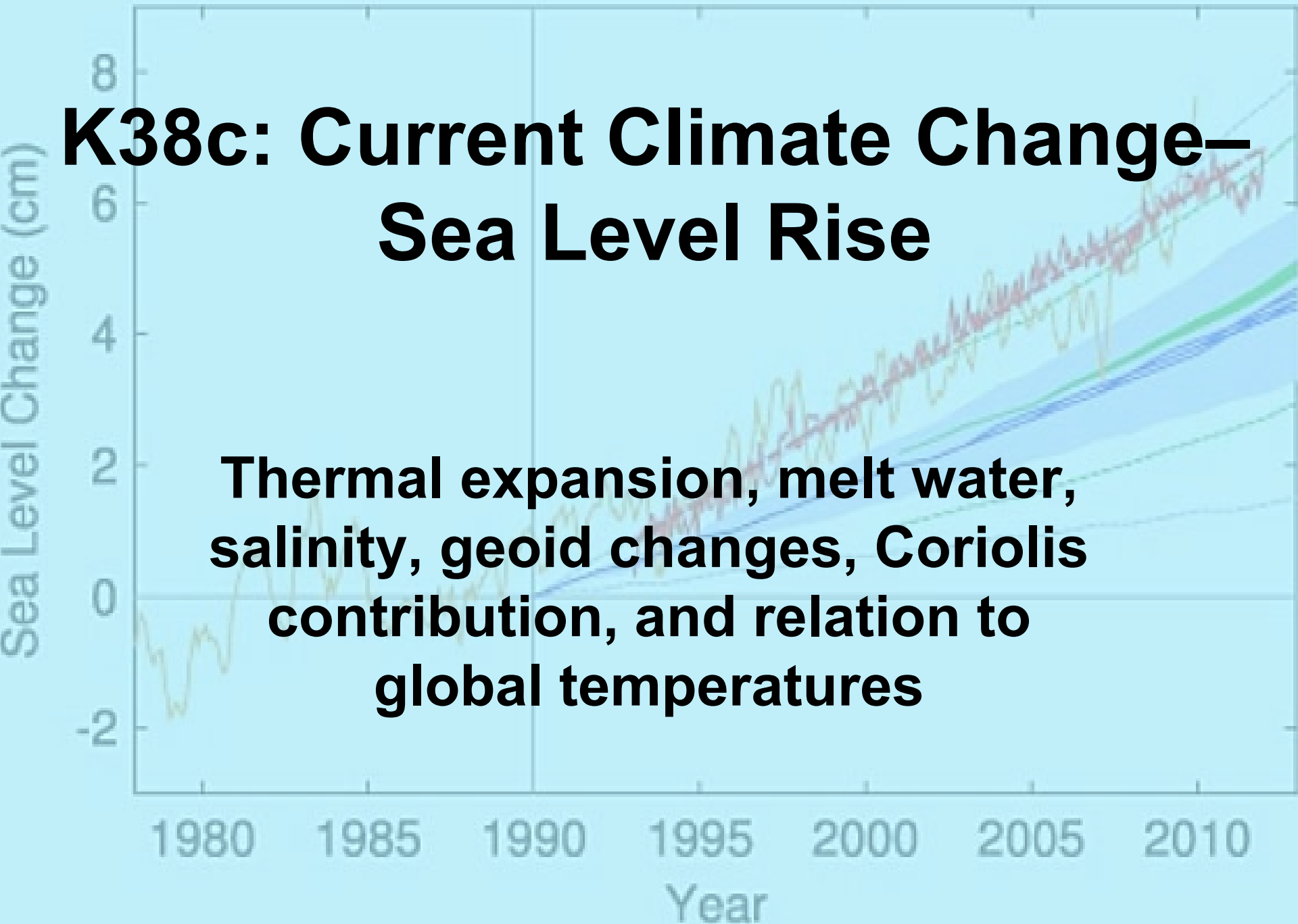


# K38c: Current Climate Change— Sea Level Rise

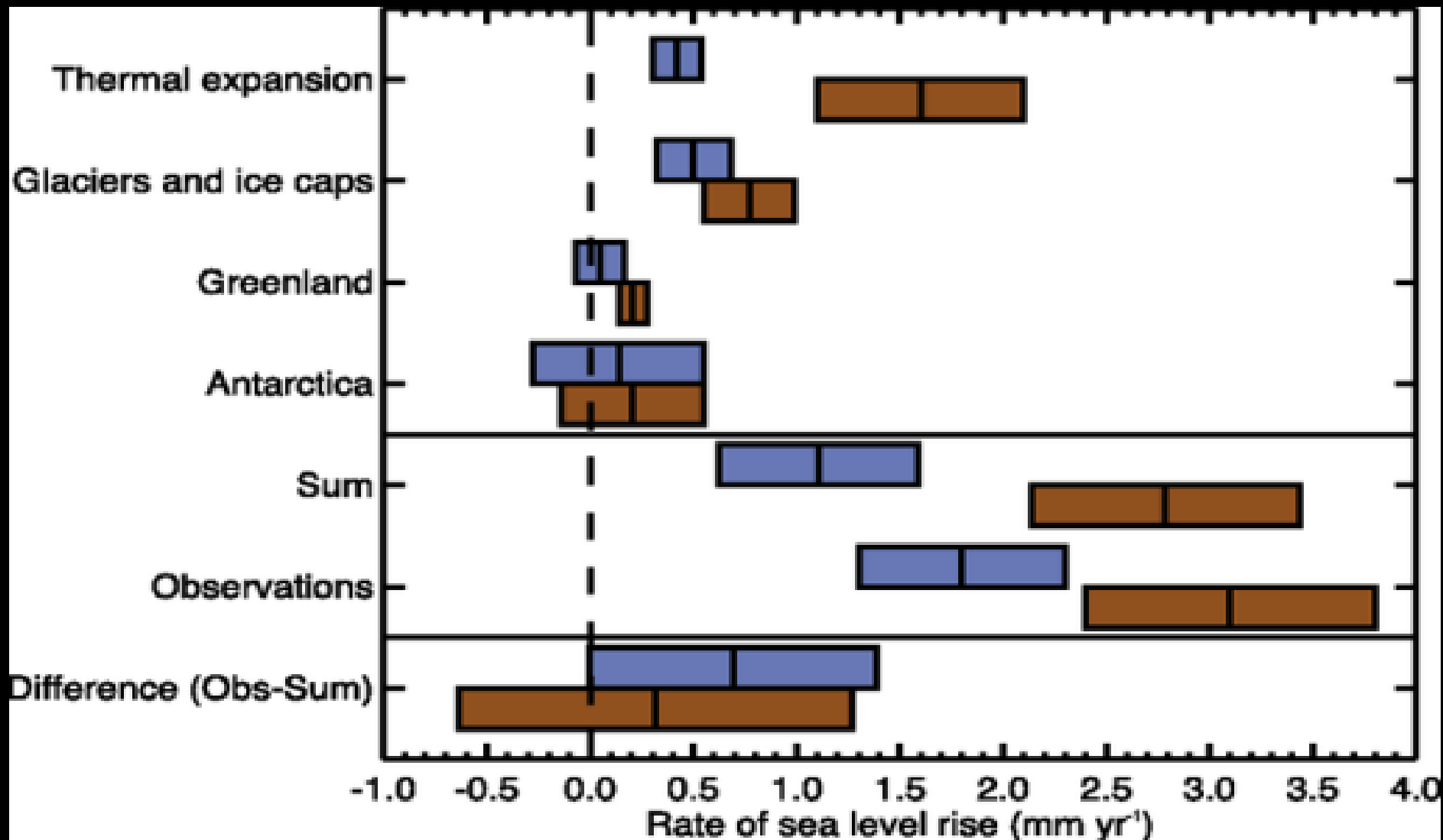
**Thermal expansion, melt water,  
salinity, geoid changes, Coriolis  
contribution, and relation to  
global temperatures**



# On ~60 year time scales, sea level rises for two reasons, both are climate-related...

- 1. Thermal expansion of warmer water (simple physics. Observe temperature profile of the ocean, integrate, derive the thermal expansion)
- 2. Melting of continental “permanent” ice (glaciers, land ice caps)
- Thermal expansion has provided most of the sea level rise of the past 100 years
- But continental melt is rapidly increasing, and now contributing ~1/2 of the current sea level rise rate, will dominate into future.
- Sea Level Rise rate = 1.8mm/year averaged over past 100 years, but is 3.3mm/year over the past 20 years.
- Note that **sea ice melting** contributes nothing to sea level rise, since floating ice already displaces water (Archimedes Principle). Thus, melting of the Arctic Ocean ice is not contributing to sea level rise
- On longer time scales, there is minor contributions from slow rebound of the land from the last Ice Age (loss of heavy glaciation causes continental land to float a bit higher, and this process is very slow).
- On time scales of a few years and shorter, there are many factors affecting sea level: tides, El Nino's, tsunamis, changing atmospheric pressure associated with storms, floods and associated salinity changes...
- [34 second video of Greenland areas of ice melting \(in red\)](#)

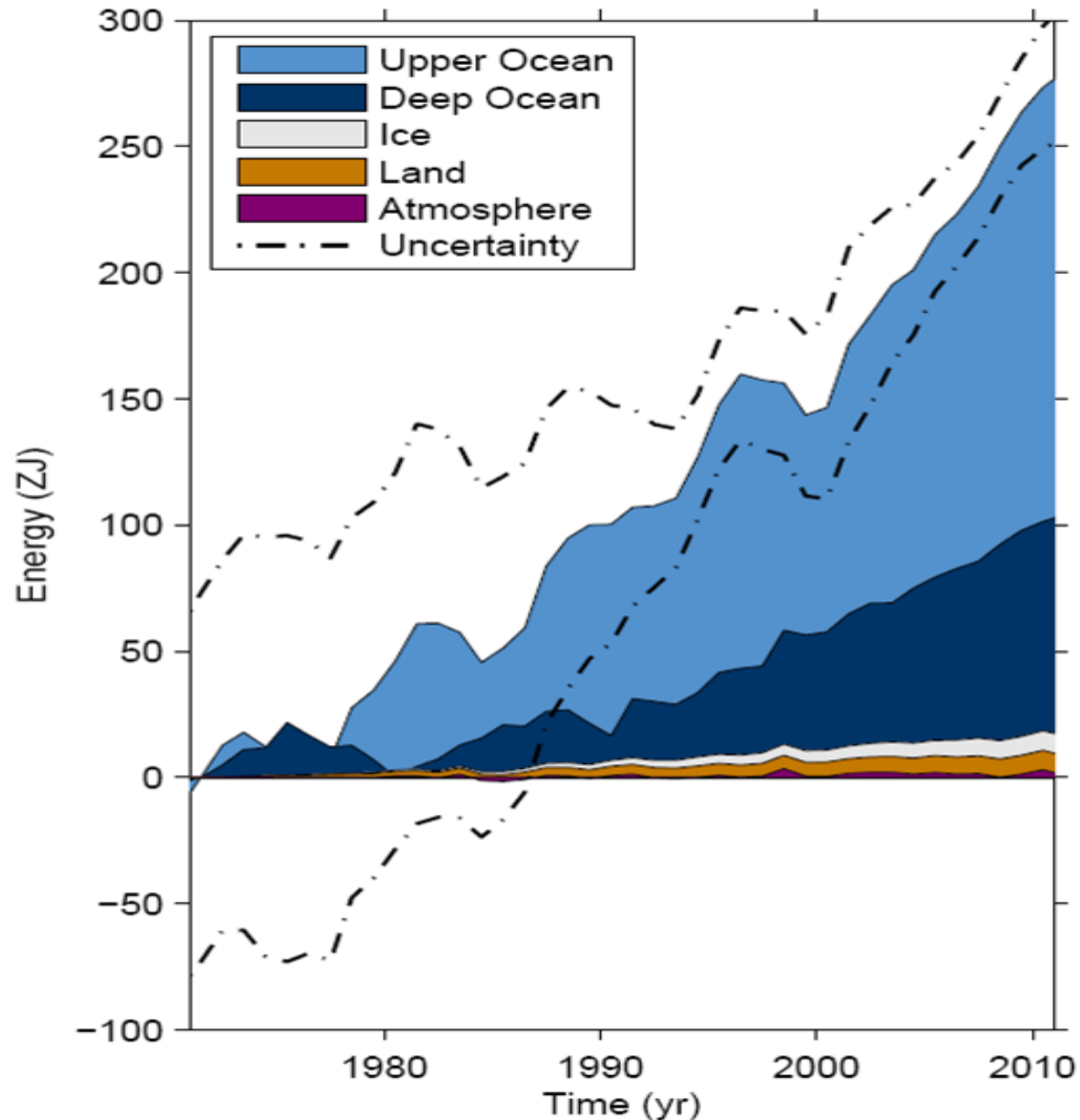
# Observations (brown) are much higher than predictions (blue). From IPCC AR4



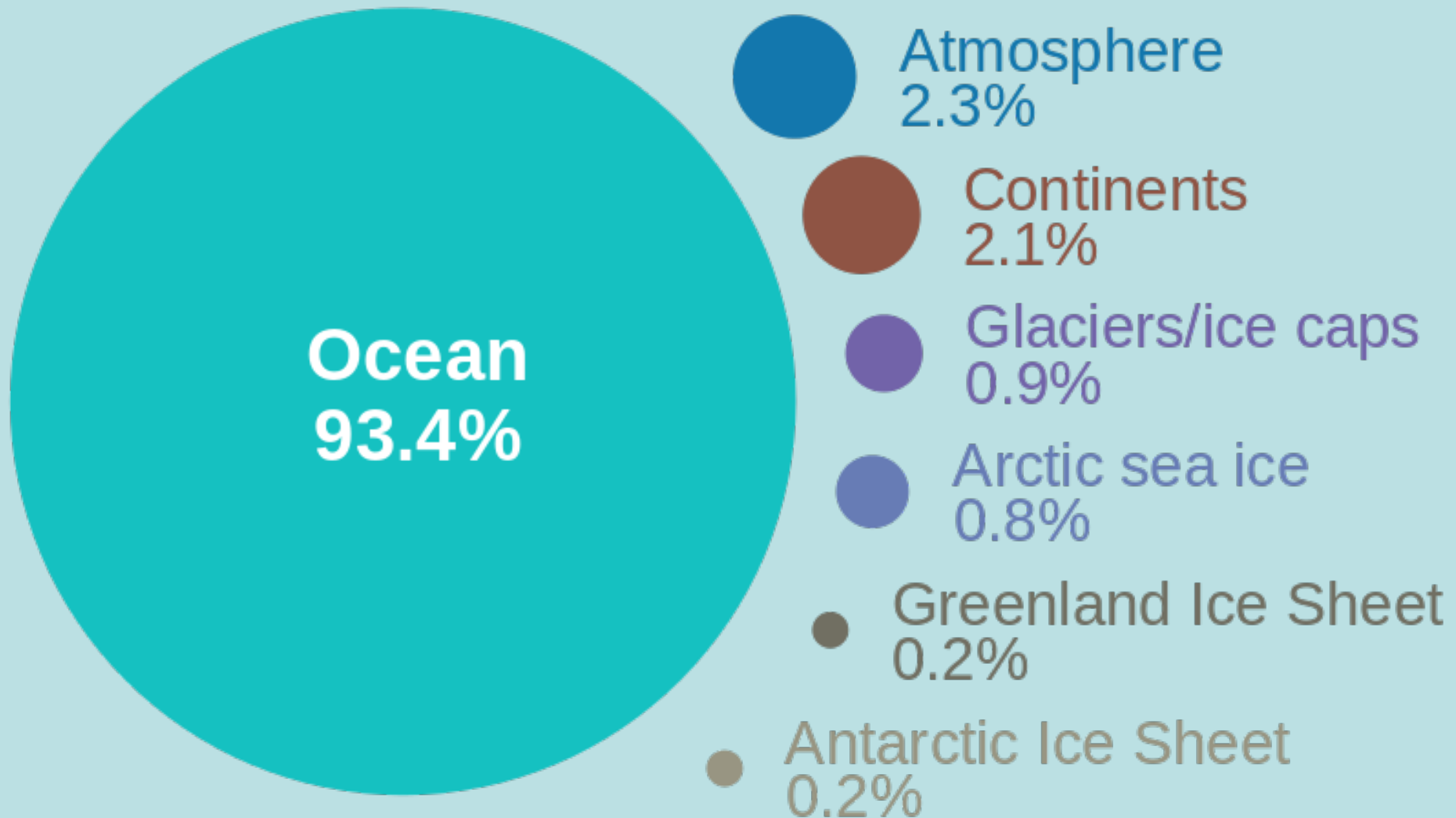
# The IPCC and Conservatism

- **One more time** – the Intergovernmental Panel on Climate Change, though staffed in large part by high quality scientists, is a UN organization and all parts of the organization must reach UNANIMOUS agreement on everything they publish
- Given that the governments of the scientists are largely the most carbon-polluting on Earth, and given the non-science people who are part of that decision cohort, it's not at all surprising that the statements and writings of the IPCC are NOT “alarmist”, but in fact, quite far on the “complacent” side of reality.
- Ocean scientist Jeremy Jackson points out (33 minutes into [this seminar](#)) that as of IPCC AR5, there are enough assessment reports to show **that IPCC projections of sea level rise are less than HALF of reality every single time.**
- **You should find this alarming, and put in context future IPCC statements or quotes of their statements in the press**

# The Oceans Have Absorbed 93% of our Greenhouse Heating

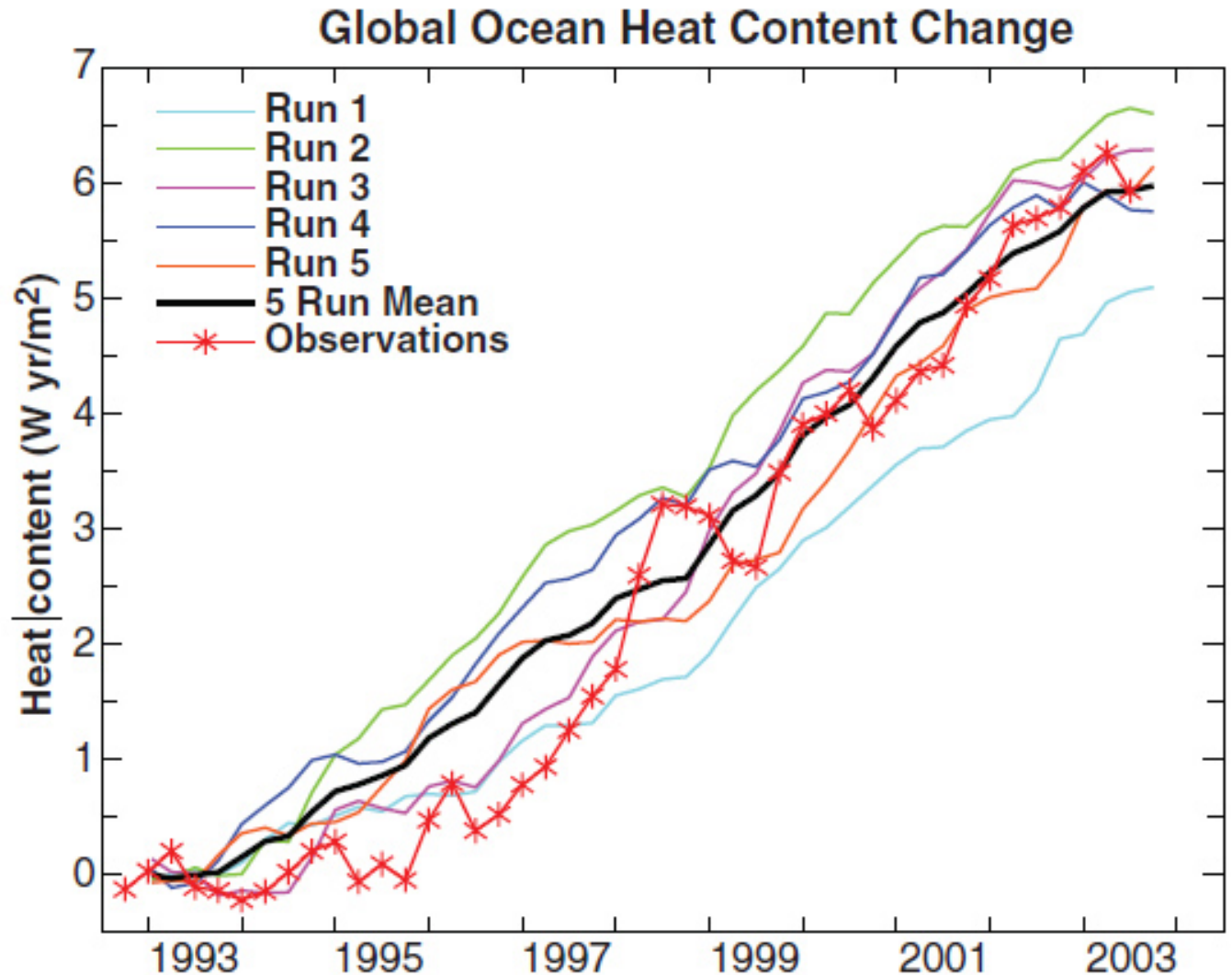


# Where is global warming going?



# GISS Climate Model Post-diction Runs Agree with Observed Ocean Heating. Rising Heat = Expanding Volume and Rising Sea Level

Fig. 2. Ocean heat content change between 1993 and 2003 in the top 750 m of world ocean. Observations are from (20). Five model runs are shown for the GISS coupled dynamical ocean-atmosphere model (8, 9).

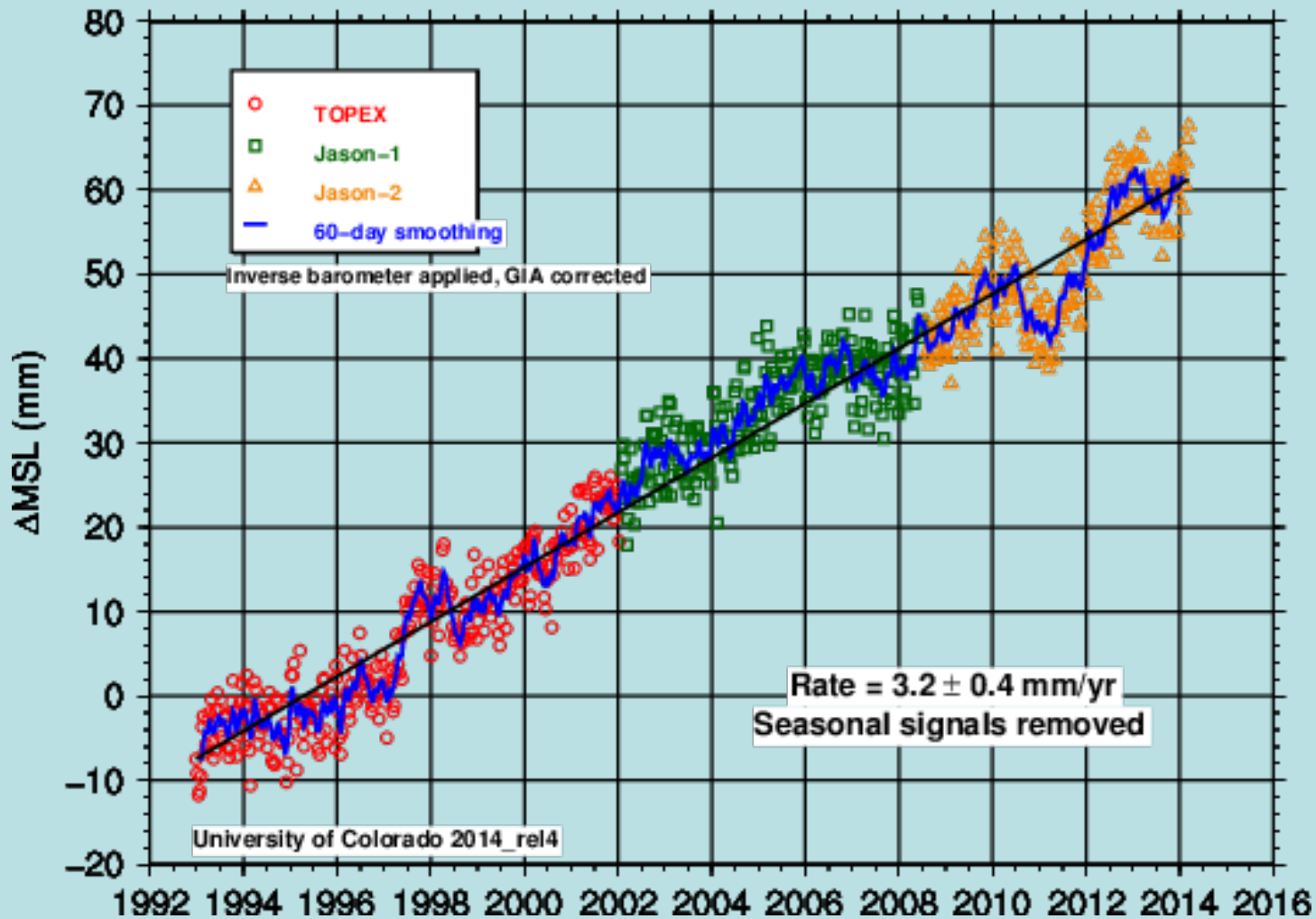


# Sea Level Rise vs. Time and Place

- El Nino's tend to cause sharper rises in sea level where the warm surface waters are, from the thermal expansion of water
- La Nina's (the (on average) cold surface water phase) does the opposite and lowers local sea level
- The height of the geoid (the gravitational potential energy surface of the Earth; a surface parallel to sea level if all other factors are ignored) changes near Greenland and Antarctica especially, as glacial melt takes gravitational mass away from these continents
- Hence, the rate of sea level rise varies from place to place at different times. Must take account of geoid changes (straight-forward to do: gravity) and other data sampled widely in location and time to get it right.
- The following data shows the many tidal gauges and satellite measurements are doing a good job of tracking global sea level rise



**Latest Data, Seasonal Oscillation Removed. Note intense La Nina in 2010/11 actually dropped sea levels temporarily (rains moved water to land until it could flow back to ocean)**



**New 2014 study by Hay et al. shows the Pre-satellite (<1990) sea levels are biased low, and sea levels were actually higher**

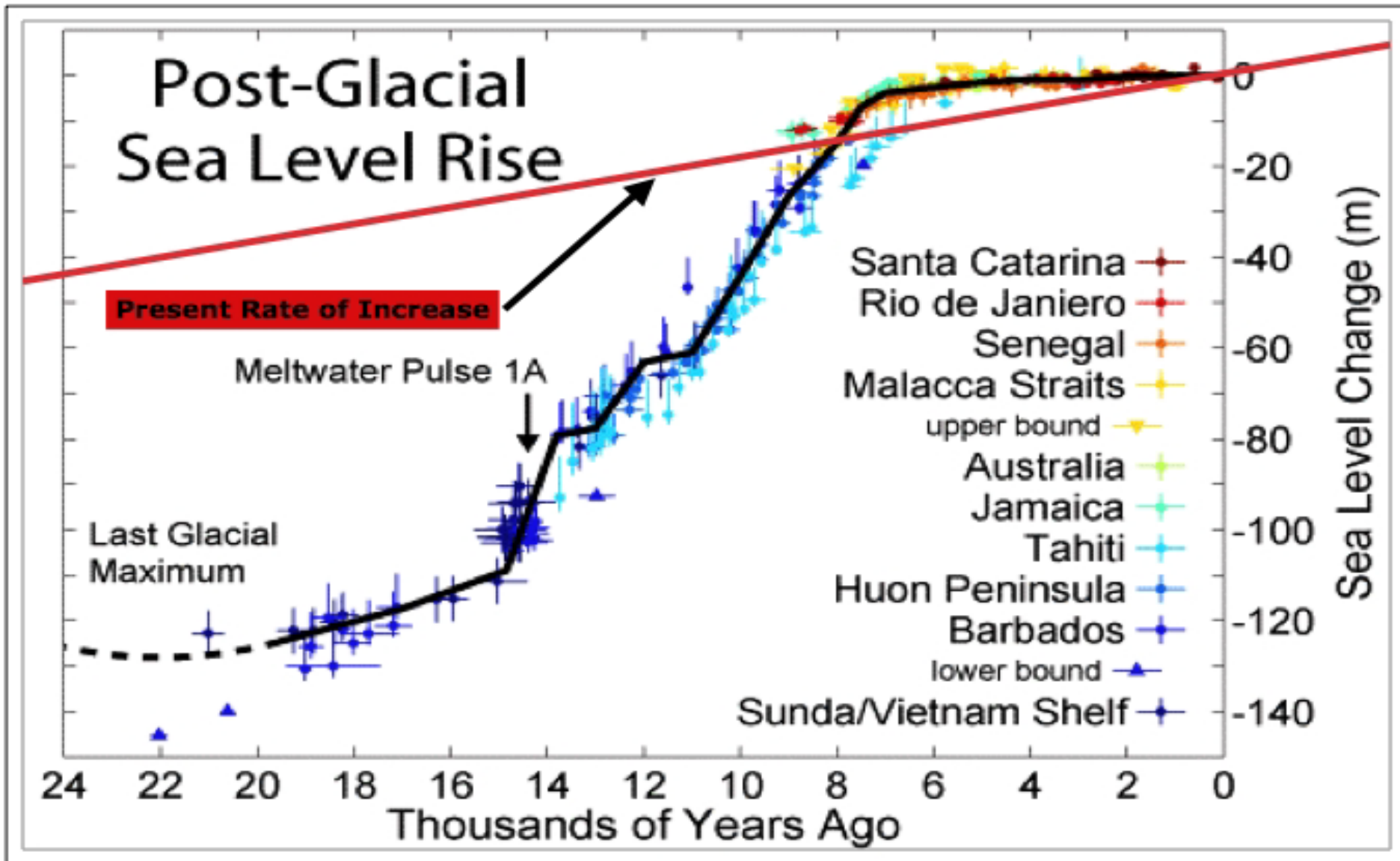
- Therefore, 1900-1990 sea level rise **rate** now looks to be a little lower than had been thought,
- This now agrees with satellite data.
- But that means post 1990 sea level rise is more accelerated than we had thought, suggesting a stronger accelerating current trend, so this is not good news



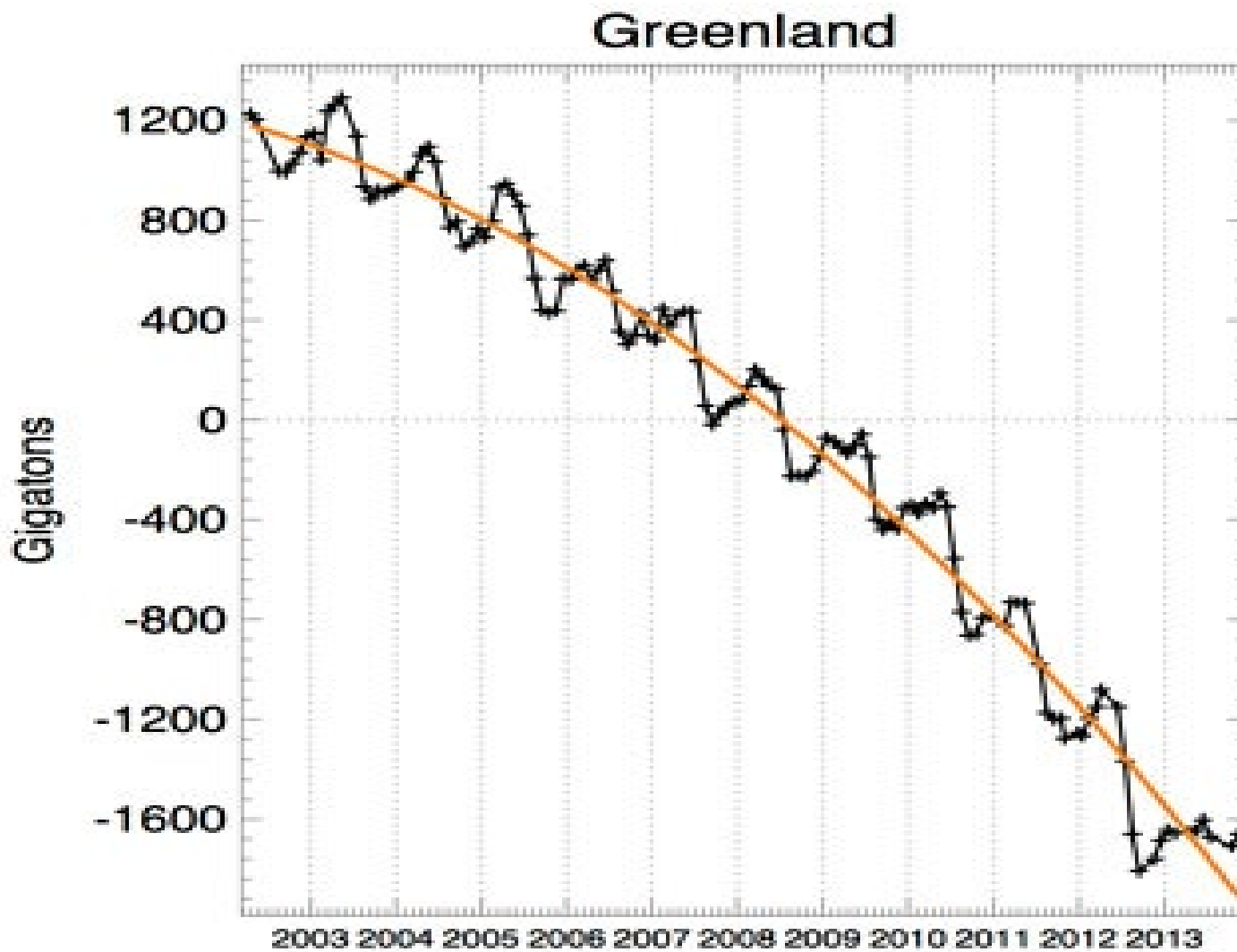
# This indicates **HIGHER** acceleration rate during the global warming era than earlier data

- The lower rise rate in the 20<sup>th</sup> century combined with the same high rate we see today – means that the rise RATE of sea level is accelerating **faster** than we had thought
- Recall we saw a similar bias in ocean temperature due to faulty calibrations between pre-WWII bucket-derived vs. newer hull and then automated bouy ocean temperatures

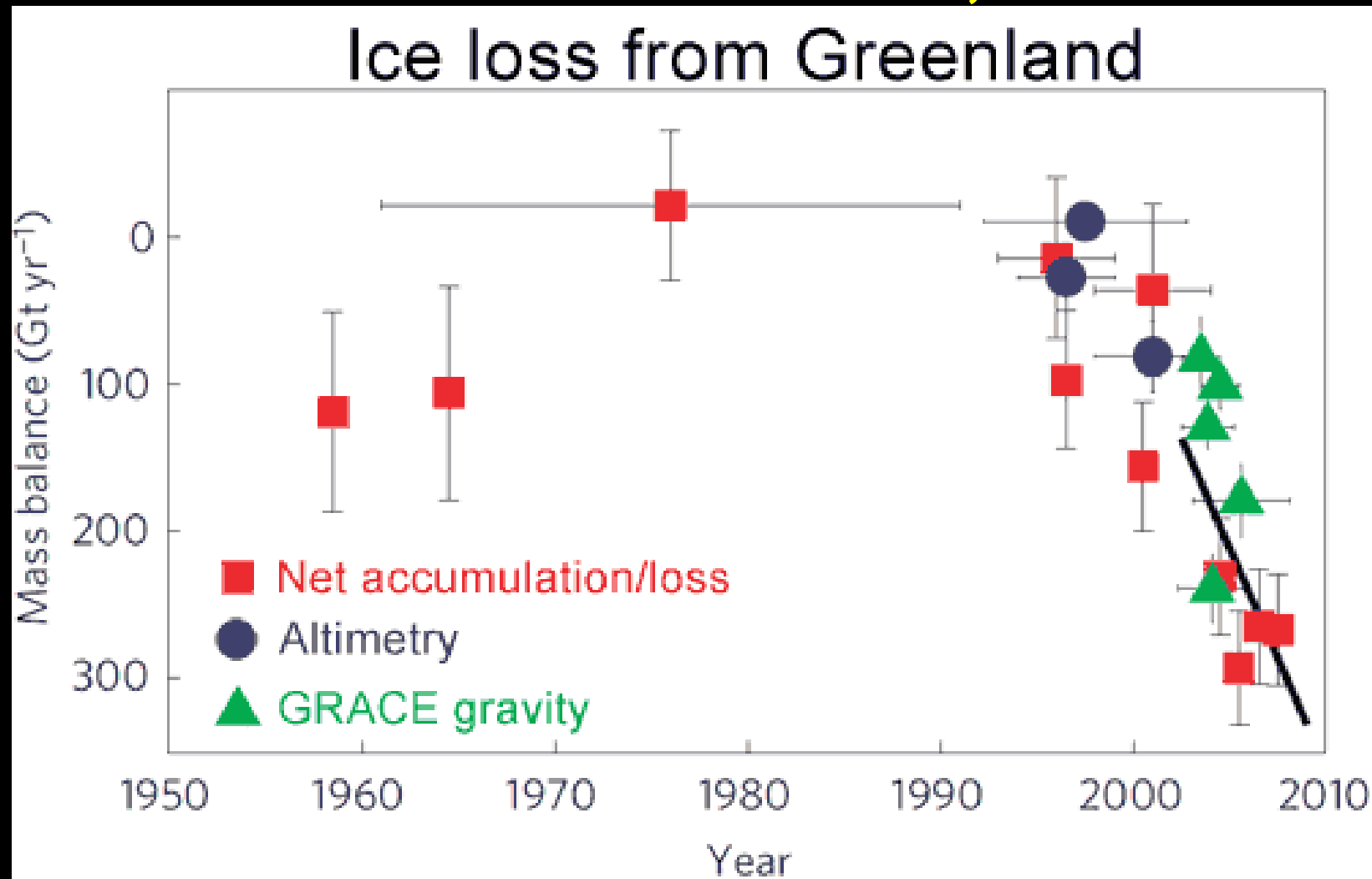
How does this rise rate compare with Ice Age transitions? Red line is 1.8mm/yr = 20<sup>th</sup> century average. Recent rate (red line) is double that: 1993-2003 satellite observed rate is 3.3mm/yr



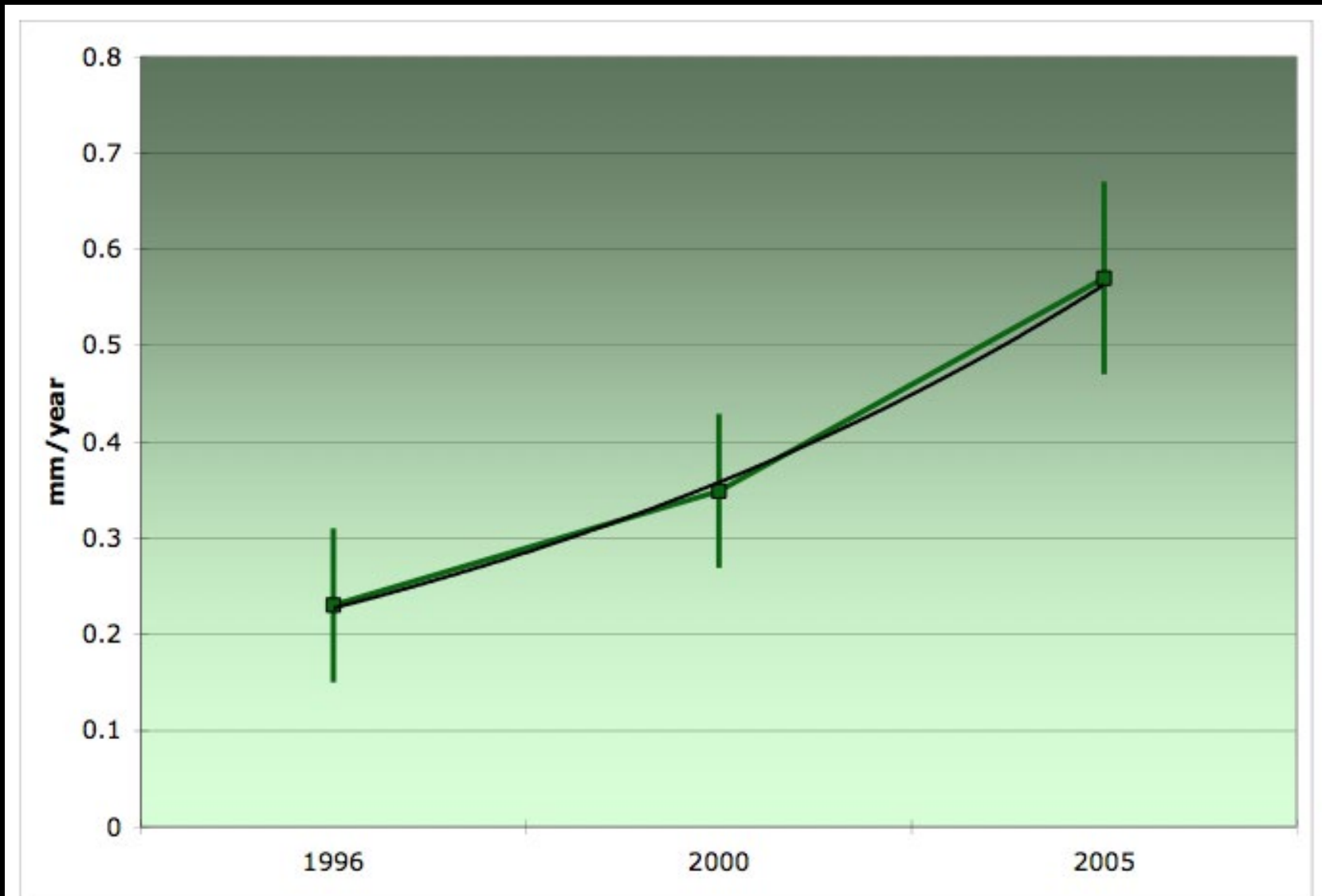
**Antarctica and Greenland are Earth's Ice Caps. GRACE Satellite uses gravity to measure total ice mass loss from Greenland. Ice loss is accelerating, raising sea levels**



The 1950-70's pause in global temperature rise stabilized Greenland ice. But now, in free-fall

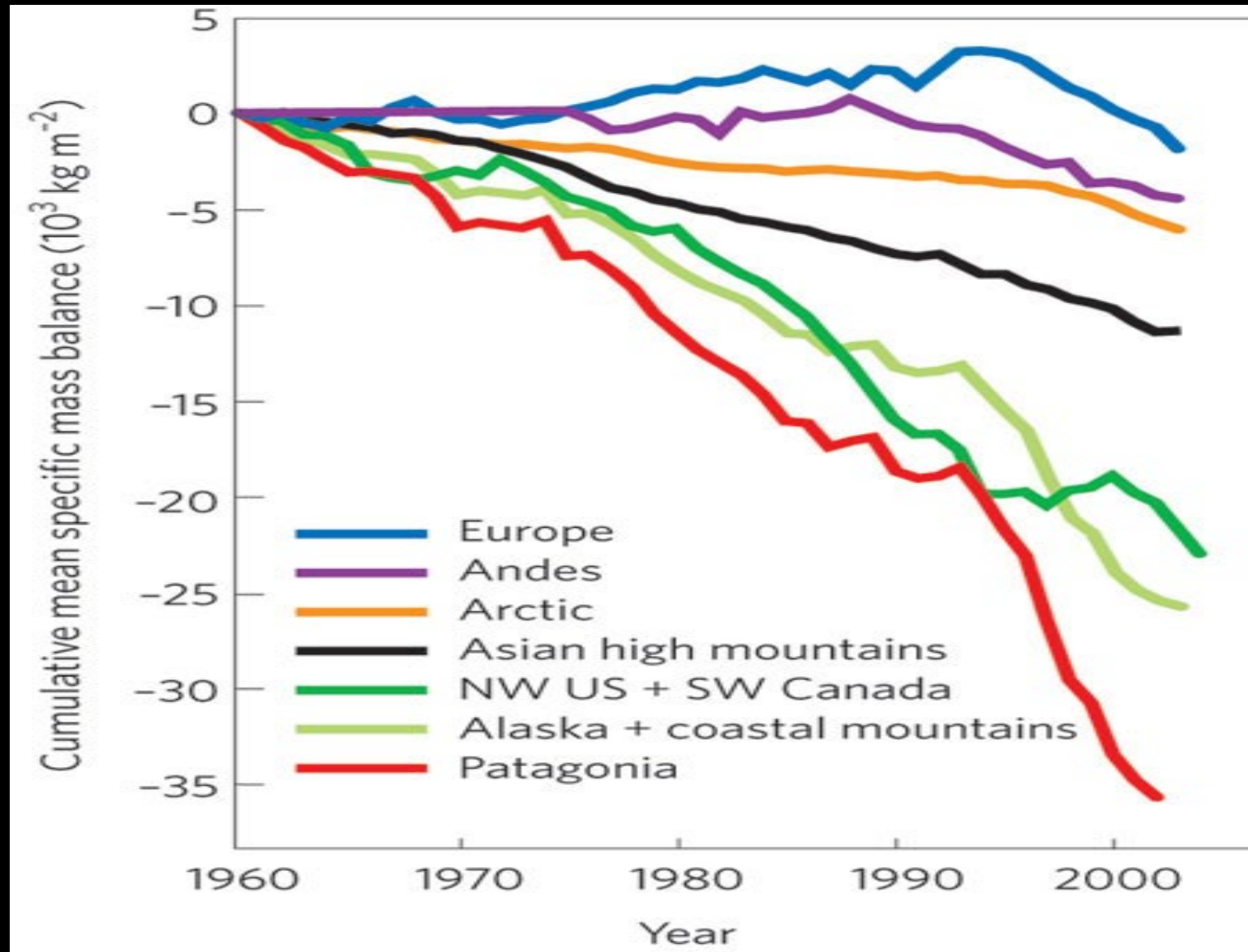


# Greenland Melt's Contribution to Rate of Sea Level Rise: Increasing At Accelerating Rate

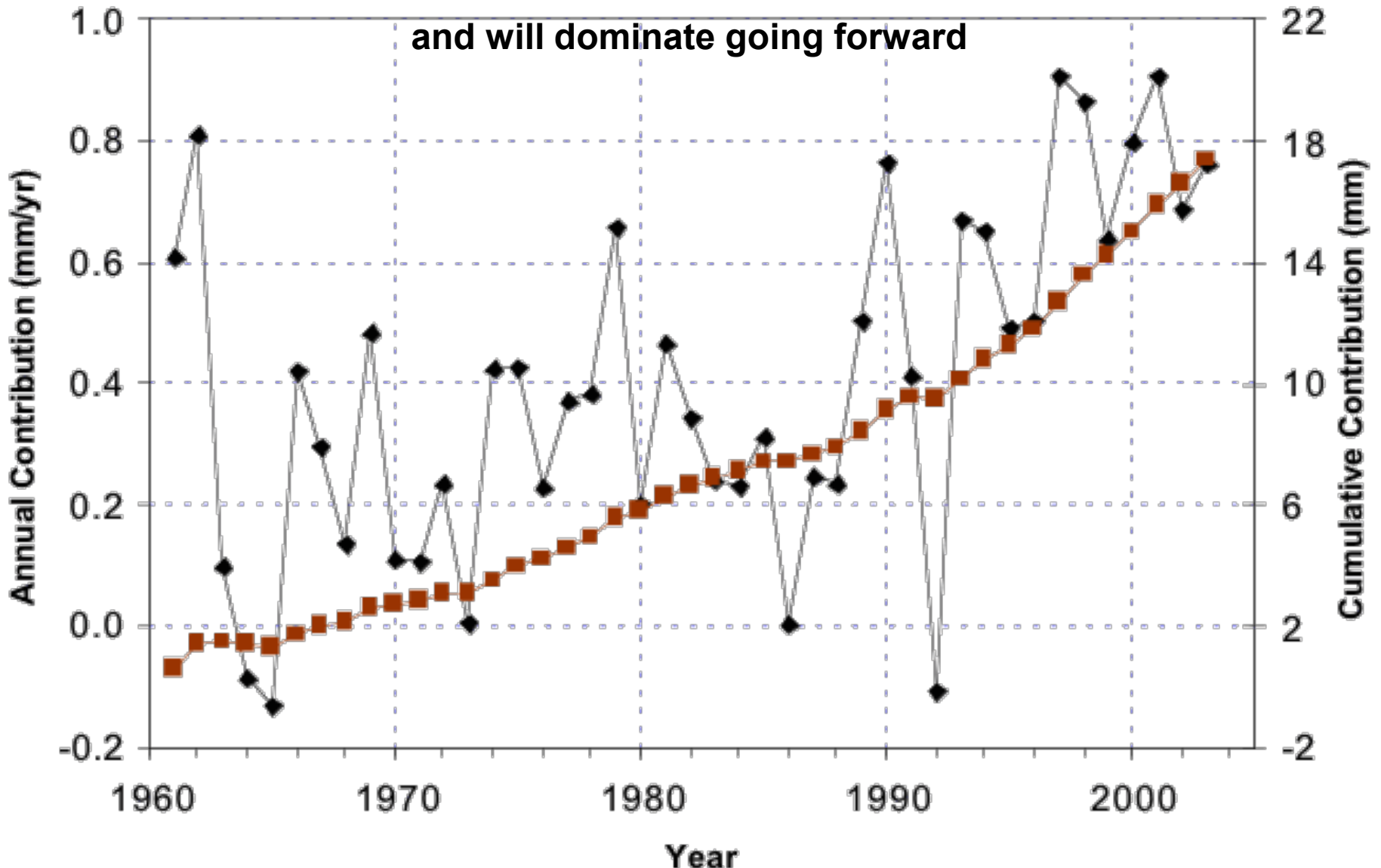




# Glacier Mass Loss Totals: Accelerating Melt Worldwide

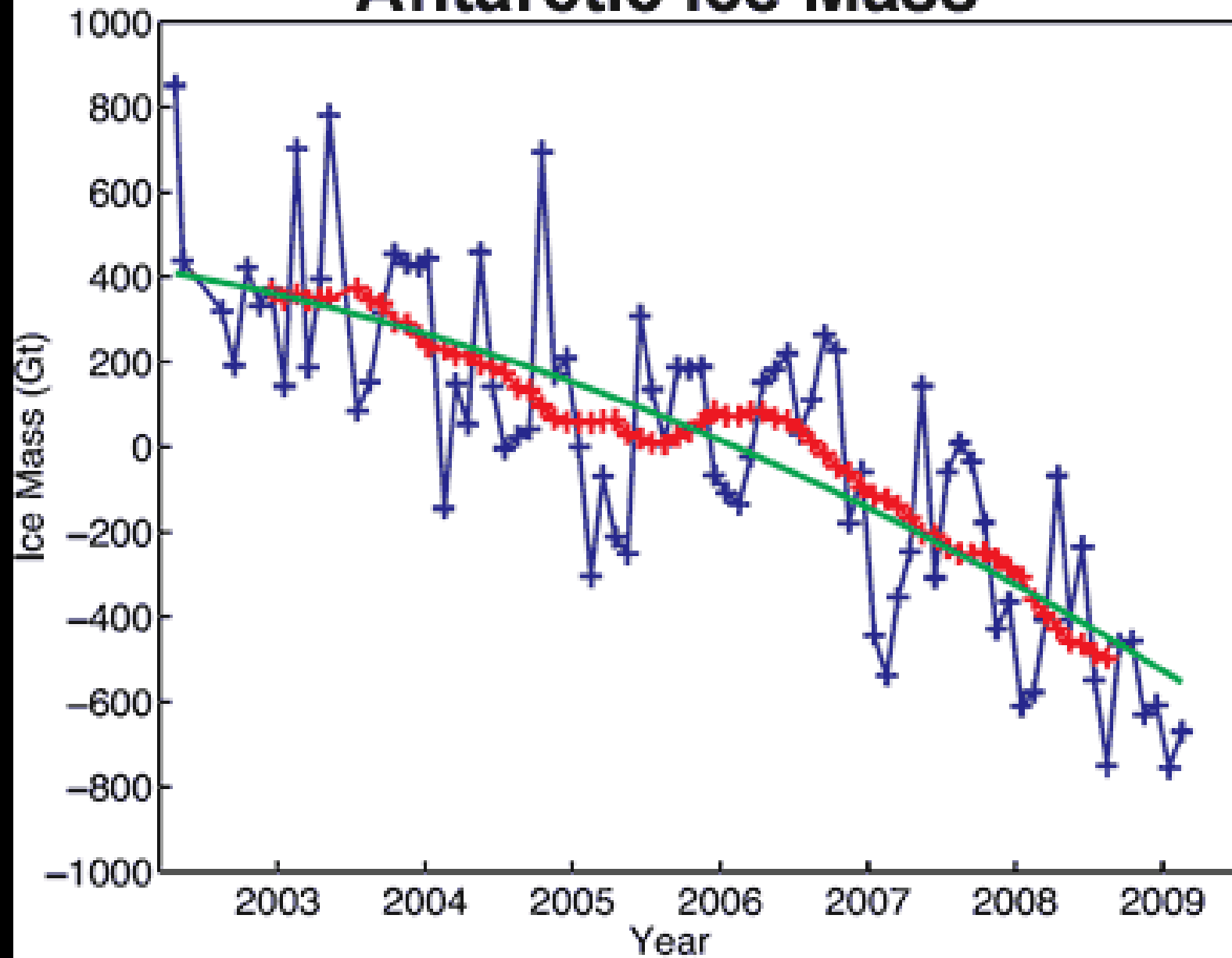


Annual change in global glacial melt contribution to sea level rise (left axis, mm of water equivalent, mm/yr) and cumulative (brown dots, right axis), based on surface area-weighted mass balance observations ([source](#)). Glacier melt now provides almost as much sea level rise as does thermal expansion of seawater, and will dominate going forward

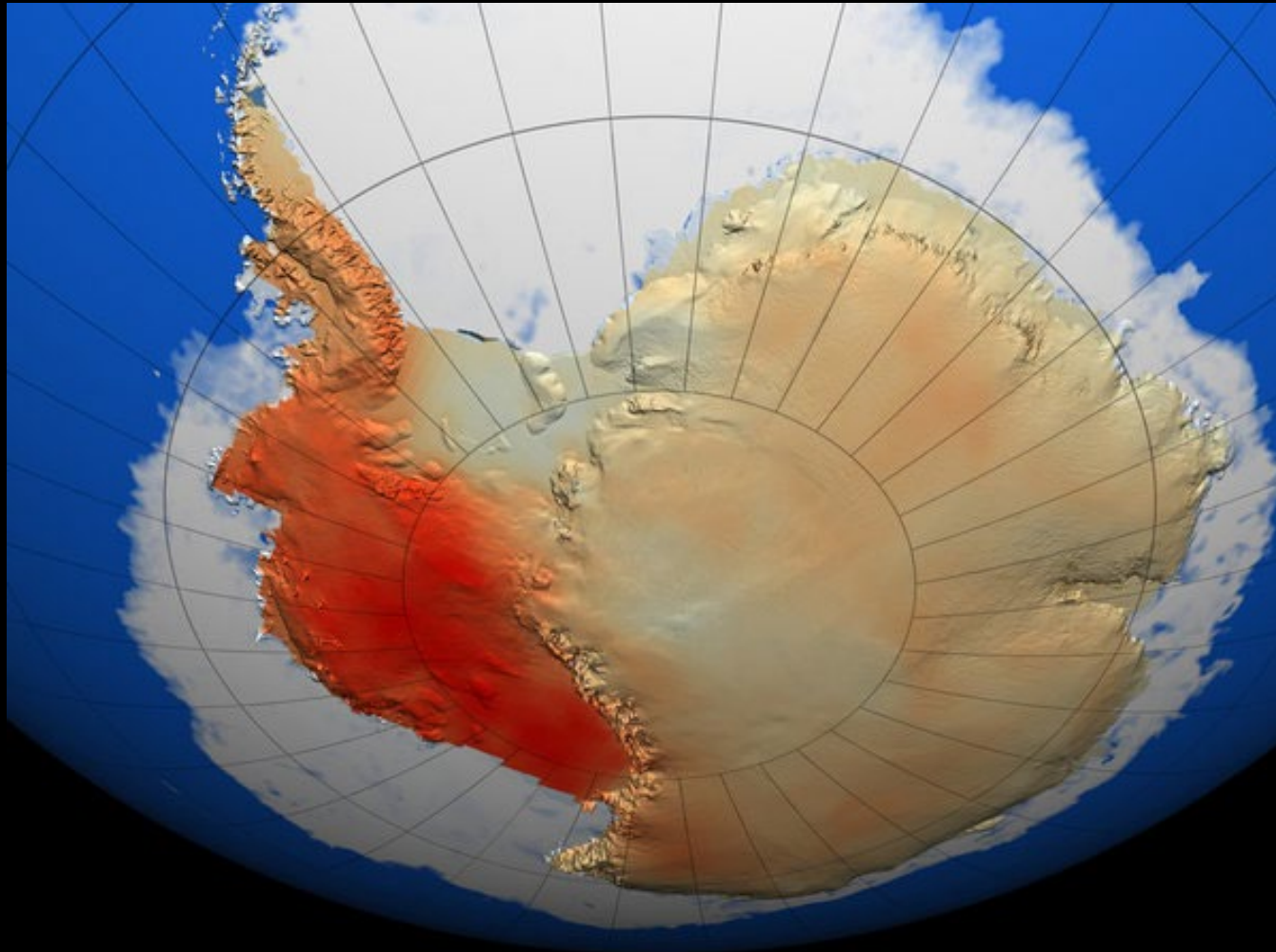


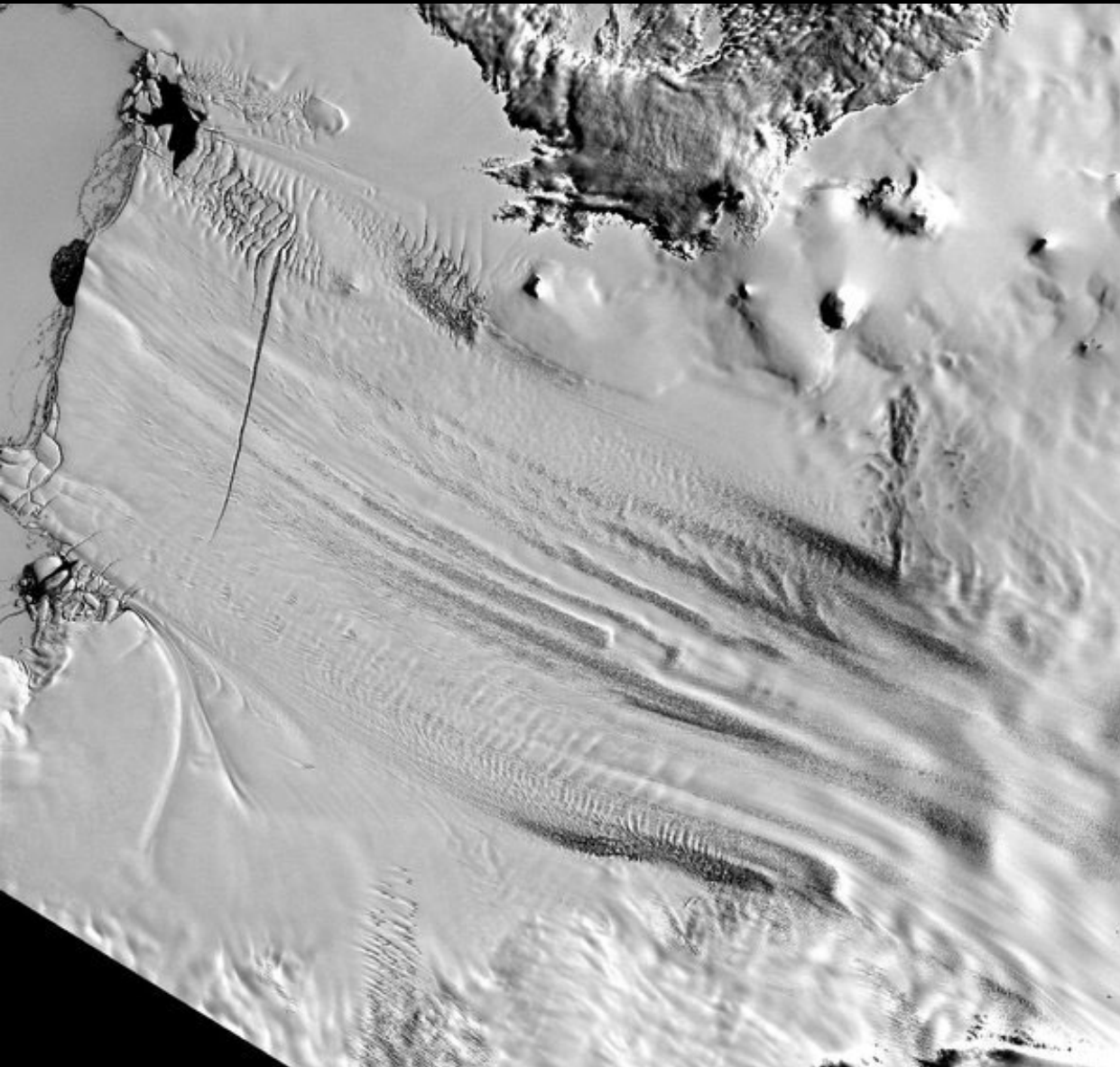
# Antarctic Ice Mass Declining Even Before WAIS Collapse Began in 2014

## Antarctic Ice Mass



**Antarctica: Melt Rate Contribution to sea level rise rate in mm/year. West Antarctic Ice Sheet (WAIS) is deep red, left of the TransAntarctic Range**





**WAIS Pine Island Glacier terminus, lost grounding in 2014. Collapse of WAIS now irreversible. Will cause 10+ ft of global sea level rise over next ~century or so. [This 6min video explains well](#)**

# Why Are the West Antarctic Ice Sheet Glaciers Melting Rapidly?

- Prime reason still calculated to be rising ocean temperatures, according to Dr. Eric Rignot of who showed the ungrounding of the terminus glaciers
- But, there is ongoing geothermal heating as well, since there is a rift zone underneath the WAIS. However, there is no evidence that this heat has taken a sudden rise rate in recent past, and the WAIS has existed for 14-34 million years, even at its current below sea level anchoring.
- [Schroeder et al. 2013](#) finds the geothermal heat flow to be about twice what had previously been estimated.
- Climate denialists are trumpeting this as destroying the credibility of human-caused global warming (not!). Newer work by [Fisher et al. 2015](#) (at UCSC) find this does NOT explain the rapid WAIS melting, and that the WAIS developed with this geothermal heating already in place. No evidence of recent increase in geothermal, but much evidence of rapid recent rise in climate-induced ocean temps surrounding Antarctica.

# New in 2017: West Antarctic Collapse Much Faster than Old Climate Models

- Glaciologists had puzzled over why their climate models failed to hind-cast the high sea level rise during the Pliocene, at temperatures very similar to today.
- The new work on West Antarctica, and the discovery by Richard Alley that marine-terminating glaciers cannot support cliffs higher than 300 ft without collapse, resolve this.
- They now predict that West Antarctic collapse will happen over decades, not centuries, and predict 6 ft of global sea level rise (more, in the U.S.) by 2100 on our current path (for the layman, [here](#))

# New in 2019 – Future Coastal Damage Badly Under-estimated

- **Kulp and Strauss (2019)** show that the satellite data for coastal elevations have not been properly corrected for buildings and vegetation projecting above ground level, by an global average of 1.9m.
- Thus, even at the understated sea level rise projections of the IPCC, the flooding to come will drown far more cities
- Over 200 million additional people, cities, newly found to be underwater by 2050.



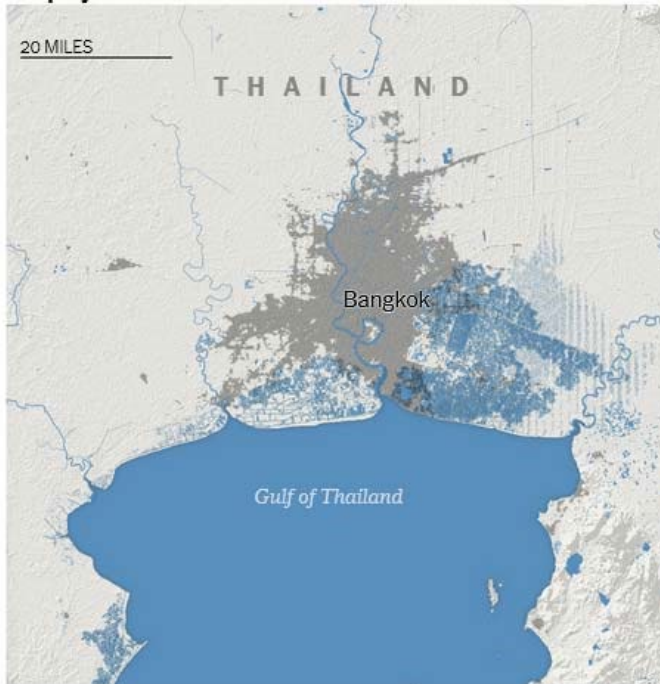
**This remarkable change is from a re-analysis and correction to flawed coastal elevations data, not from higher sea level rise from climate change.**

- If sea level rise is worse, from more severe climate change, that will add on top of this new and very large additional damage

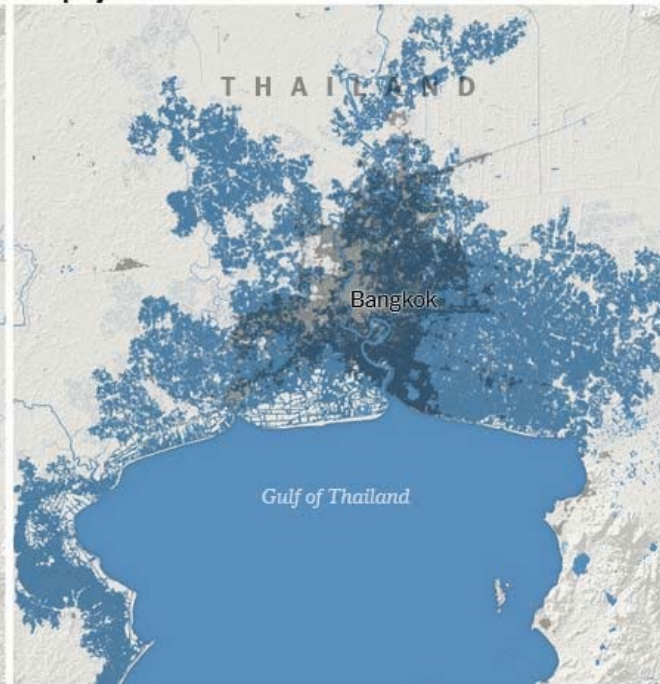
# 2050 Thailand will have 10x more people underwater than previously thought, for the same climate scenario

■ Land underwater at high tide ■ Populated area

Old projection for 2050



New projection for 2050

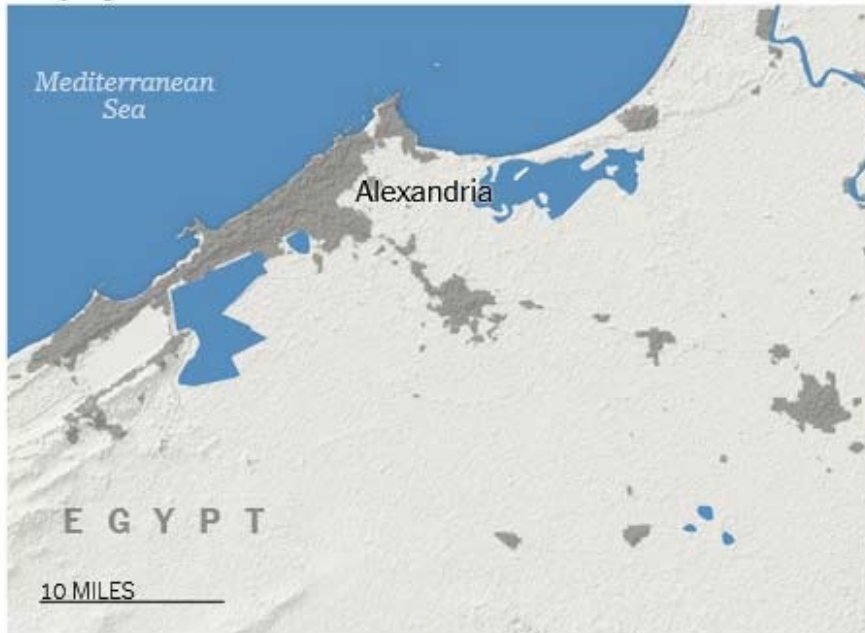


Standard elevation measurements using satellites struggle to differentiate the true ground level from the tops of trees or buildings, said Scott A. Kulp, a researcher at Climate Central

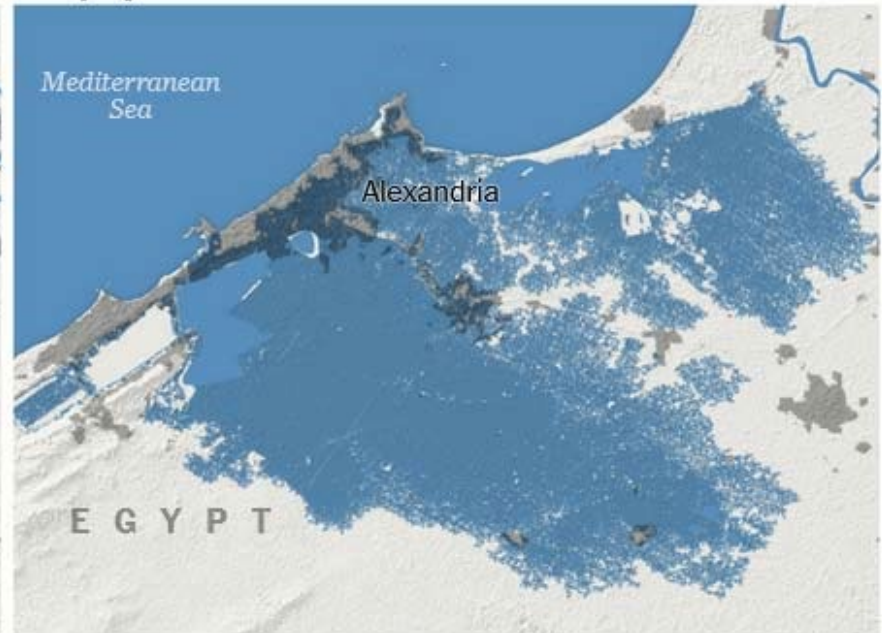
# Alexandria, Egypt Disappears

■ Land underwater at high tide ■ Populated area

**Old projection for 2050**



**New projection for 2050**



The disappearance of cultural heritage could bring its own kind of devastation. Alexandria, Egypt, founded by Alexander the Great around 330 B.C., could be lost to rising waters.

# Same for Mumbai, India's financial center and largest city

Old projection for 2050



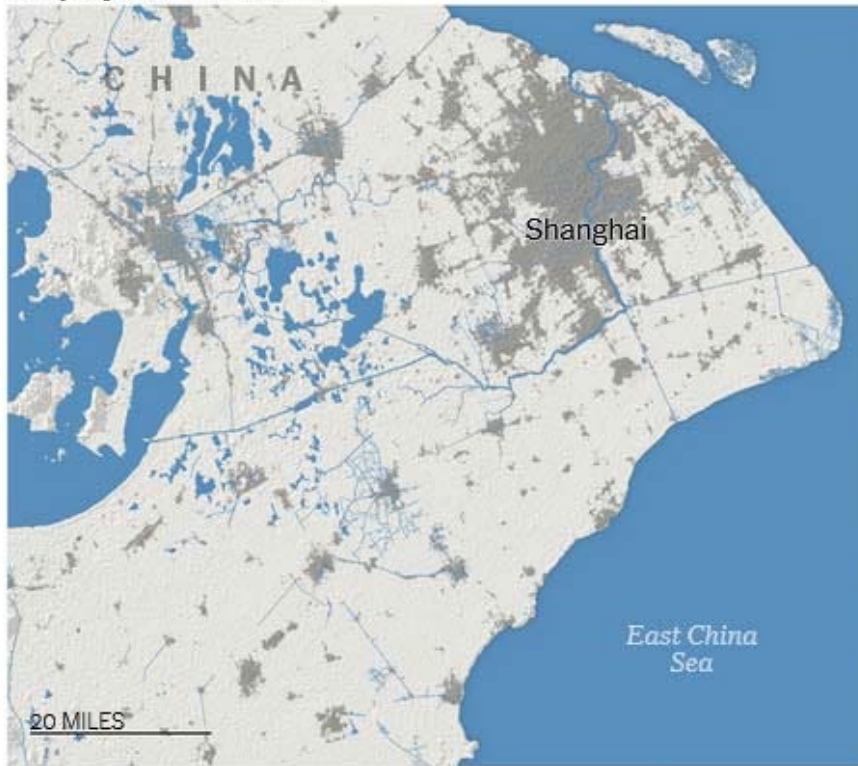
New projection for 2050



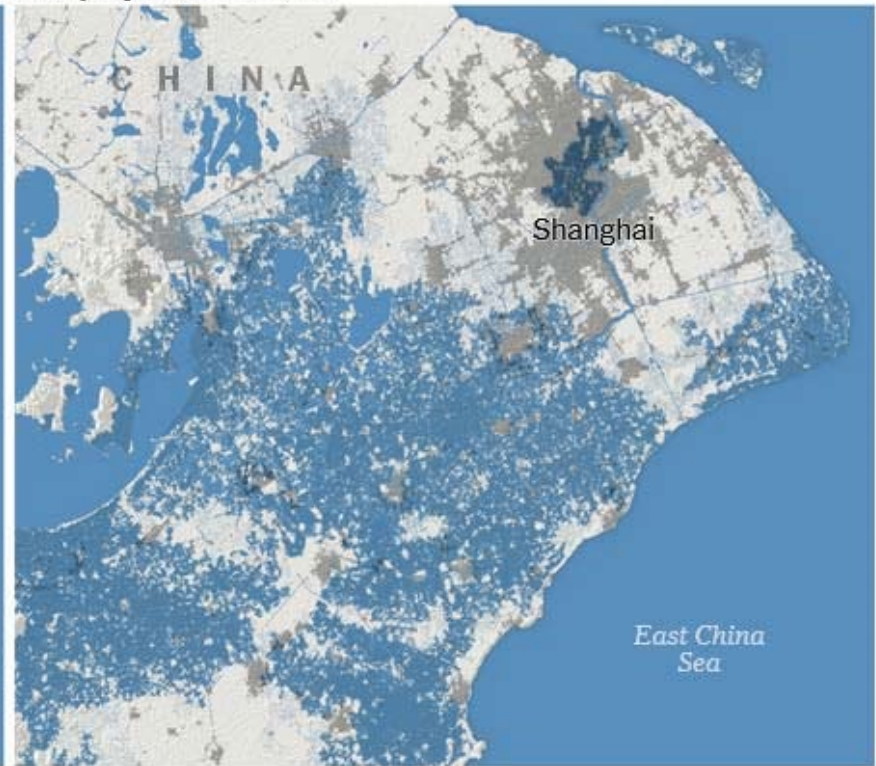
# The Heart of Shanghai, underwater by 2050

■ Land underwater at high tide ■ Populated area

Old projection for 2050



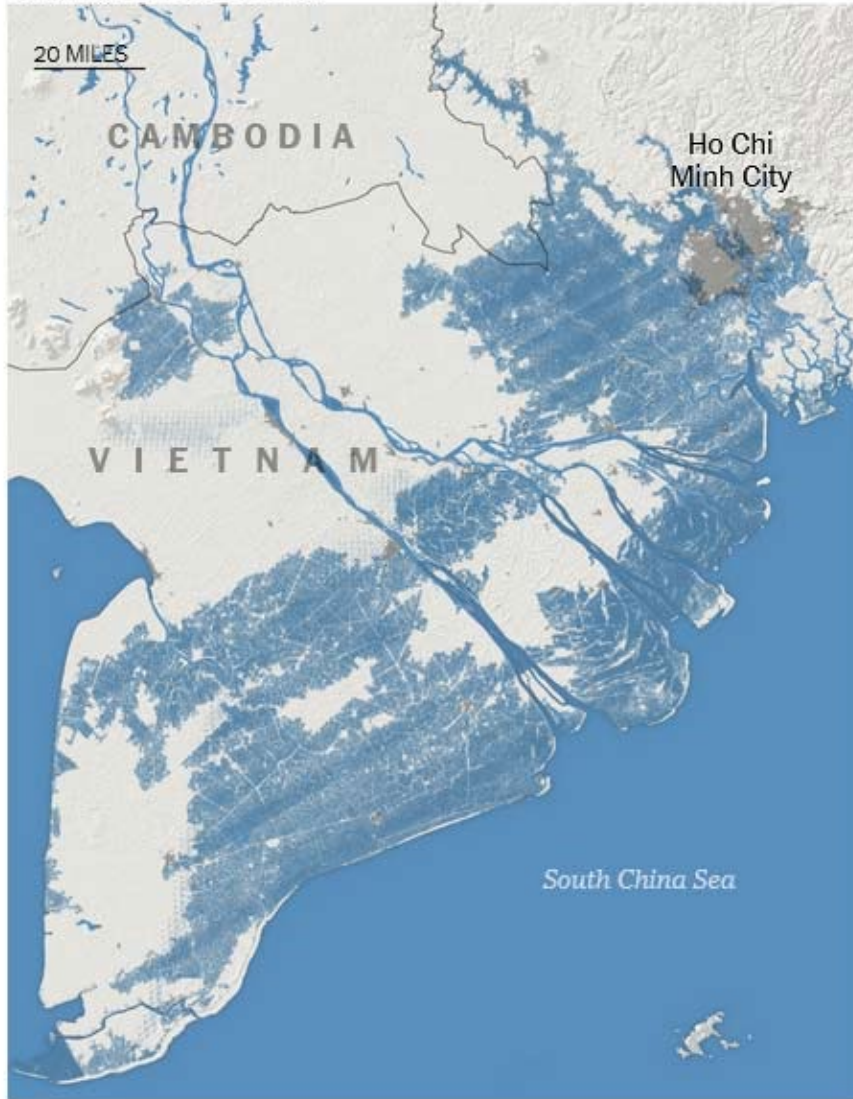
New projection for 2050



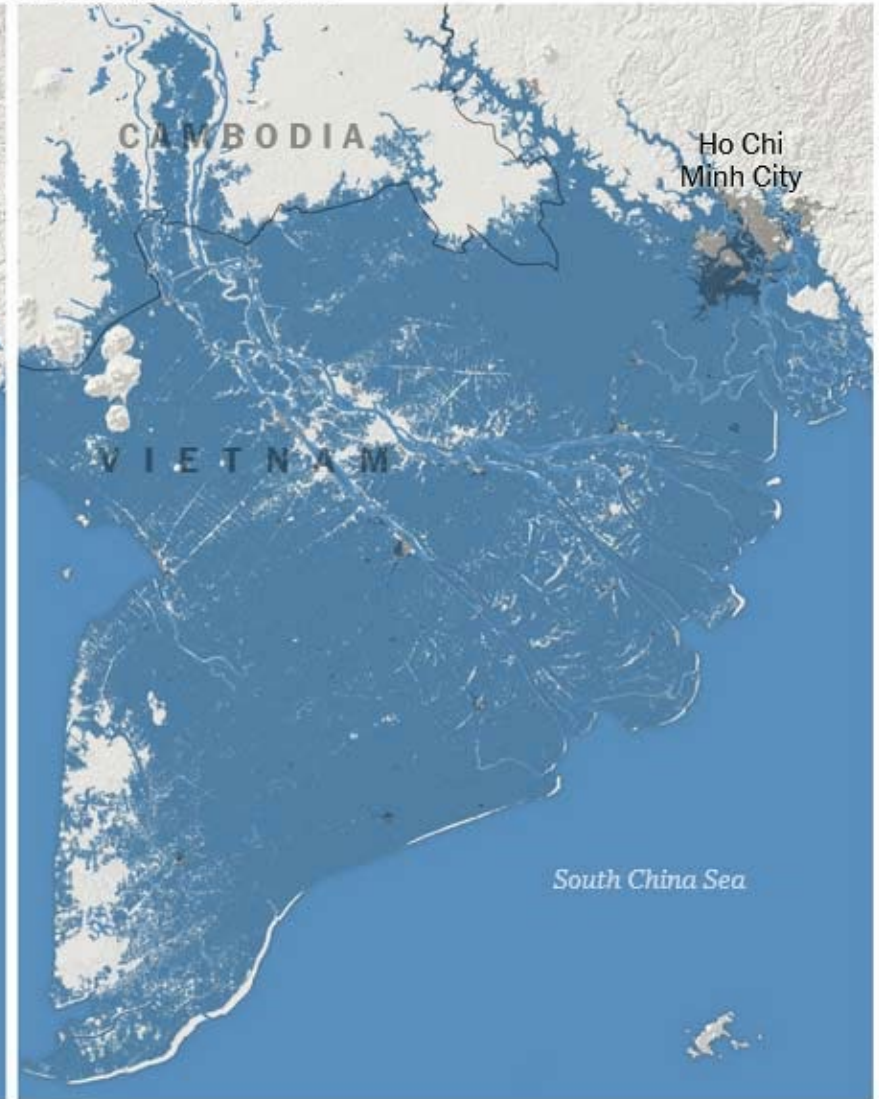
In Shanghai, one of Asia's most important economic engines, water threatens to consume the heart of the city and many other cities around it.

# South Vietnam – Mostly Underwater

Old projection for 2050



New projection for 2050



Southern Vietnam could all but disappear.

# What's Ahead...

- *“At the 4-degree end of the range, we would see not only ‘the destruction of the world’s coral reefs, massive loss of animal species, and catastrophic extreme weather events,’ (Prof. Michael) Mann said, but also ‘meters of sea-level rise that would challenge our capacity for adaptation. It would mean the end of human civilization in its current form.’”*
- A +4C world is not the far tail of apocalyptic possibilities, it's quite well inside the bulk of scenario possibilities, especially with ECS at 4-5C

# Key Points: Current Climate Change – Sea Level

- 20<sup>th</sup> century average sea level rise rate: 1.7mm/year
- Past 20 years avg rate: 3.3 mm/year and rising fast
- Half of sea level rise so far has been due to thermal expansion of existing ocean water
- Most sea level rise in the future will be due to melting continental ice  
Melting icebergs and other floating ice do NOT contribute to sea level rise, by Archimedes Principle
- Glacier terminus in shallow coast ocean can be anchored by the “grounding line”, slowing glacier flow, but thinning ice via warmer water can unground the terminus; free-floating glaciers slide into sea
- West Antarctic Ice Sheet now (2014) has begun irreversible collapse, will alone cause ~12+ ft of sea level rise over next century or so.
- A still minor contribution is geothermal heat from a spreading zone beneath WAIS, ~twice what was earlier thought, but not increasing.
- New measurements of global coastal elevations show, even for a given climate sea level rise, far more land is endangered (2019)