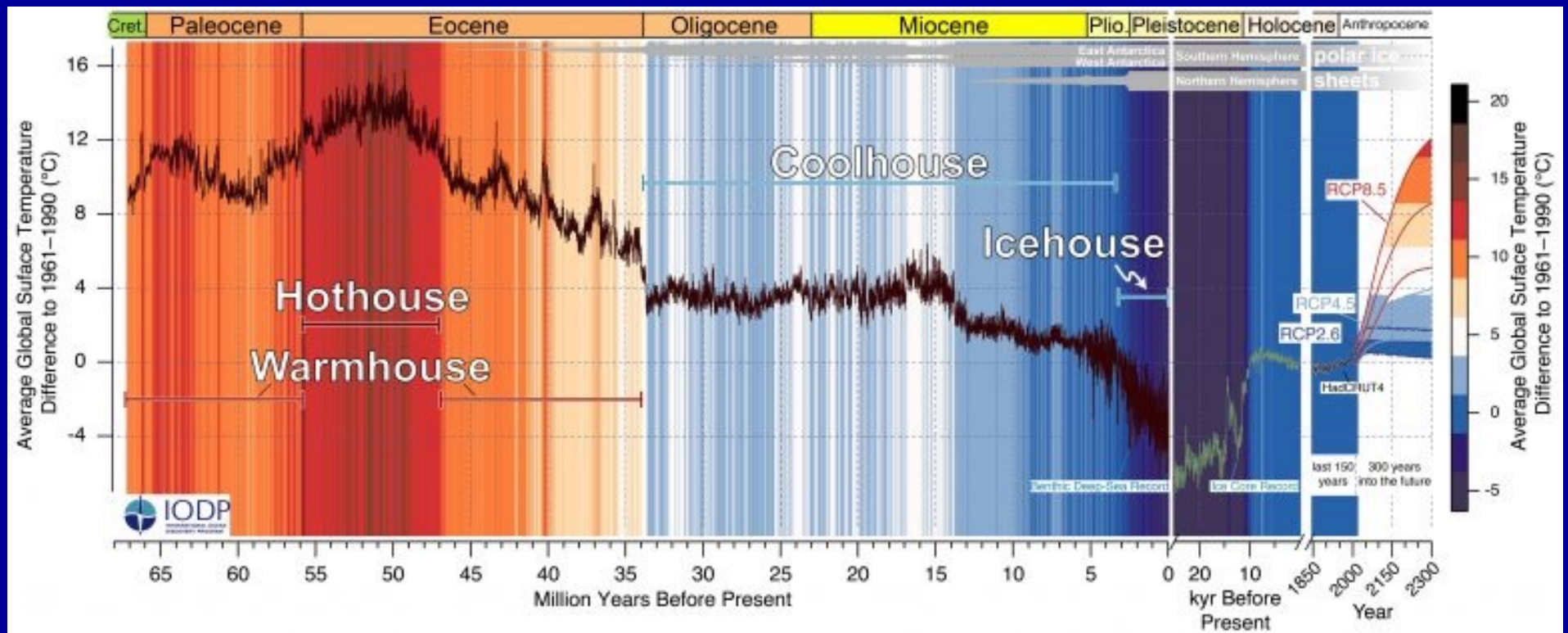
Lorius et al., 1990 *Nature* 347, 139 - 145

Ending the cycles: new work

- Solar heating of the Antarctic
 - sea-ice albedo changes -> increase melt
 - freshwater release to the deep ocean
 - deep ocean warms
 - takes >1000 years for the Arctic to warm
 - ocean circulation time scale
- Oscillations (aka seesawing) of N-S temps

Still under debate! However, once the temp goes up (down), CO₂ goes up (down) and we're off and running. Either T or CO₂ can drive a warming feedback cycle.

66 Million Years of Earth's Climate History Uncovered – Puts Current Changes in Context



September 10, 2020 *Science*,