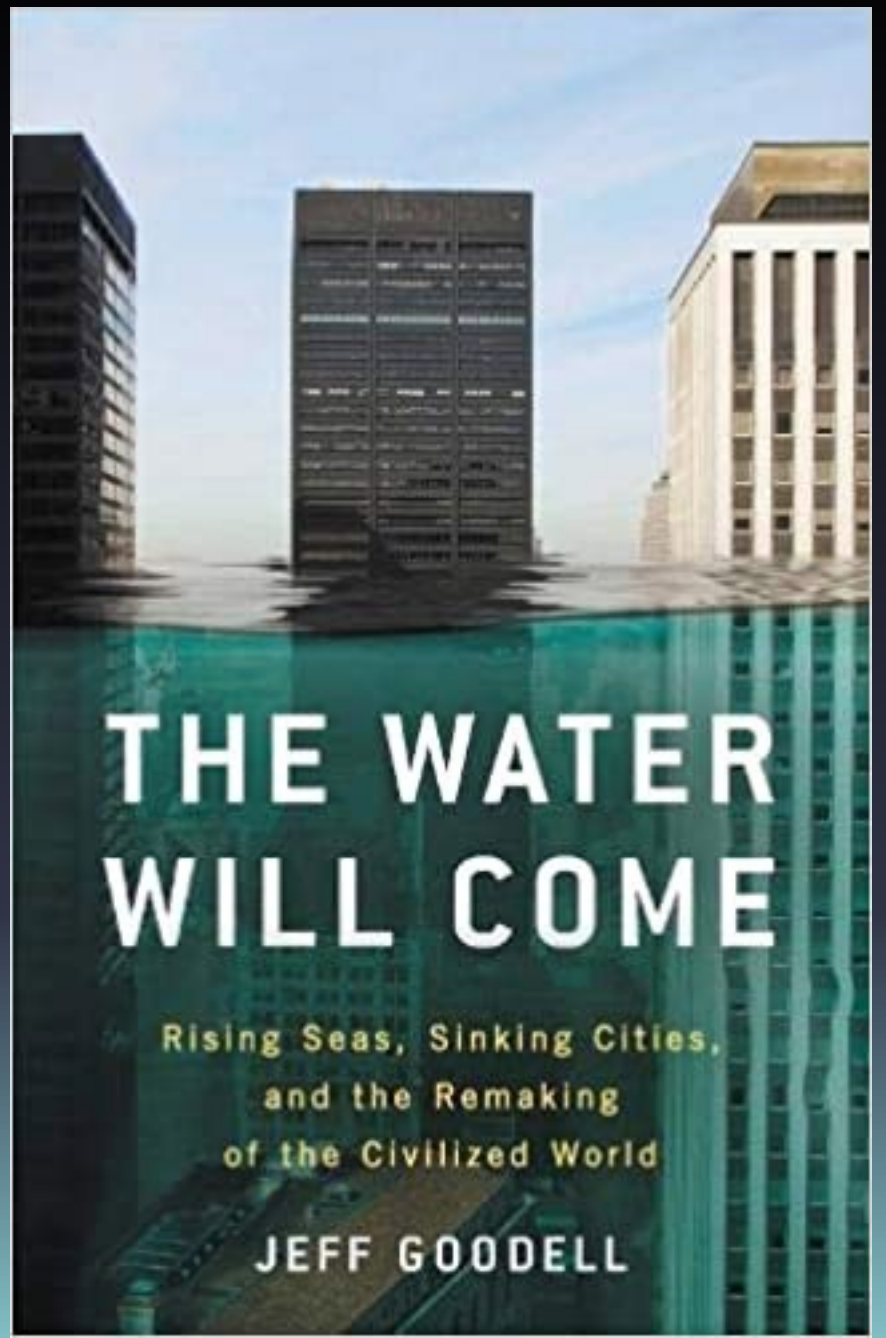
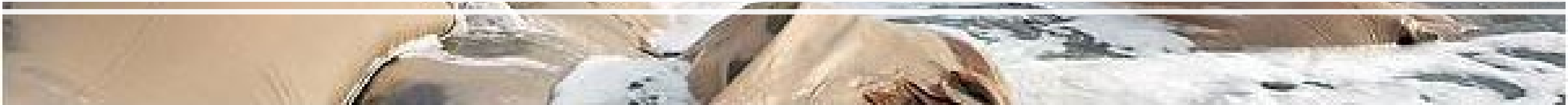
Sea-level rise

Dr. Andrea Dutton, University of Wisconsin-Madison

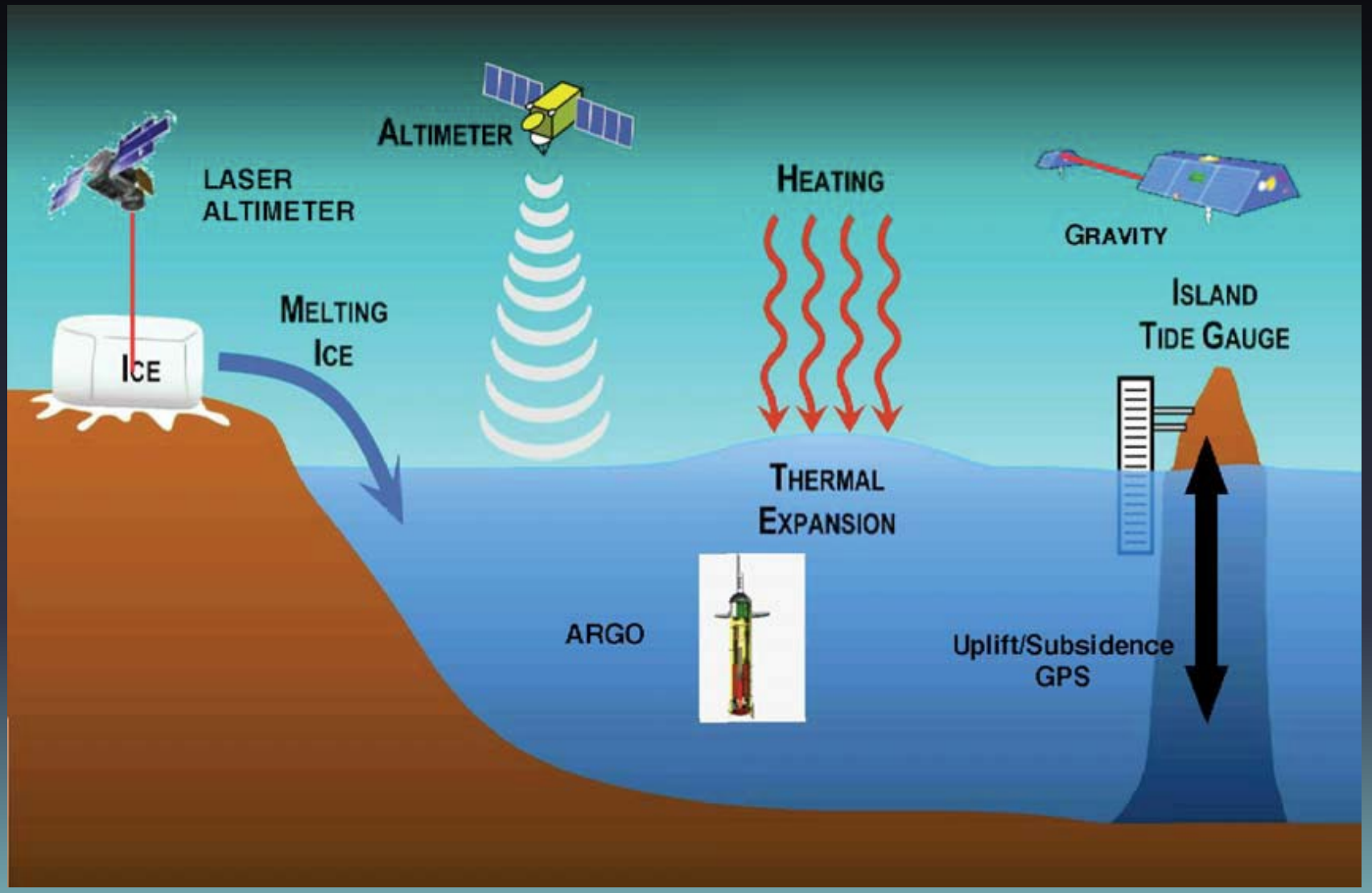
dutton3@wisc.edu, @DrAndreaDutton)



This is a more realistic representation of how SLR will manifest in the future

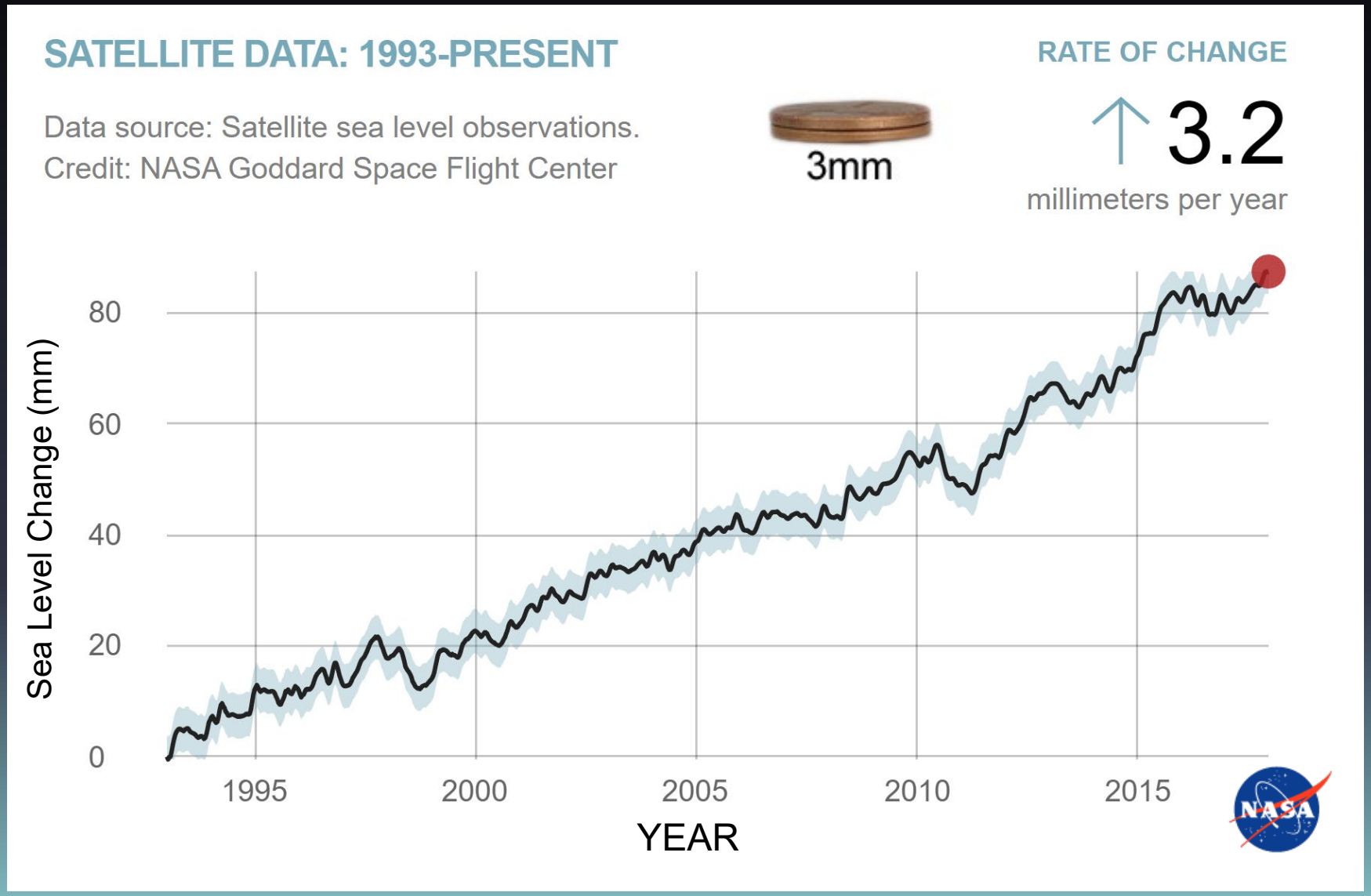


What is sea level? How do we measure it?



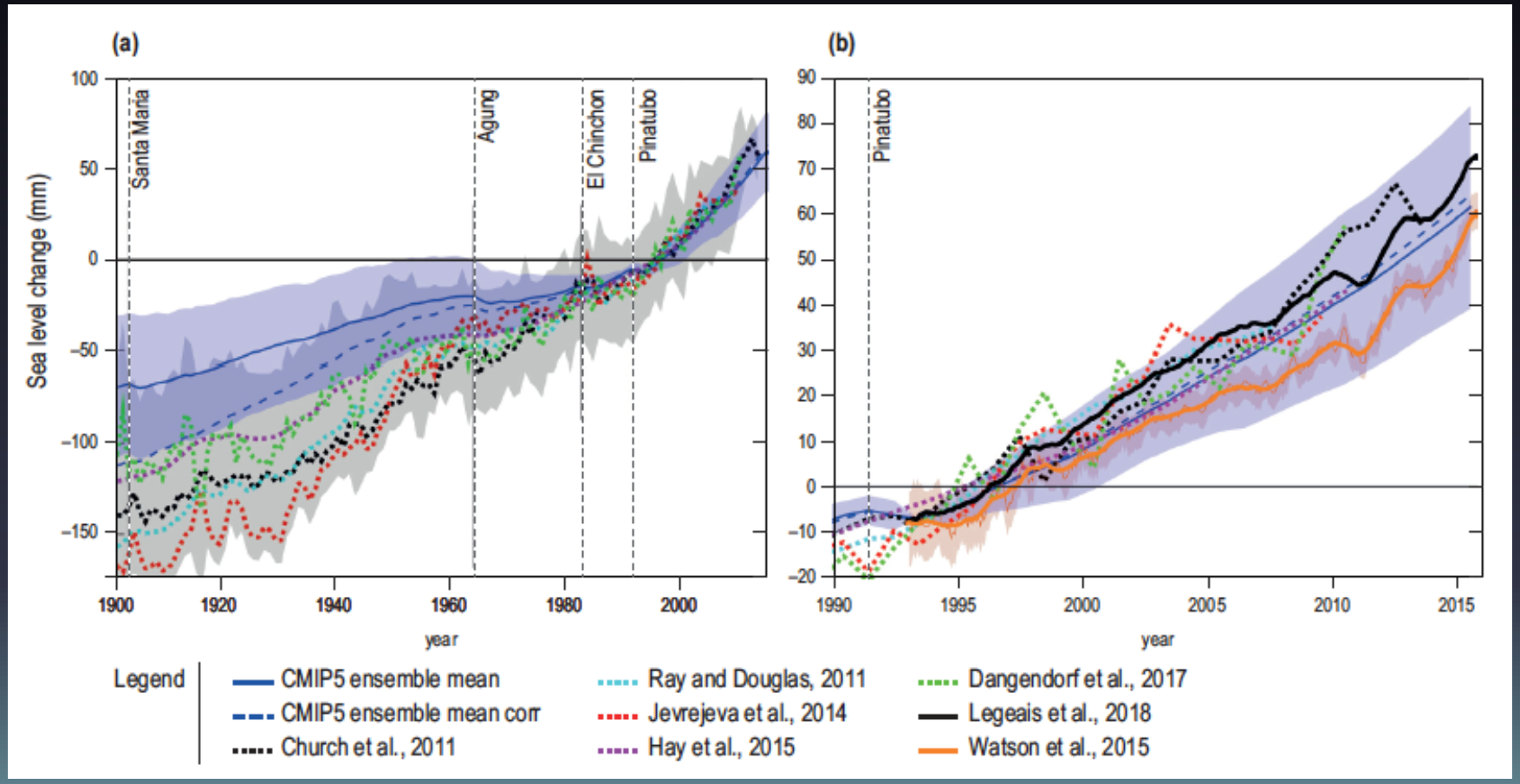
The satellite record

SLR is accelerating; at fastest rate in last 2700 yrs



Sea level is rising:

average of **1-2 mm per year** for the 20th century
and **3.7 mm per year (2006-2018)**



SROCC, 2019

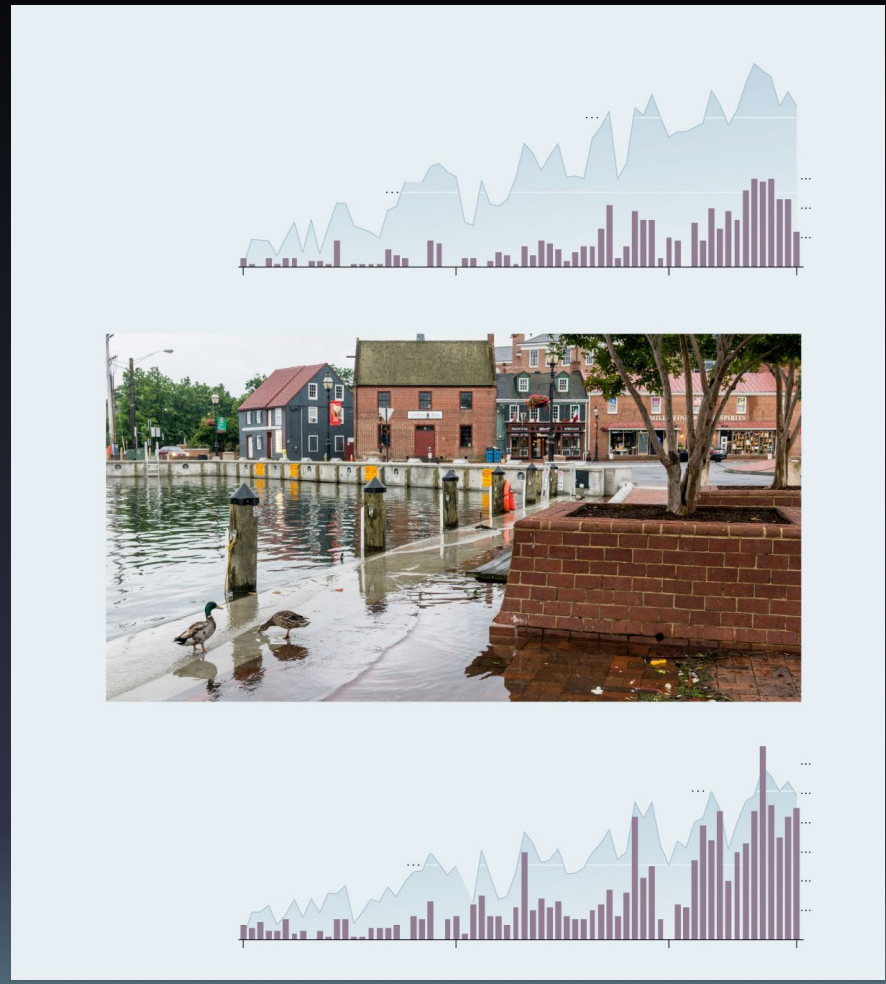
Take home message: Sea level rise is accelerating

Flooding of Coast, Caused by Global Warming, Has Already Begun

Scientists' warnings that the rise of the sea would eventually imperil the United States' coastline are no longer theoretical.

By JUSTIN GILLIS SEPT. 3, 2016

The New York Times



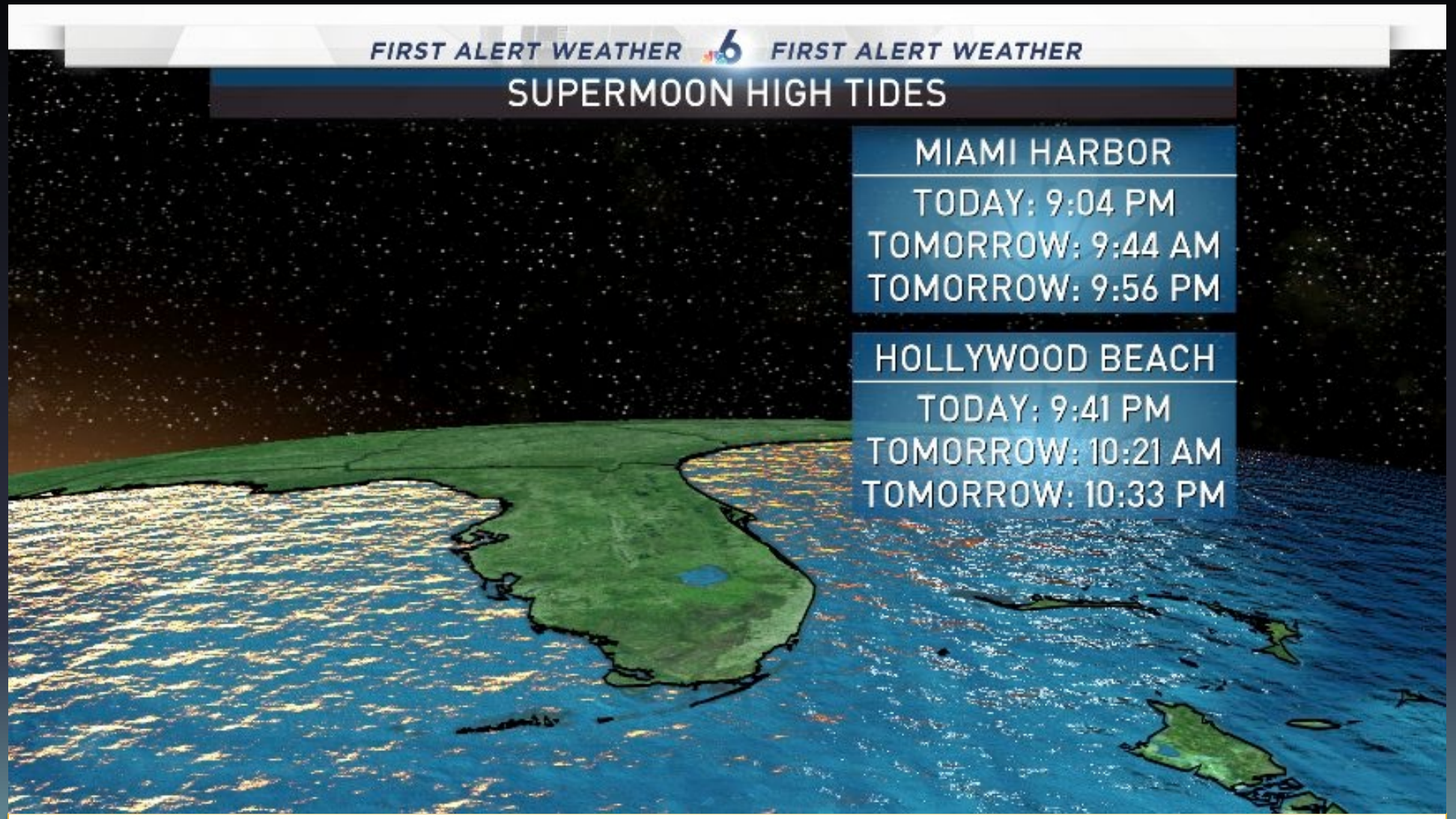
A Sharp Increase In 'Sunny Day' Flooding

By JONATHAN CORUM SEPT. 3, 2016

tides during full moon (perigee)

Ft. Lauderdale Nov-2016:

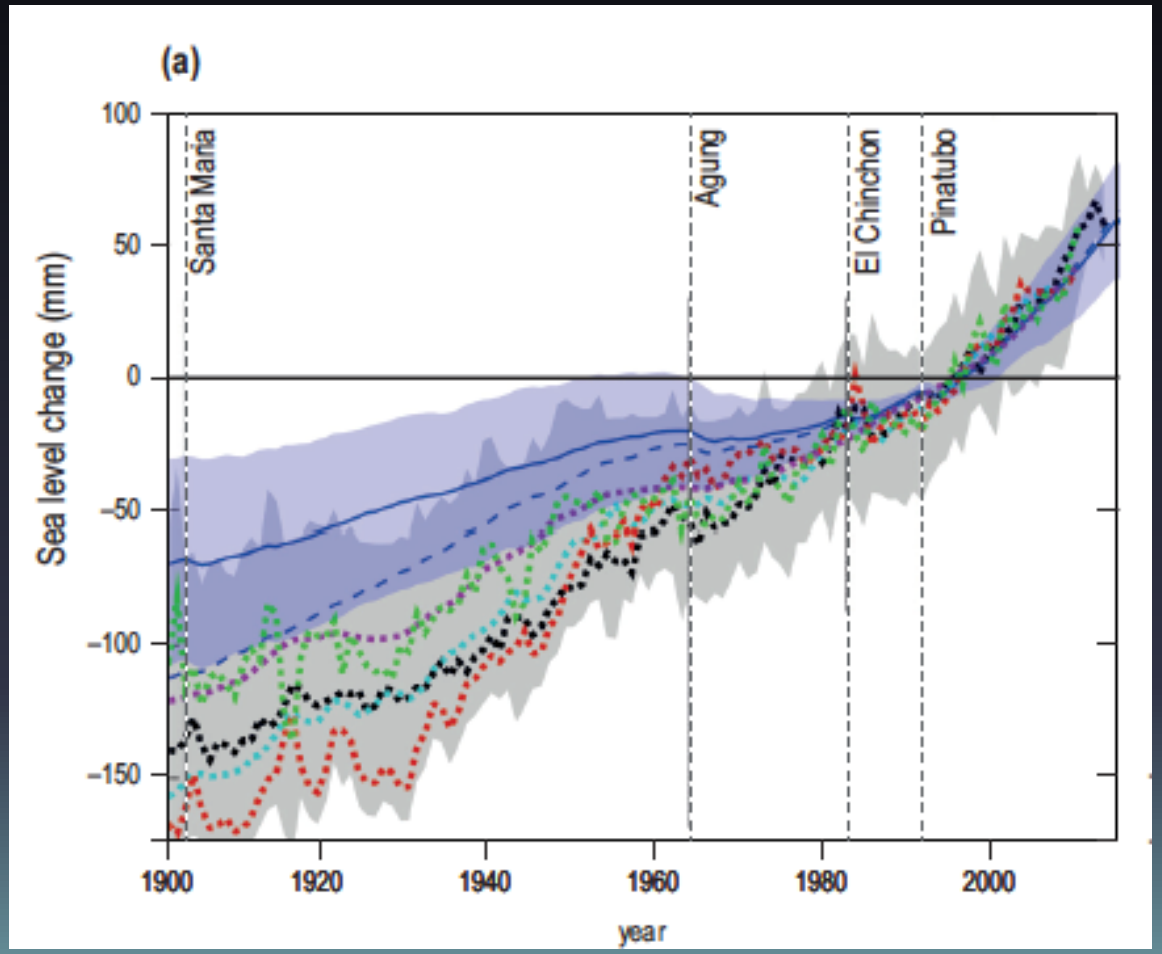
Miami Beach Nov-2016:



John Morales @JohnMoralesNBC6 20h ago

Because you still need to keep track of this until at least tomorrow if you want to save your car or shoes.

What are the components of SLR? Why is sea level rising?



SROCC, 2019

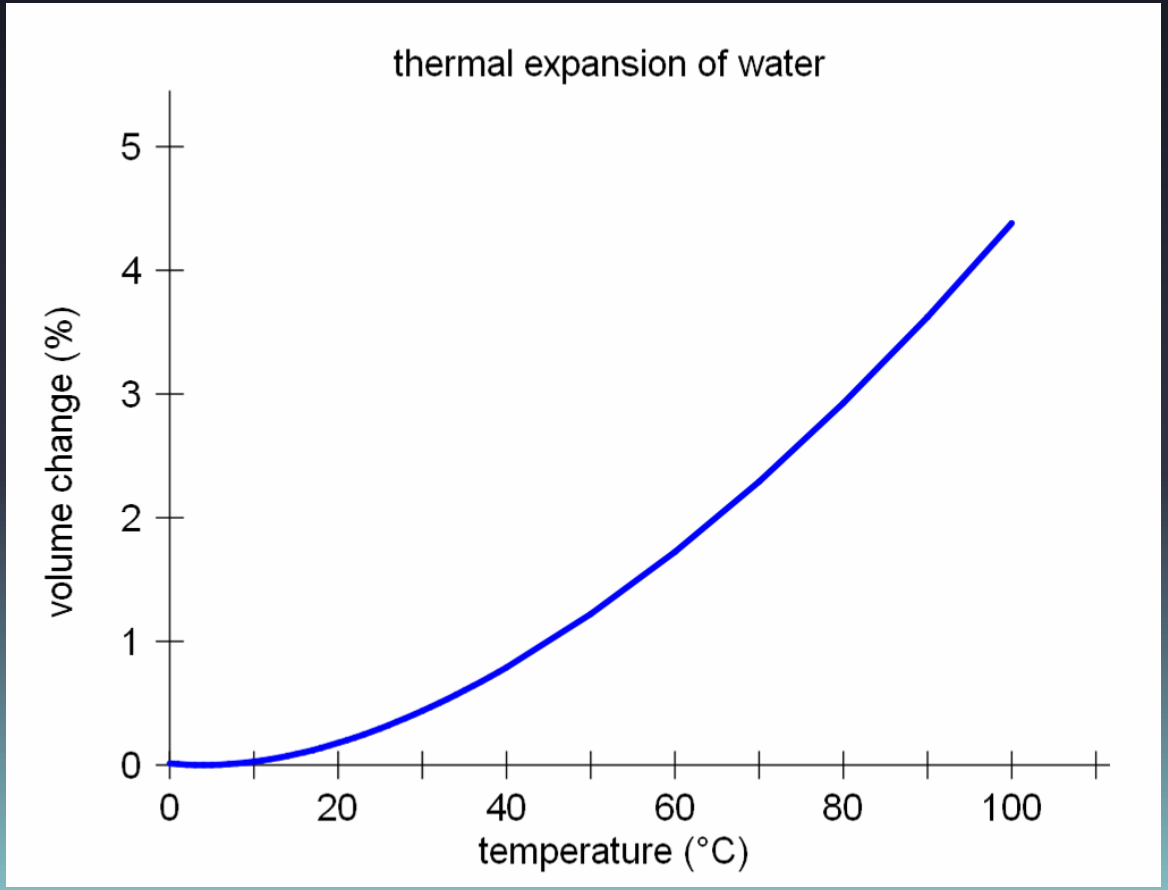
In the last century this signal was dominated by thermal expansion & mountain glaciers

Acceleration is mostly driven by the increasing contribution from polar ice sheets.

Why is global sea level rising today?

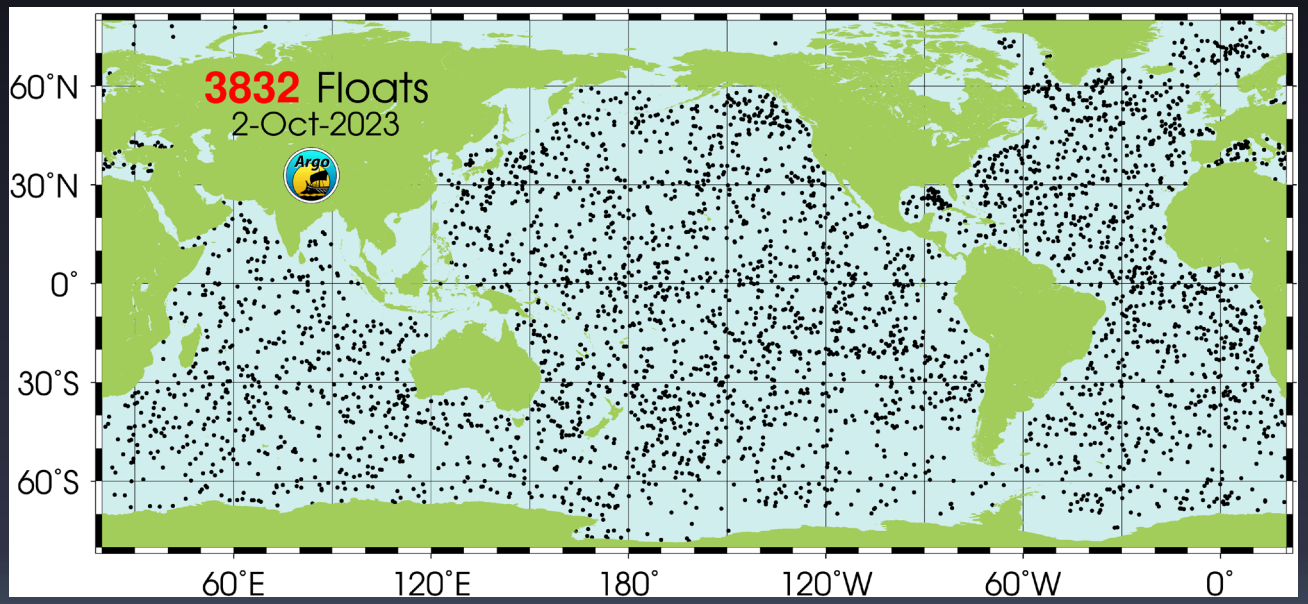
Thermal Expansion

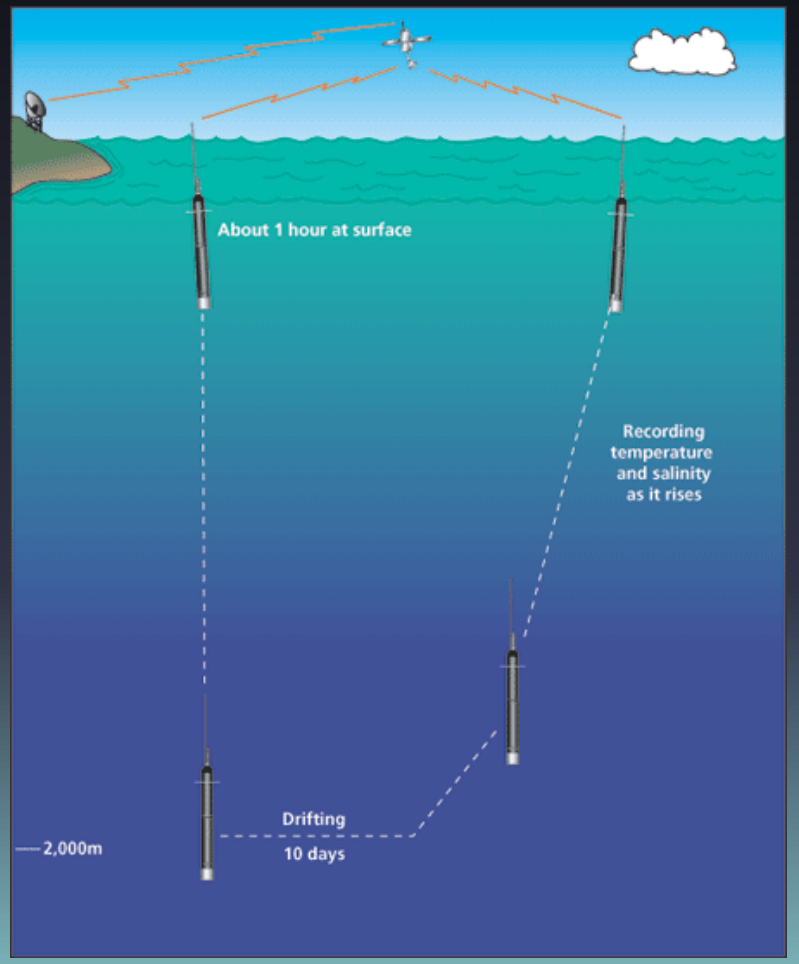
- ocean has gained heat
- Warmer water less dense due to warming of surface ocean

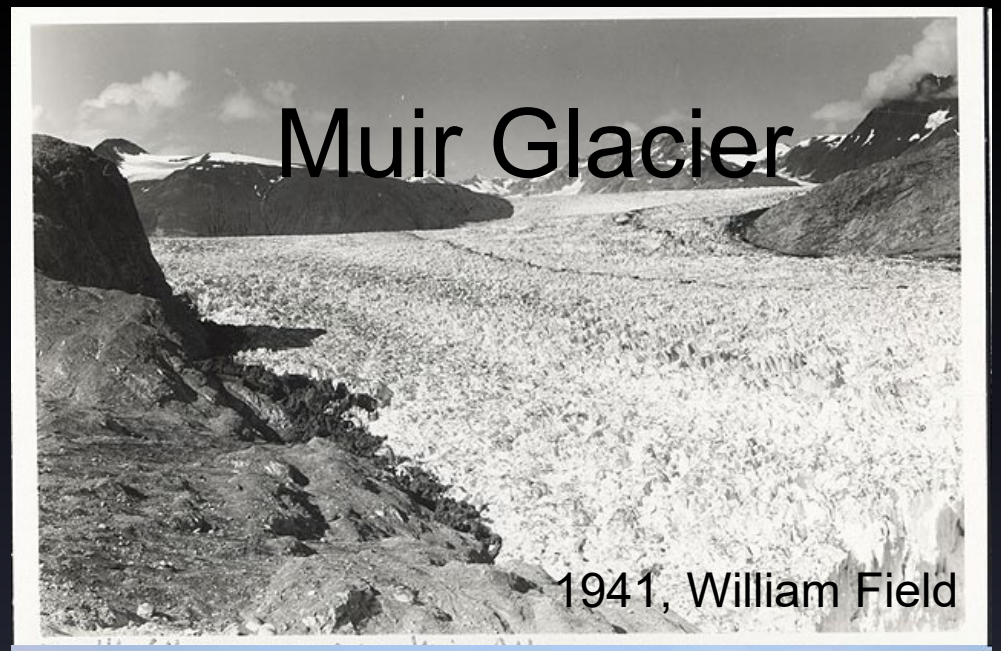


How do we know the surface ocean is warming?

Ocean heat content from ARGO profiling floats (0–700 m layer)







Loss of Land-based ice:

Glacial Retreat

- Most glaciers world-wide are in retreat

& Melting Polar Ice Sheets

(next slide)

From the *Glacier photograph collection*. Boulder, Colorado USA: National Snow and Ice Data Center/World Data Center for Glaciology. *http://nsidc.org/data/glacier_photo/repeat_photography.html*

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

Source: Roger Braithwaite, University of Reading (UK)

Loss of Land-based ice:

Glacial Retreat (last slide)

Retreat of Polar Ice Sheets

- Both Greenland and Antarctic Ice Sheets are melting (losing volume)
- The rate of melting of BOTH polar ice sheets is INCREASING → acceleration of melting
    - Melting land ice adds to ocean volume (melting sea ice does not)

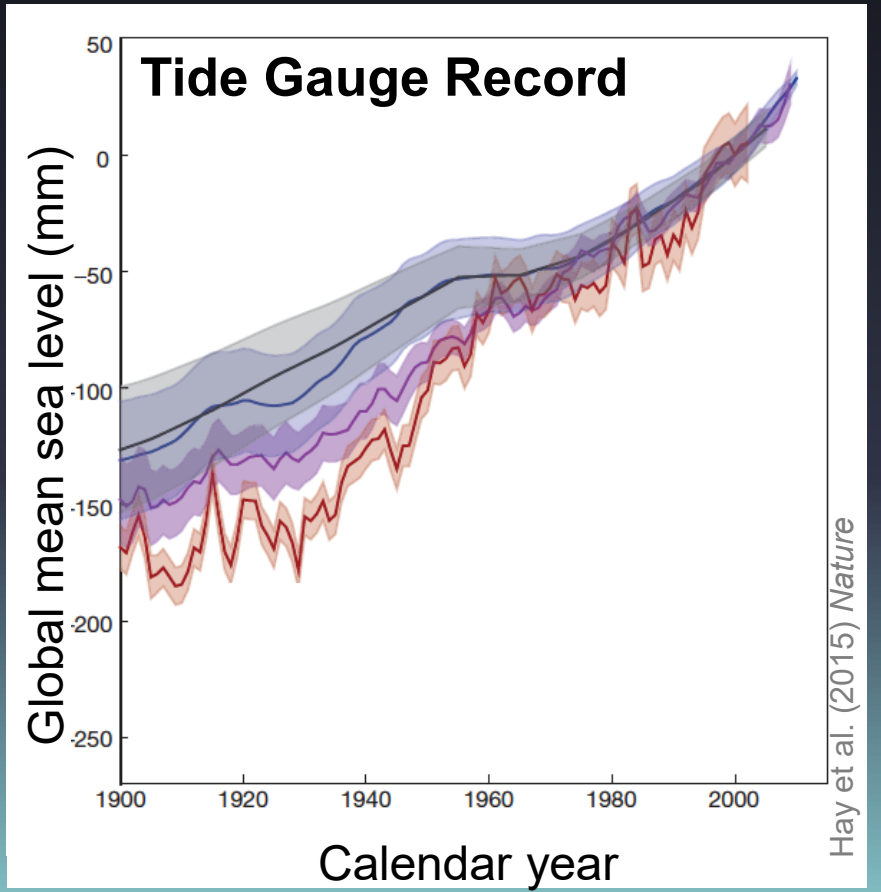
The Rate of Sea Level Rise is accelerating

This finding is not new: AR4, AR5, SROCC, AR6

Since 1900 the rise has accelerated.

Rising at a rate of 3.7 mm/year. (2006-2018), nearly 3x as fast as during 1901-1971

This acceleration is due to an increasing contribution of meltwater from the polar ice sheets (Antarctica & Greenland).

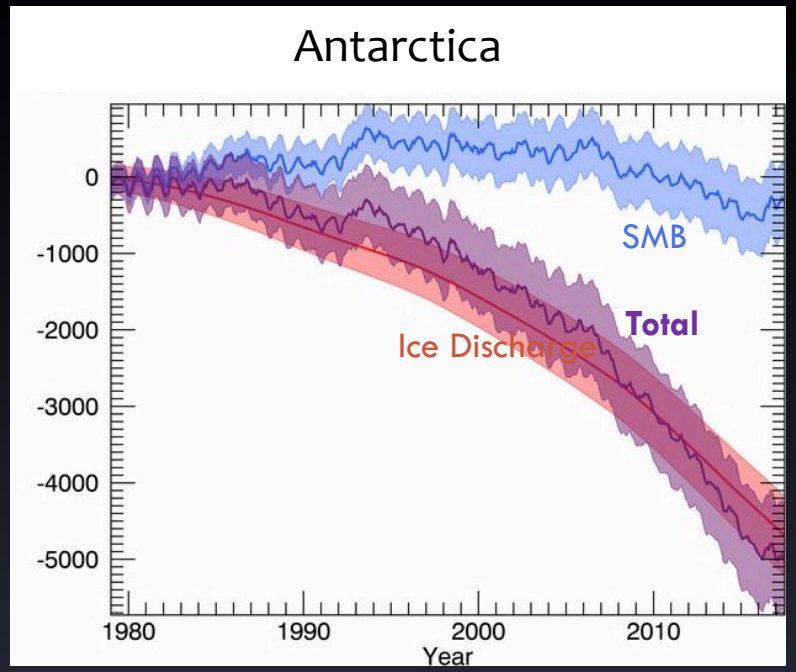


Attribution

New to AR6

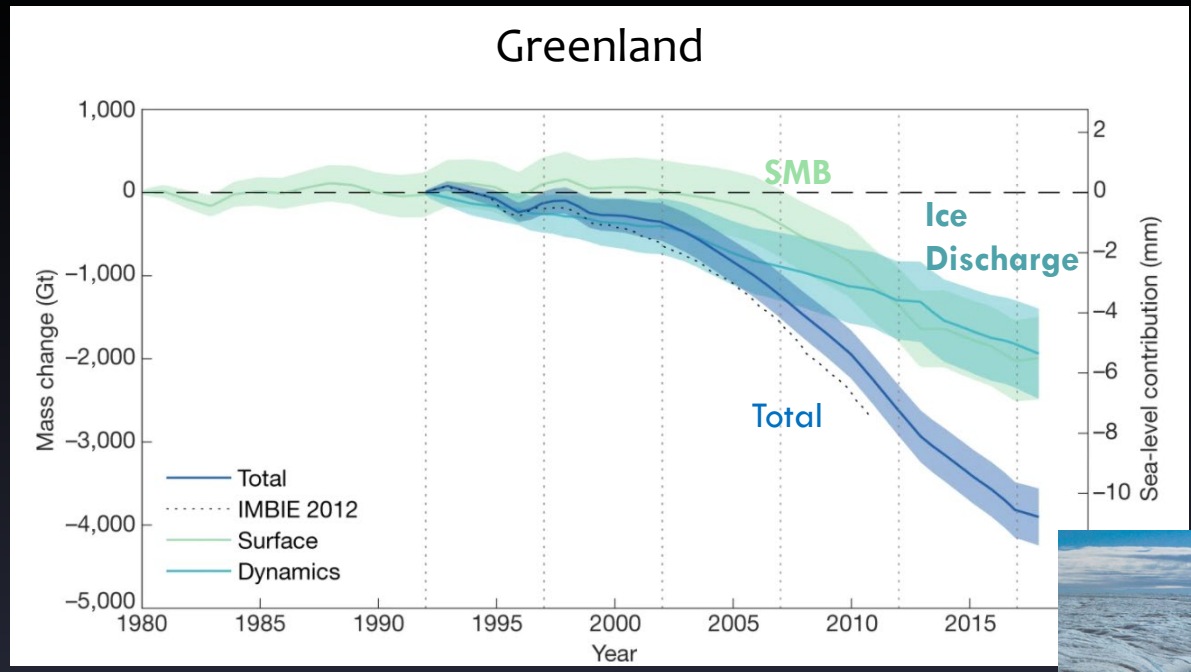
"that the main driver of the observed global mean sea-level rise since at least 1970 is very likely anthropogenic forcing".

Antarctica

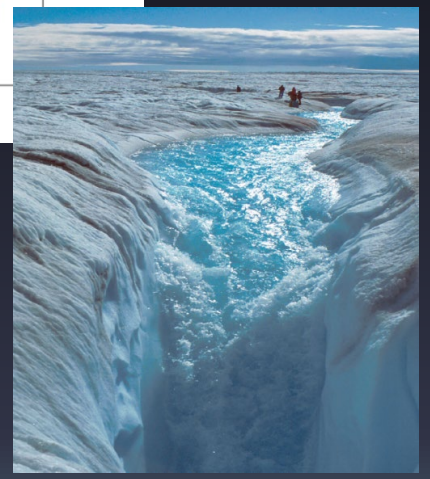


Rignot et al., *PNAS*, 2019

Greenland



The IMBIE team, *Nature*, 2020

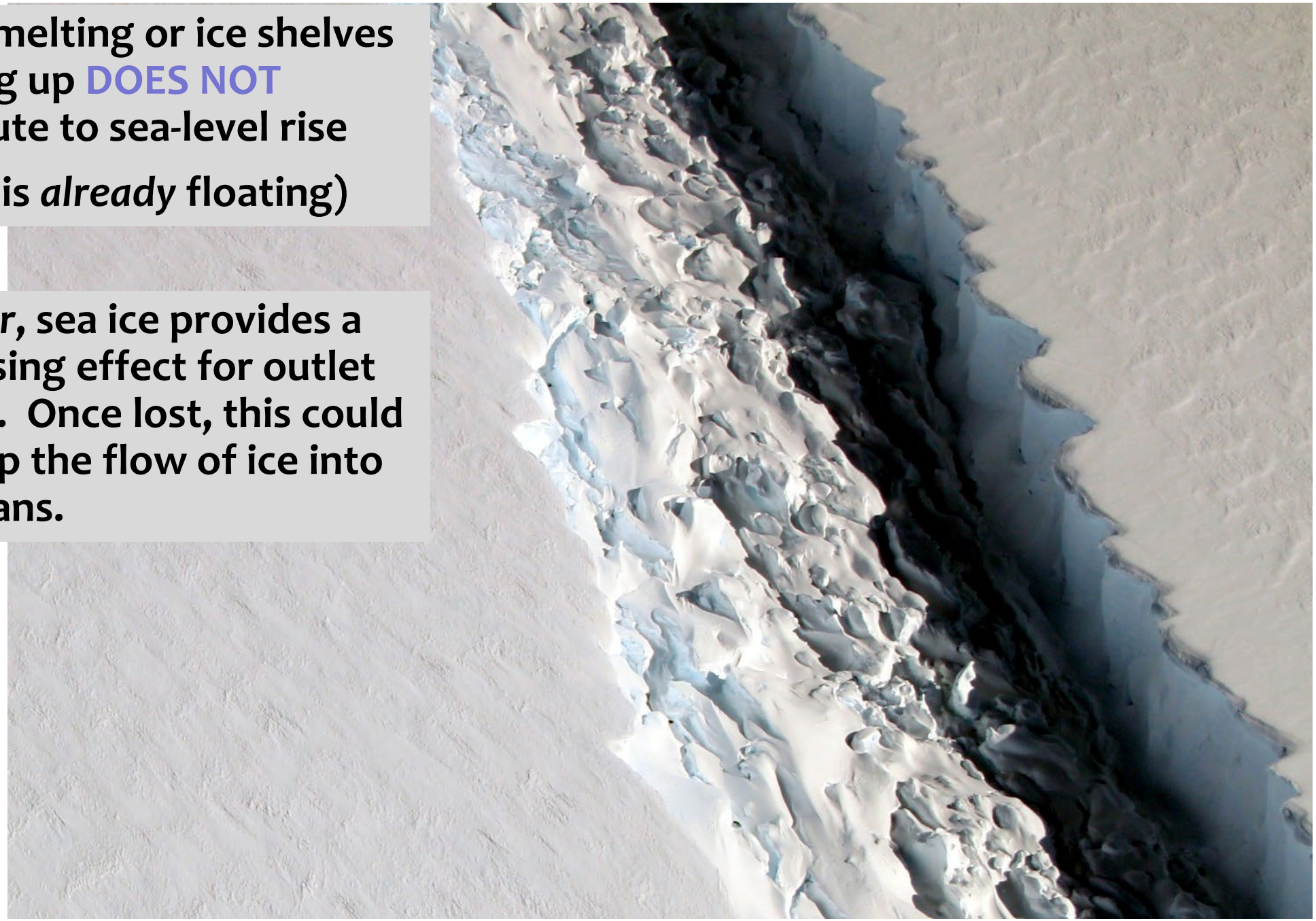


SLR acceleration is largely due to an increasing contribution of meltwater from the polar ice sheets (Antarctica & Greenland).

Sea ice melting or ice shelves breaking up DOES NOT contribute to sea-level rise

(sea ice is *already* floating)

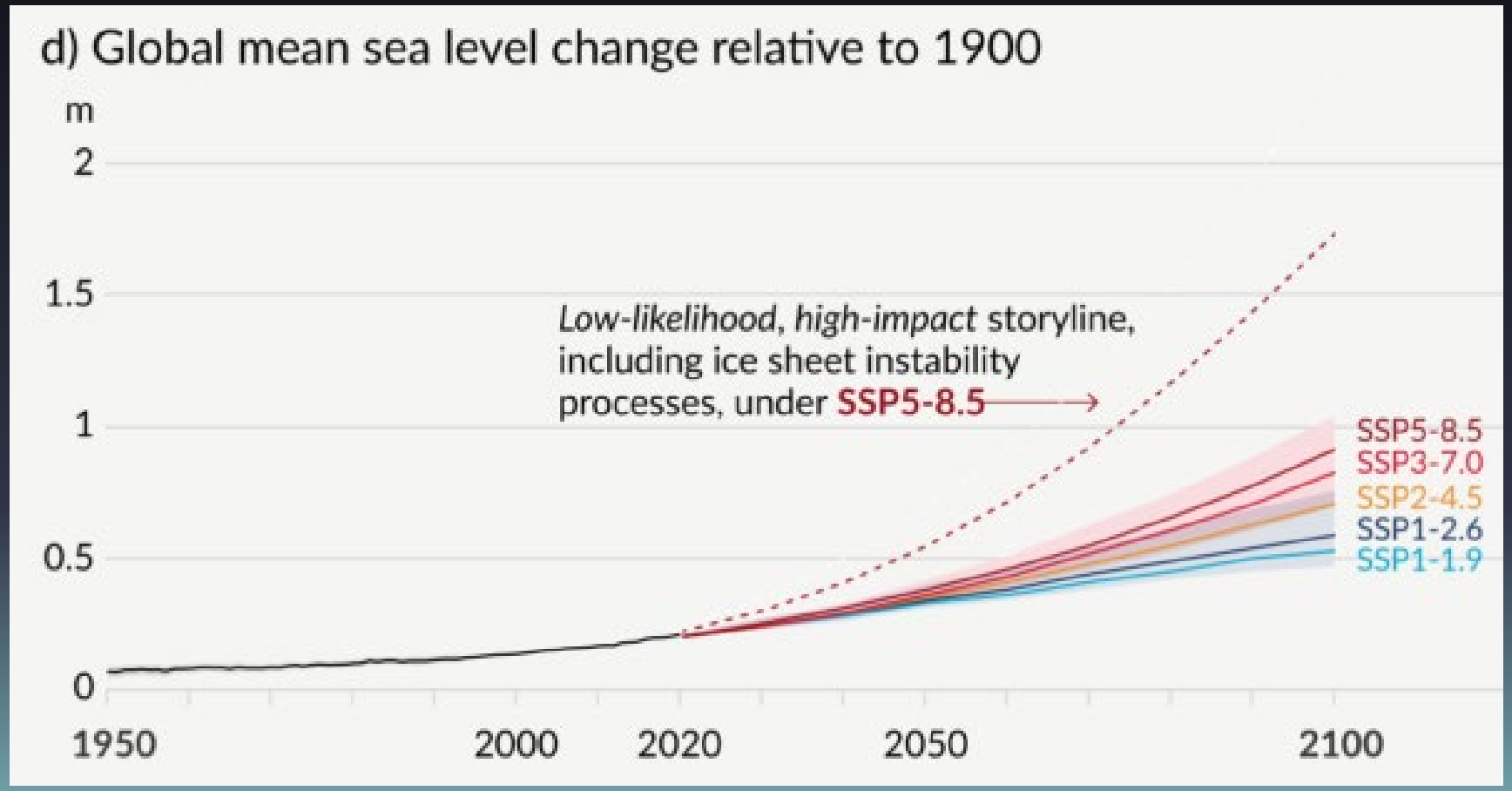
However, sea ice provides a buttressing effect for outlet glaciers. Once lost, this could speed up the flow of ice into the oceans.



The Larsen C rift on Nov. 10. (John Sonntag/NASA)

Sea Level Rise is here to stay

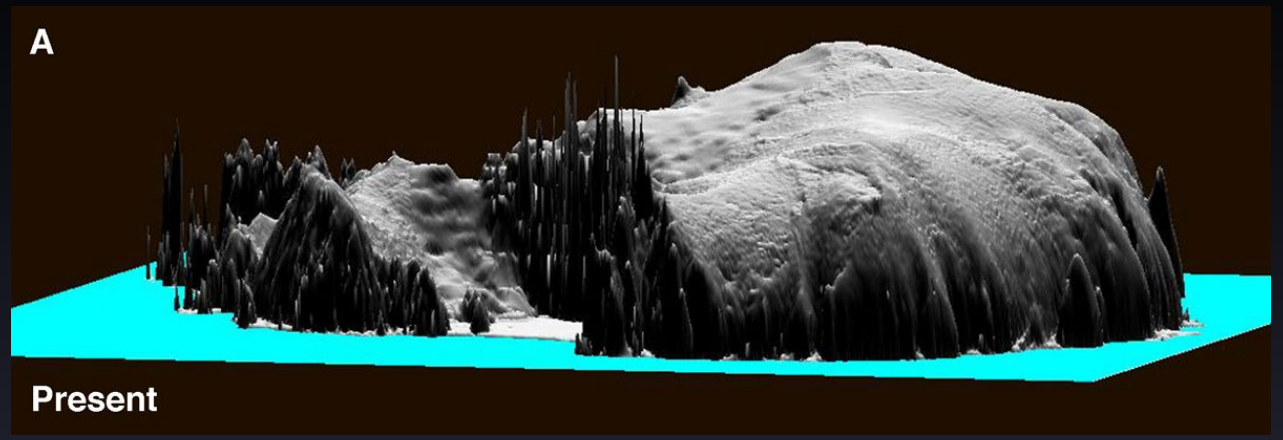
"It is virtually certain that global mean sea level will continue to rise over the 21st century in response to continued warming of the climate system."



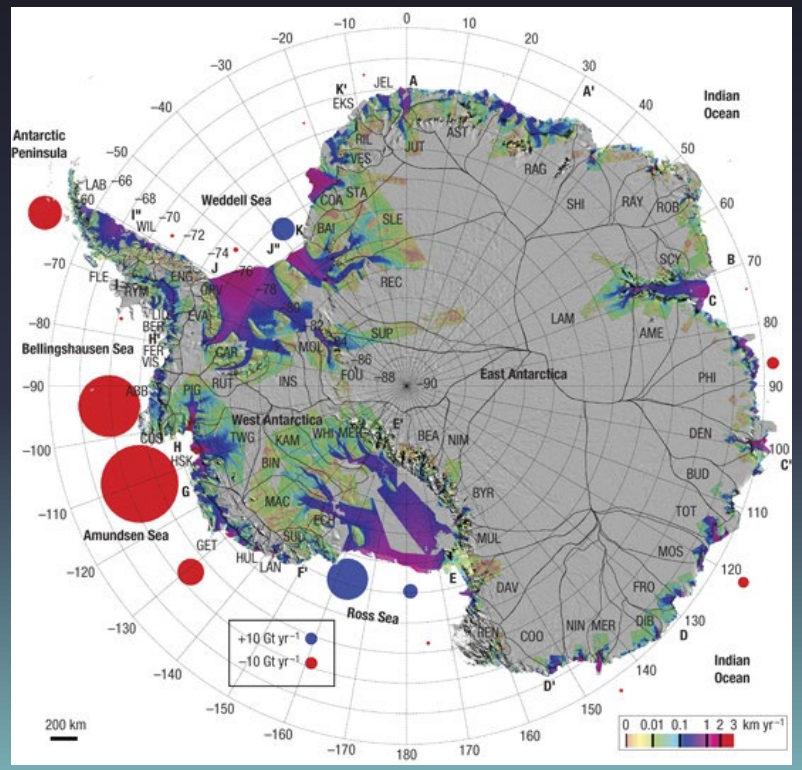
- Mass loss from the polar ice sheets is expected to exceed other contributions to global sea-level rise under future warming.
- We still lack a complete knowledge of the physics involved with the dynamic retreat of ice sheets.

Source: IPCC AR6, Figure SPM.8

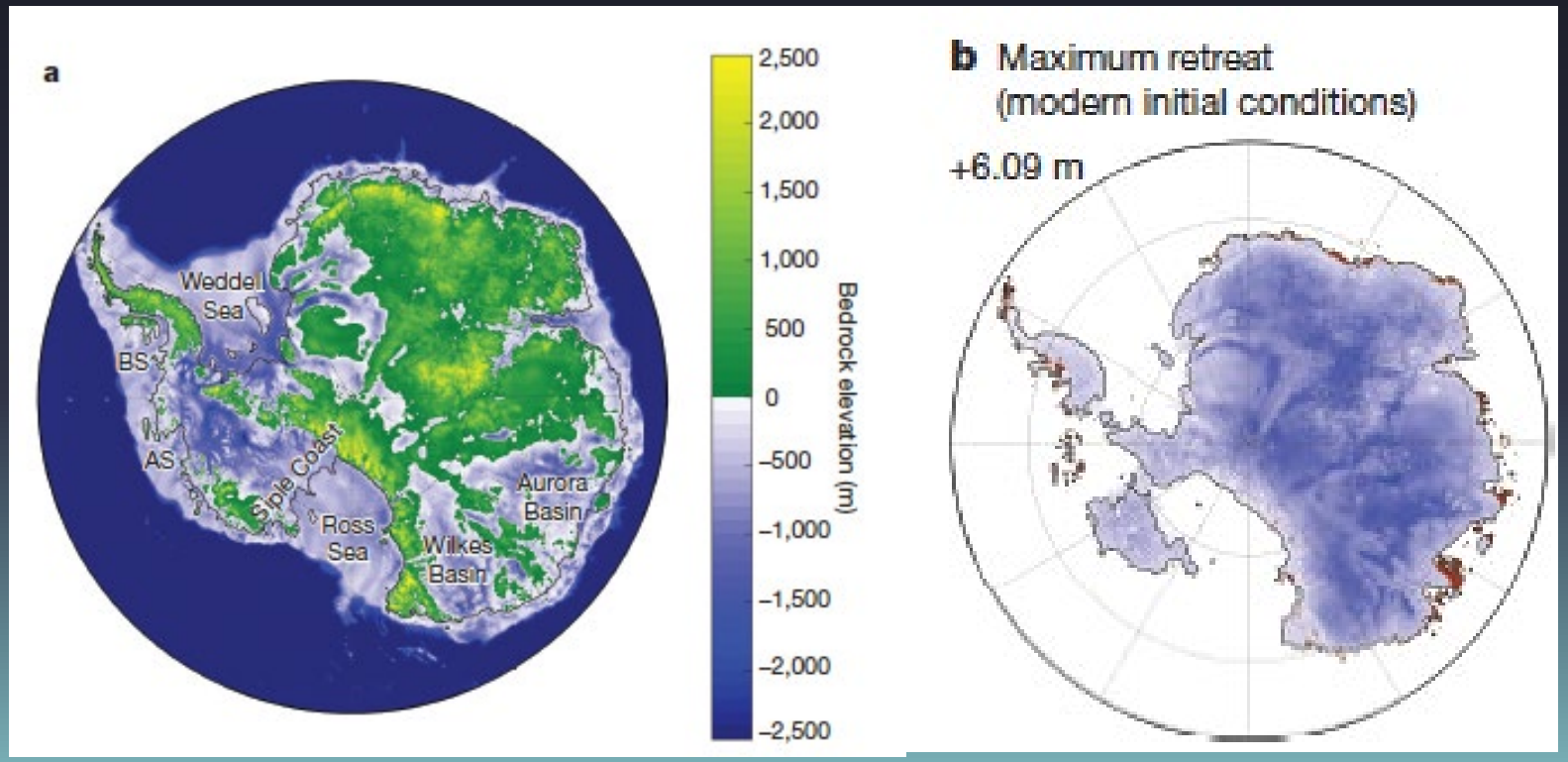
Vulnerability of the West Antarctic Ice Sheet (WAIS)



Bindschadler, *Science*, 1998

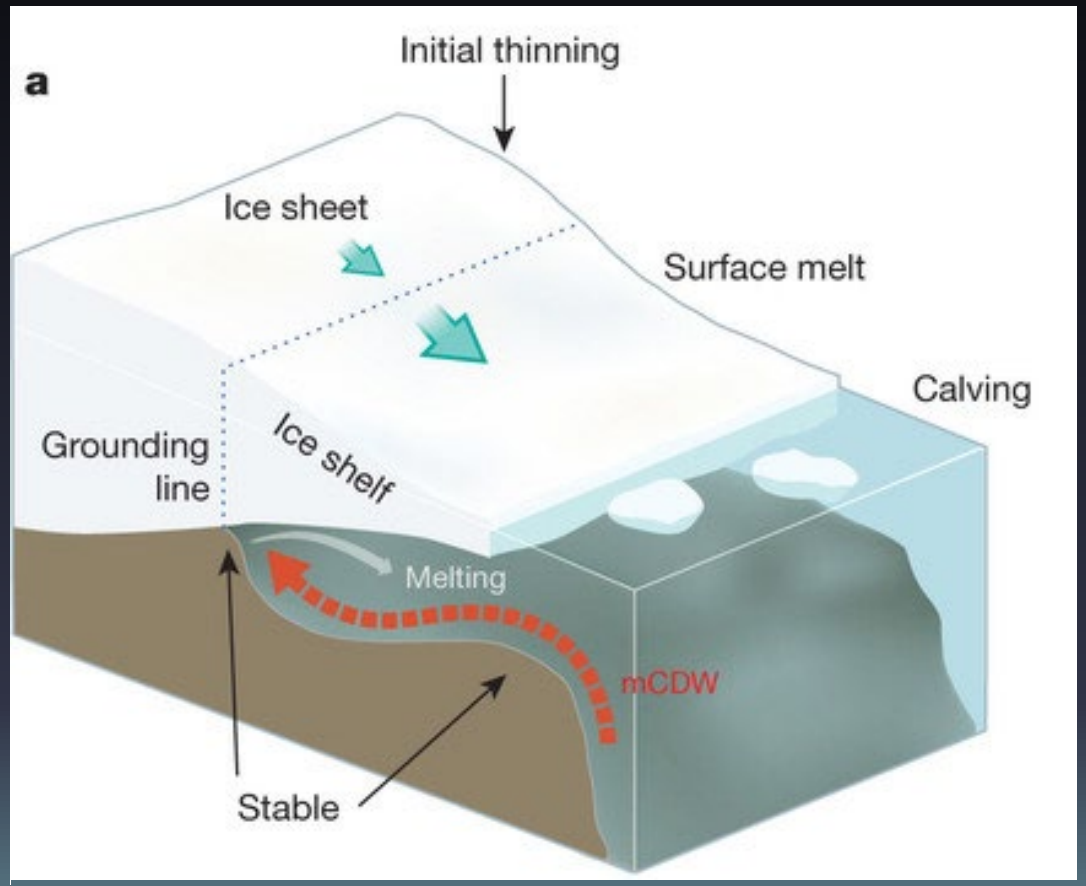


Rignot et al. (2008) *Nature Geoscience*



DeConto & Pollard (2016) *Nature*

What is the tipping point for the Antarctic ice sheet?

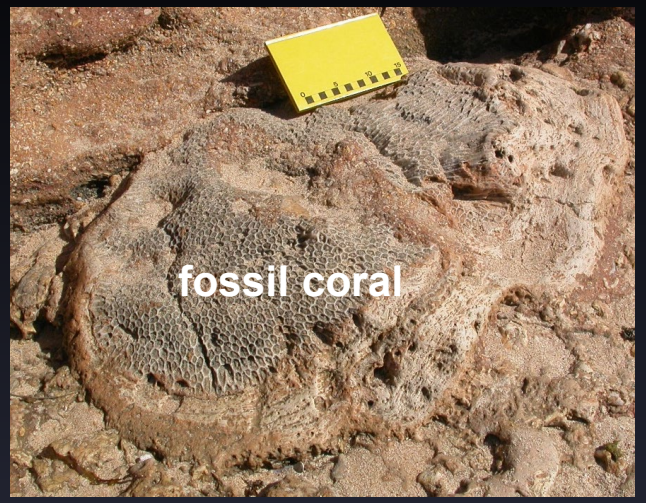


Hanna et al. (2013) *Nature*

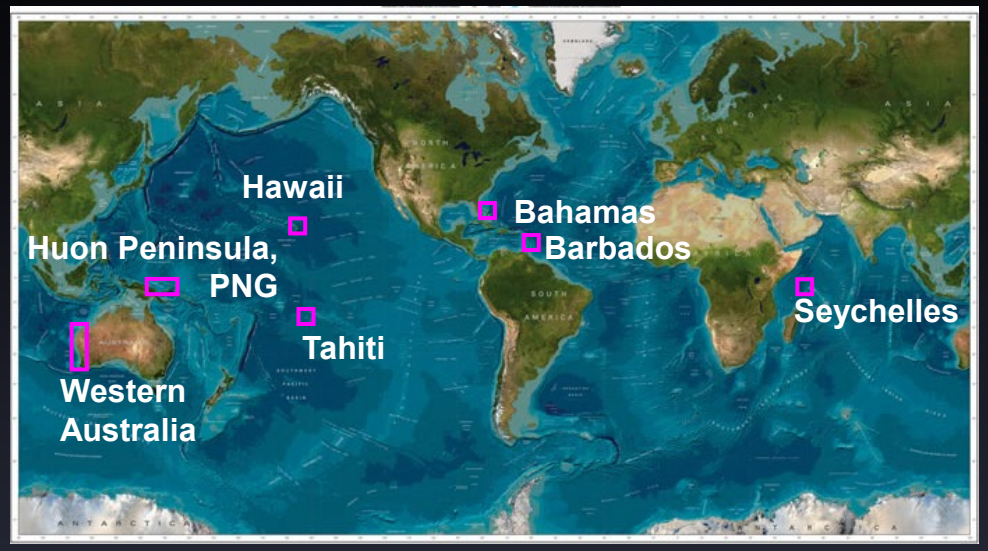
Marine ice sheet instability (MISI)

Marine ice cliff instability (MICI)

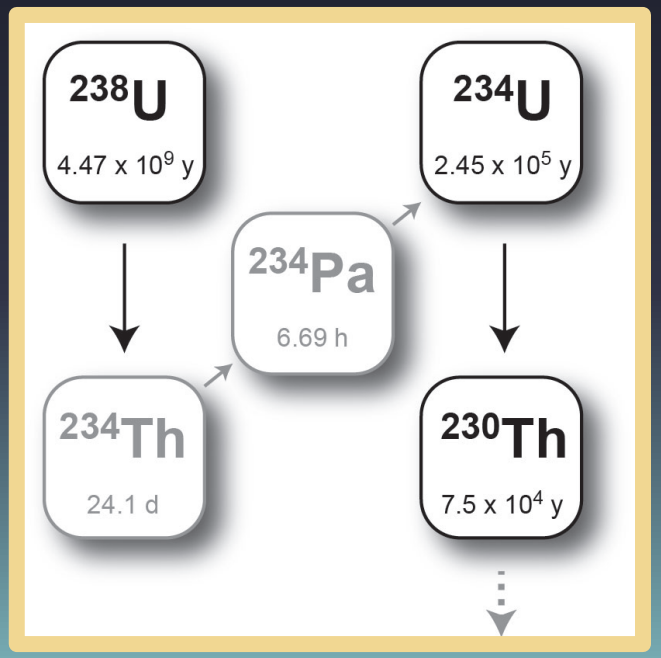
Fossil Corals Record Past Position of Sea Level



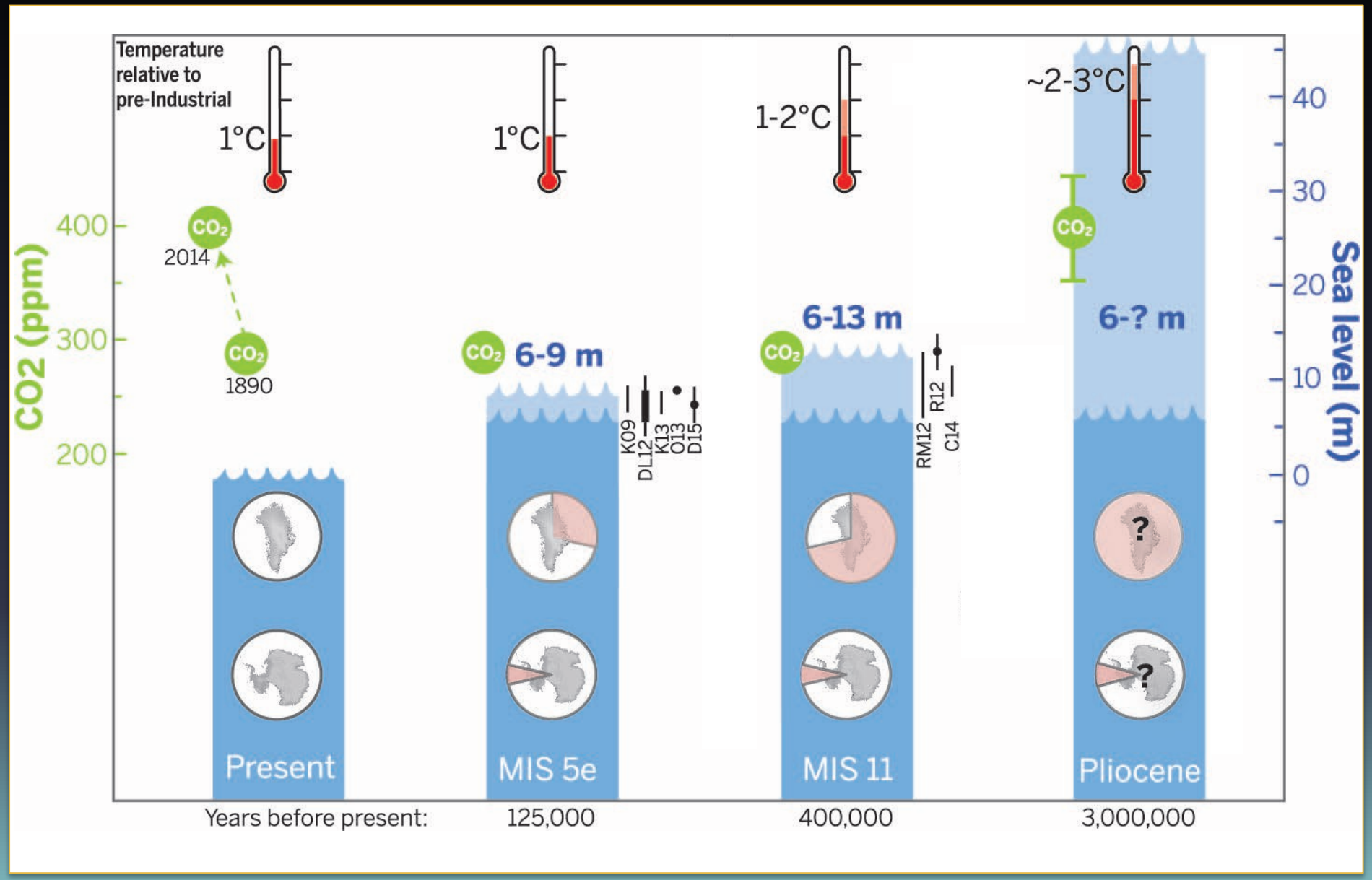
Location of some important fossil coral reefs that are used to reconstruct sea level



Map modified from the GEBCO world map, http://www.gebco.net



Summary of Warm Periods During the Last 3 Ma

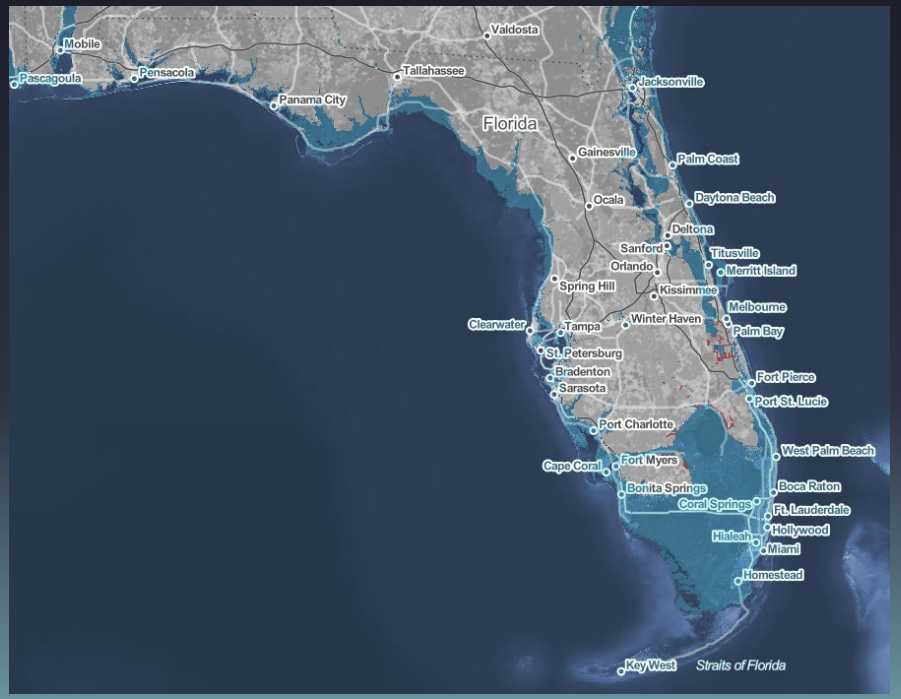


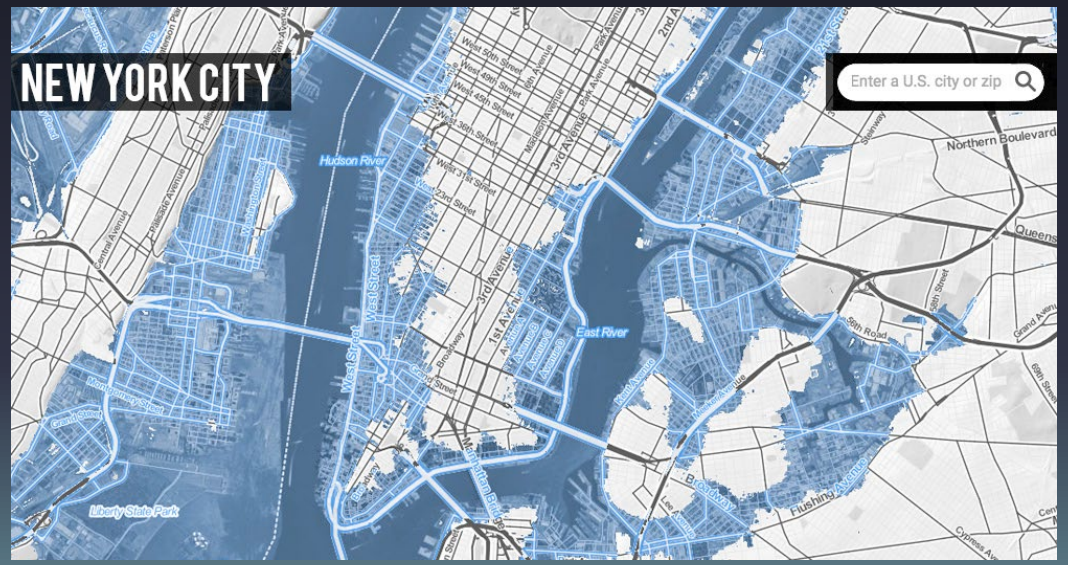
Dutton et al. (2015) *Science*

Main take-away

"…during recent interglacial periods, small increases in global mean temperature and just a few degrees of polar warming relative to the preindustrial period resulted in ≥6 m of GMSL rise."

Dutton et al. (2015) *Science*





http://ss6m.climatecentral.org

Geographic variability in sea-level rise

What causes local sea level to be different from the global average?

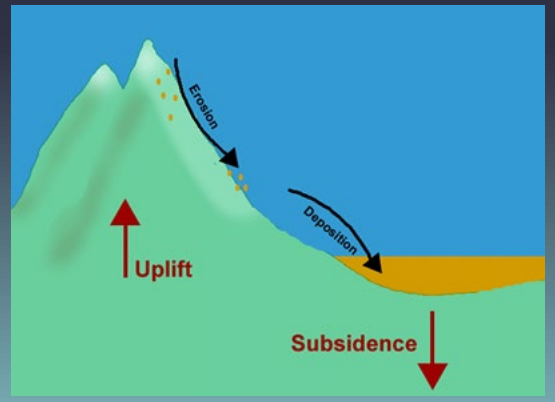
Relative sea level

Eustatic sea level

- **Sea level rise is not like filling a bathtub!!**
- **There are large geographic differences in the rate of sea level rise**
- **In some places, sea level is falling!**

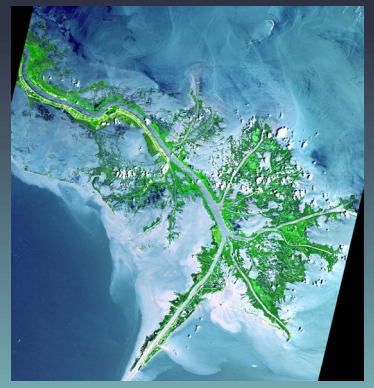
Examples of changes in land motion relative to sea level position:

Tectonics

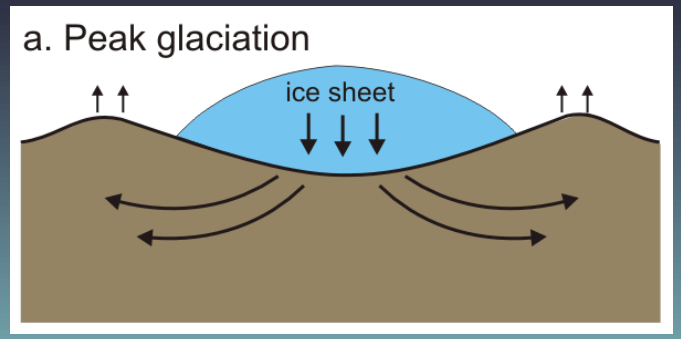


Faulting, sediment loading

Sedimentation



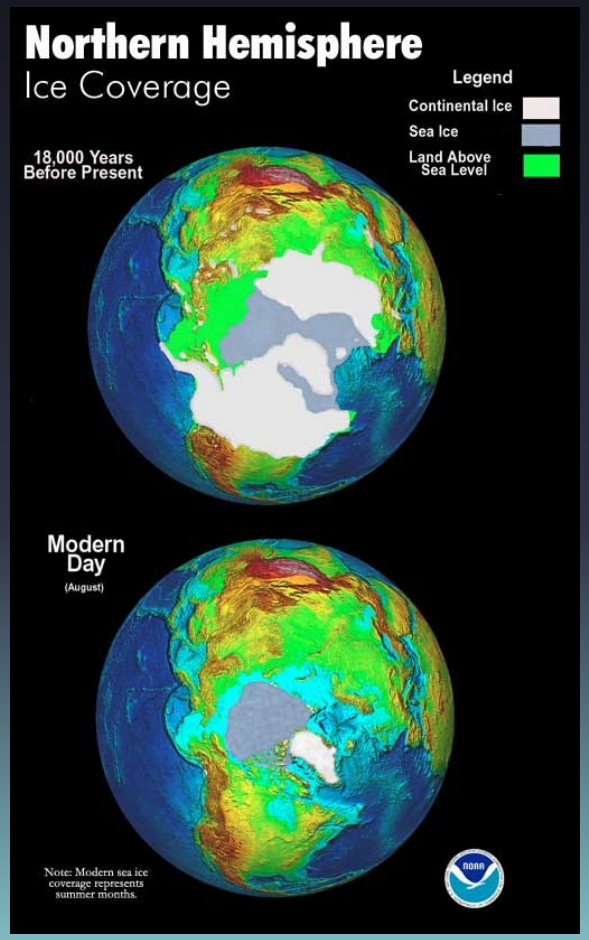
Glacial Isostasy

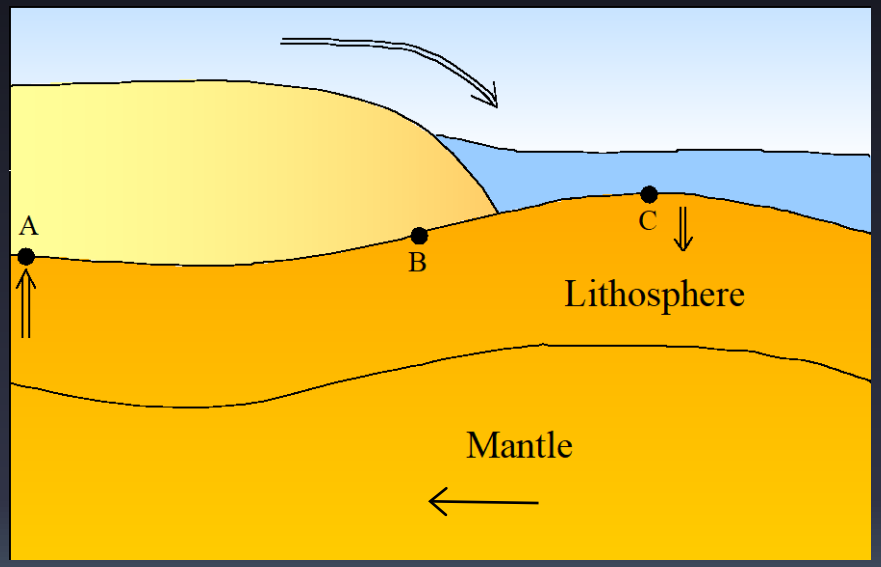


Sea-level rise is not uniform around the globe

Glacial Isostatic Adjustment (GIA)

Perturbations to the Earth's gravity field and solid surface associated with glacial isostatic adjustment (GIA) cause the total (observable) sea-level change to depart from the eustatic curve.



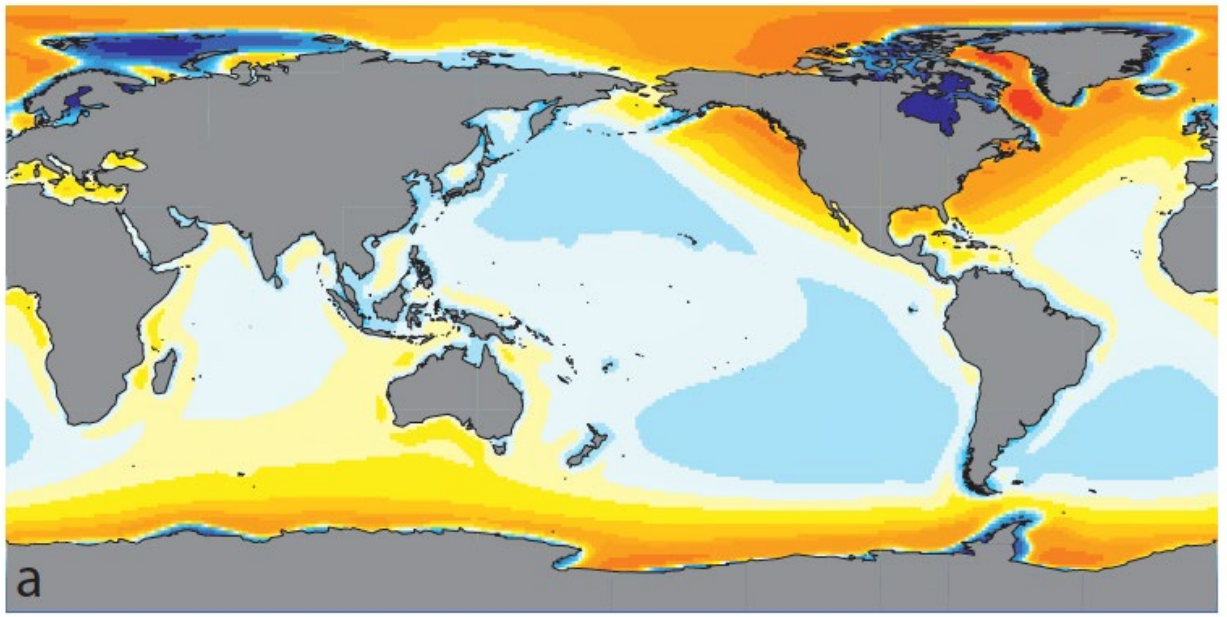


- Solid Earth deformation
- Gravitational component
- Rotational component

Because of ongoing adjustment due to deformation of the earth's surface from the last glacial maximum ice sheets (from ~20,000 yrs ago)…

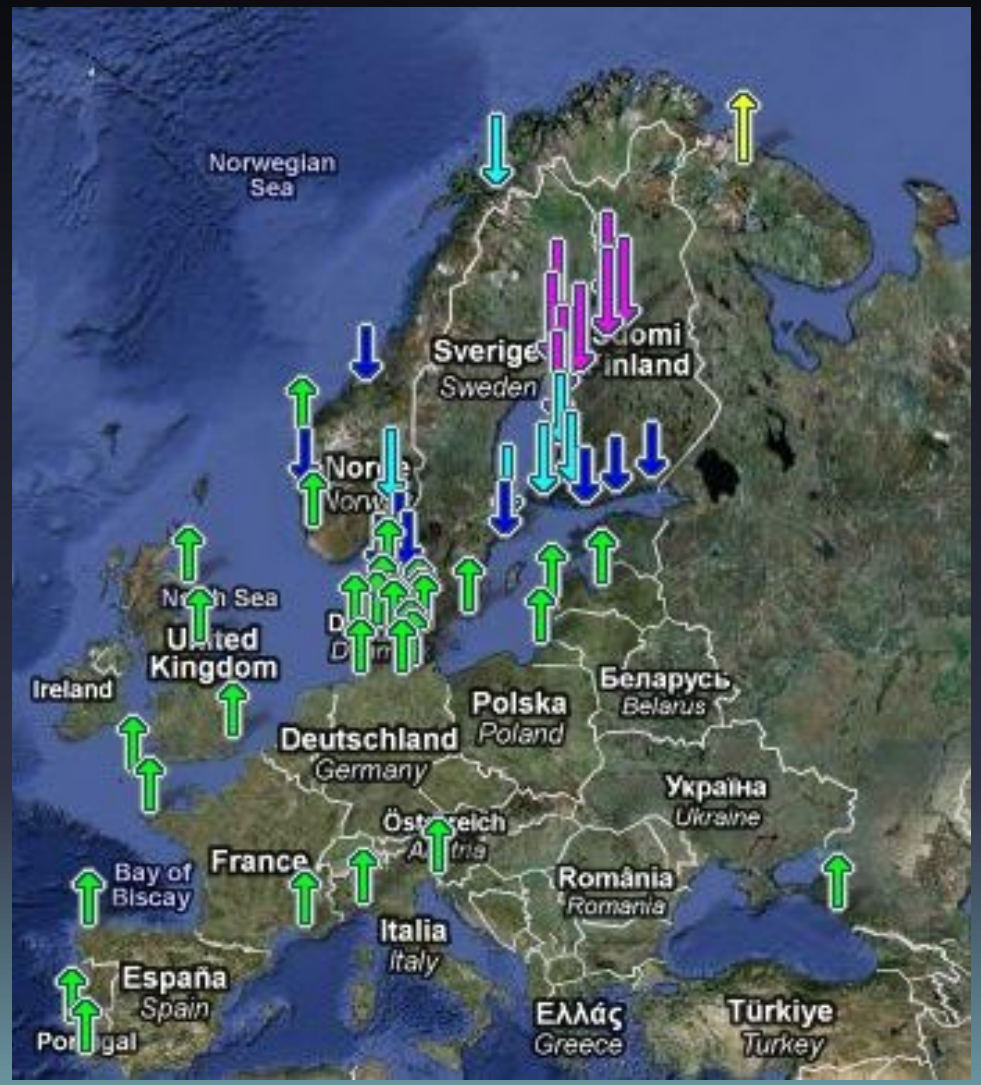
Global sea level rise is NOT uniform

across the earth's surface

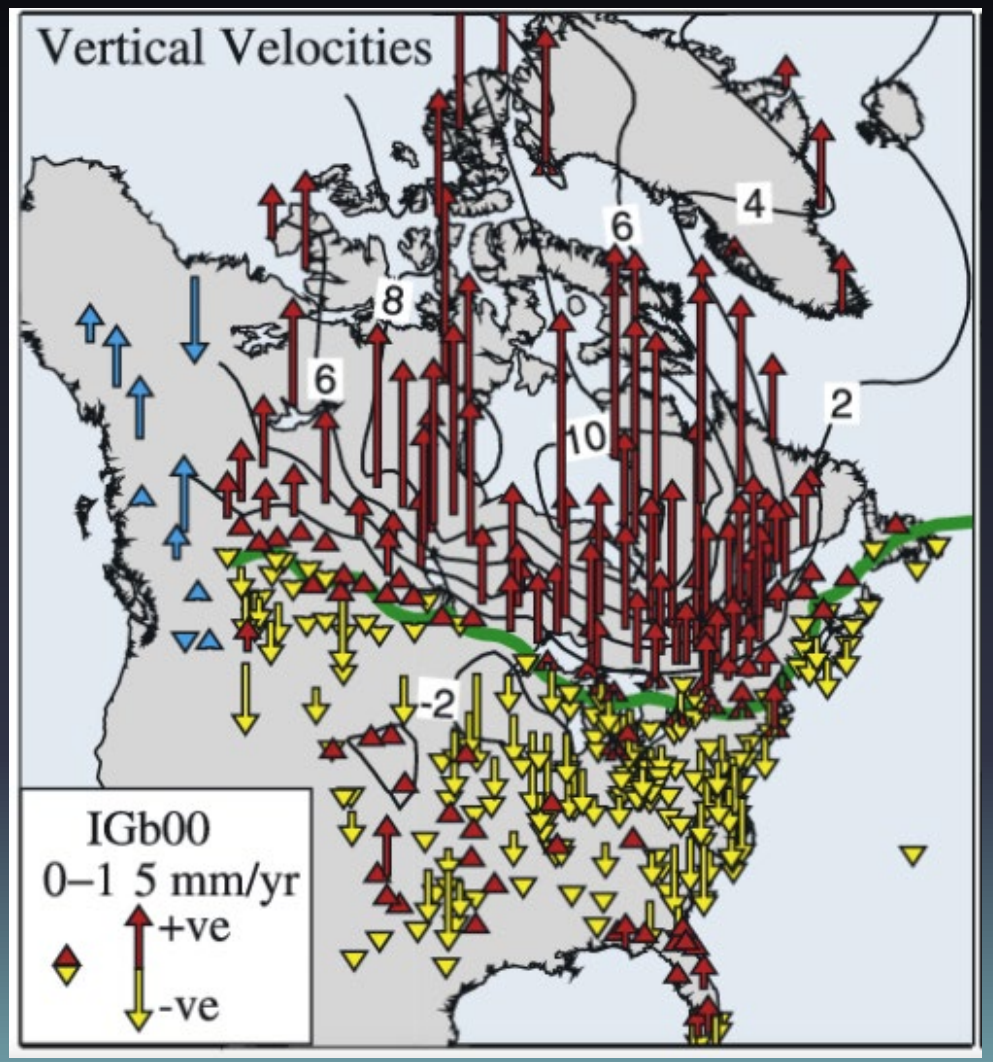


Amount of present-day sea level change shown above is only from GIA.

Glacial Isostatic Adjustment (GIA)



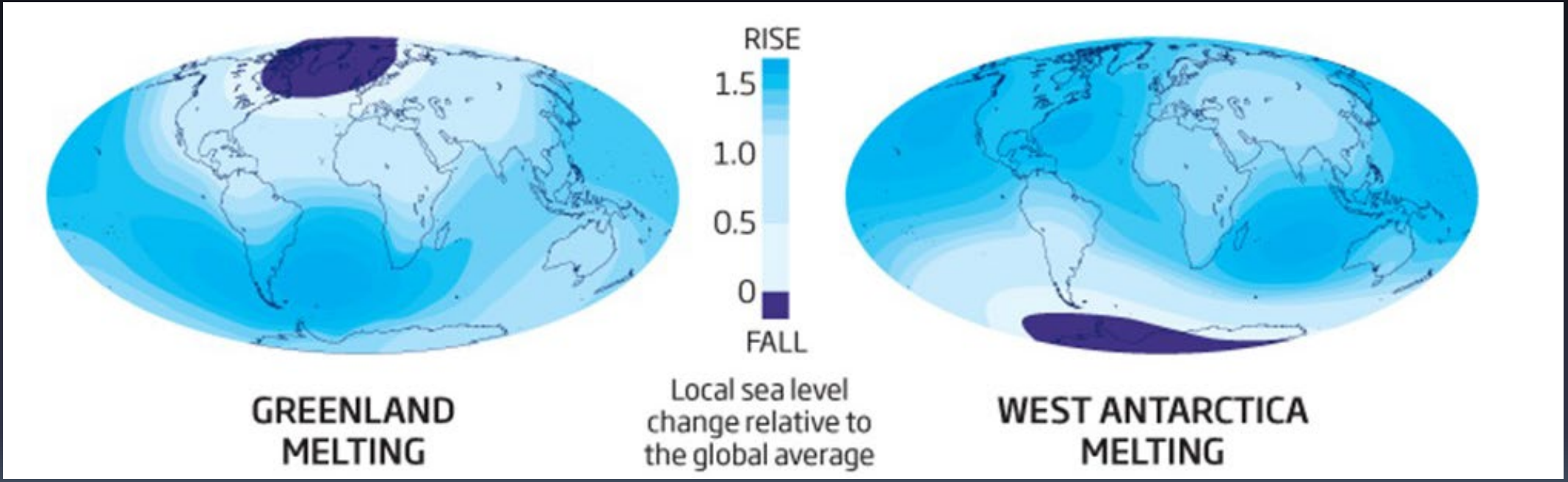
Arrows denote direction and magnitude of SL change



Sella et al. (2007) *GRL*

Ice sheet fingerprints

The geographic pattern of sea-level rise will vary depending on which ice sheet melts.



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Relative sea level

Eustatic sea level

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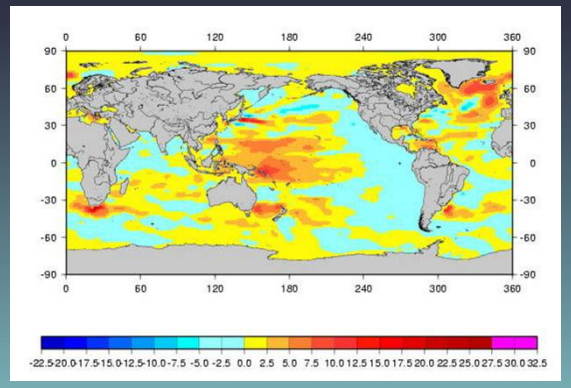
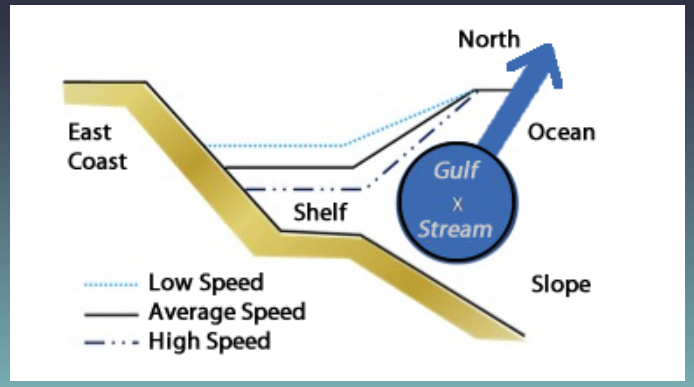
Examples of changes in ocean dynamics:

Heat Distribution

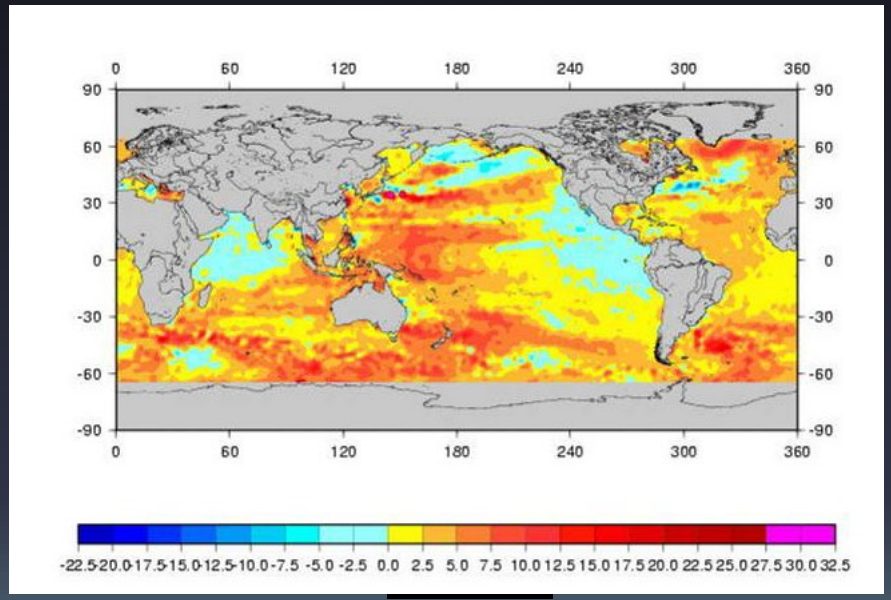


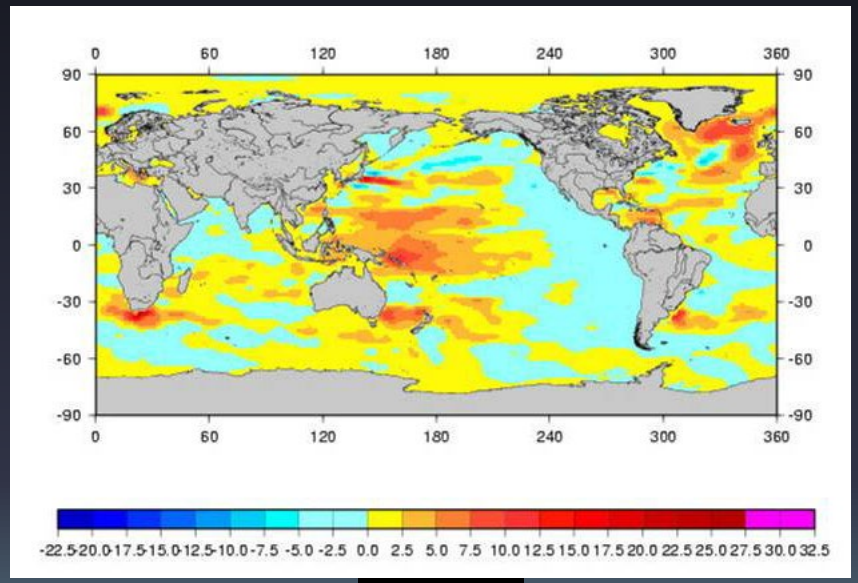
Change in strength of currents



Heat Distribution:

Spatial patterns of thermal expansion and observed sea level (*satellite altimetry*) trends (1993-2005)



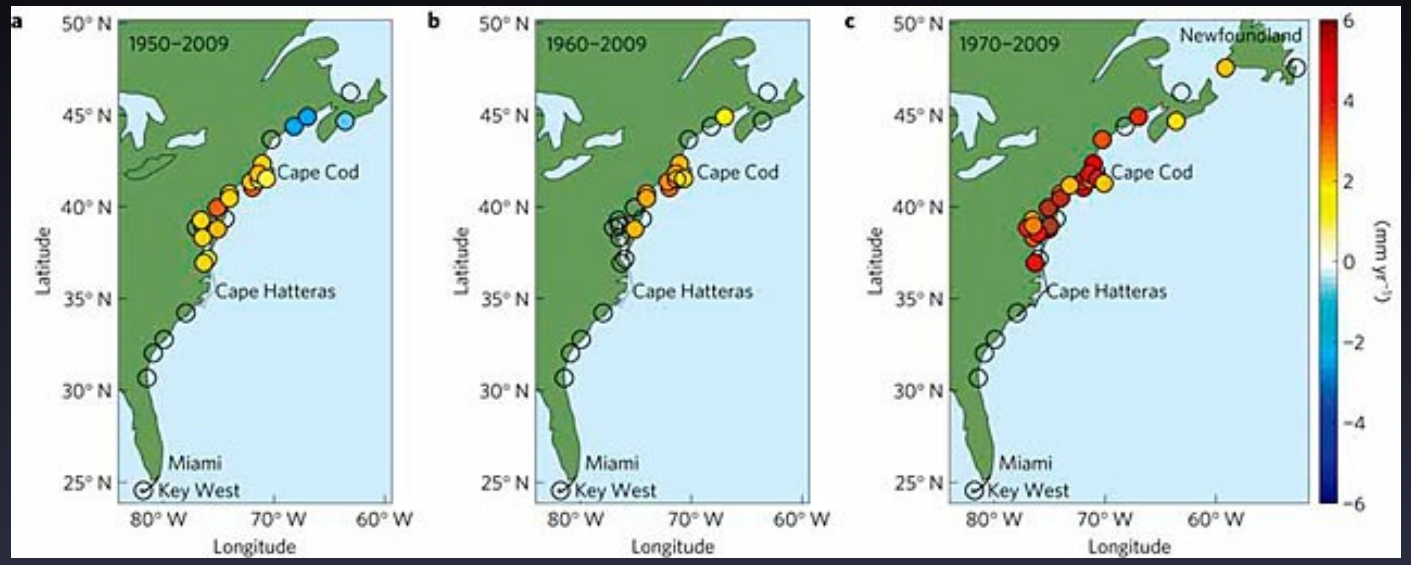


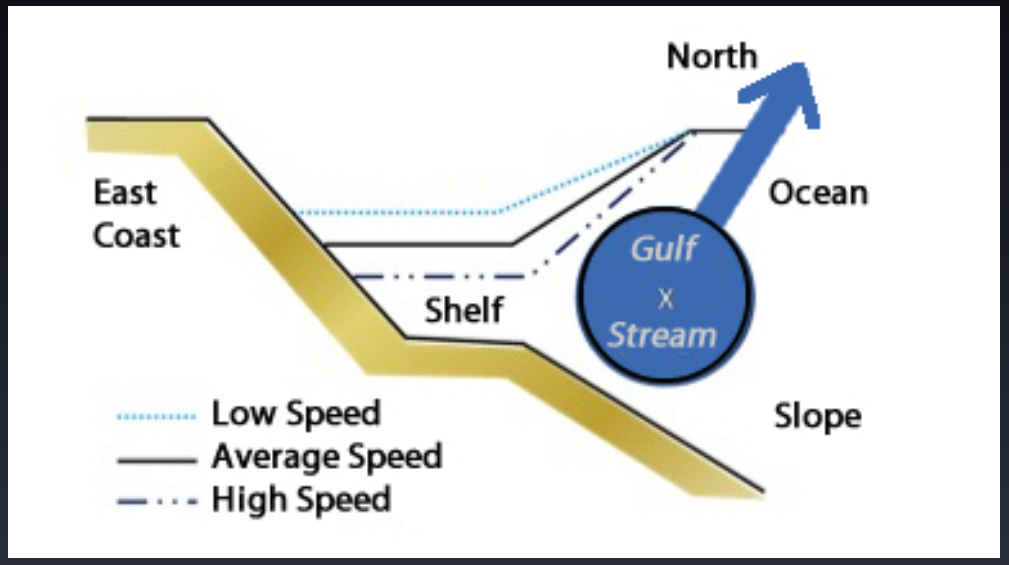
mm/yr

Satellite Altimetry

Thermal Expansion

Current change in Gulf Stream and Effects on Sea Level





Theory: Changes in current strength caused higher acceleration N of Cape Hatteras

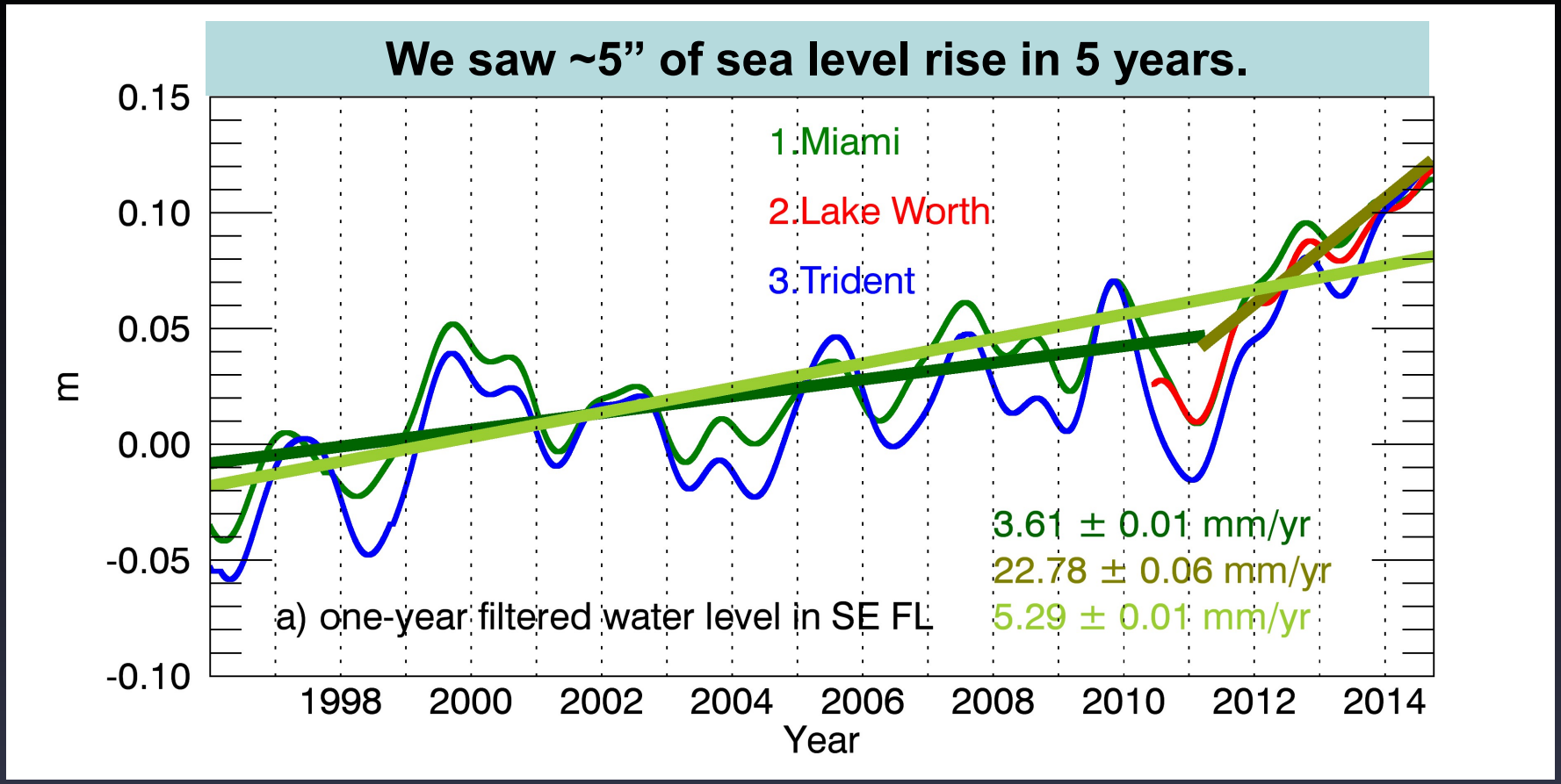
Recent research has also shown that this short-term acceleration was primarily controlled by the superposition of the effects of ENSO and the NAO on how much water gets pushed into the western part of the N. Atlantic basin.

The Sea Level Did, in Fact, Rise Faster in the Southeast U.S.

By JUSTIN GILLIS AUG. 9, 2017

Flooding in Charleston, S.C., last summer. From 2011 to 2015, the sea level along the southeastern American coastline rose six times faster than the long-term rate of global increase.

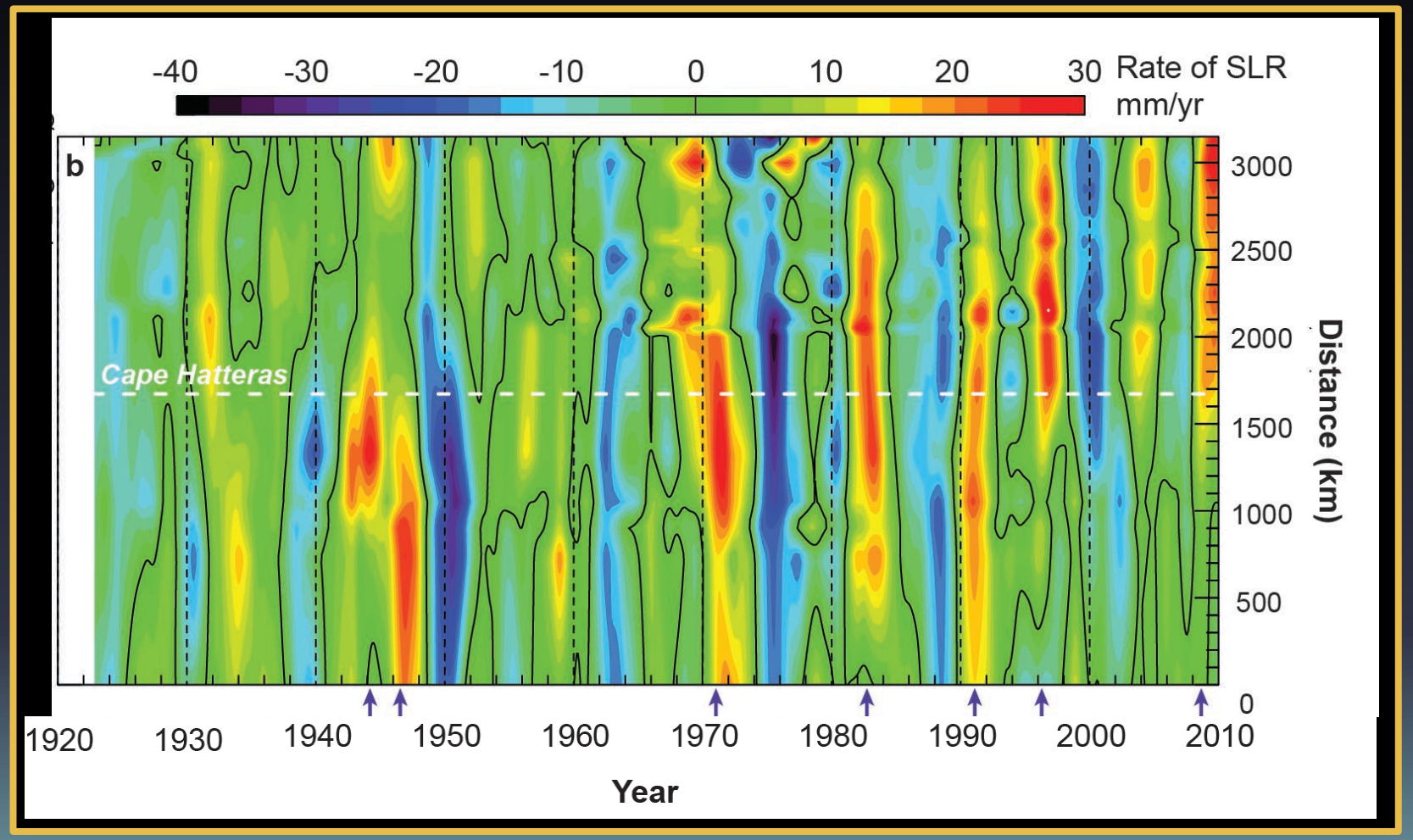
Hunter McRae for The New York Times



Valle-Levinson et al. (2017) *Geophysical Res. Letters*

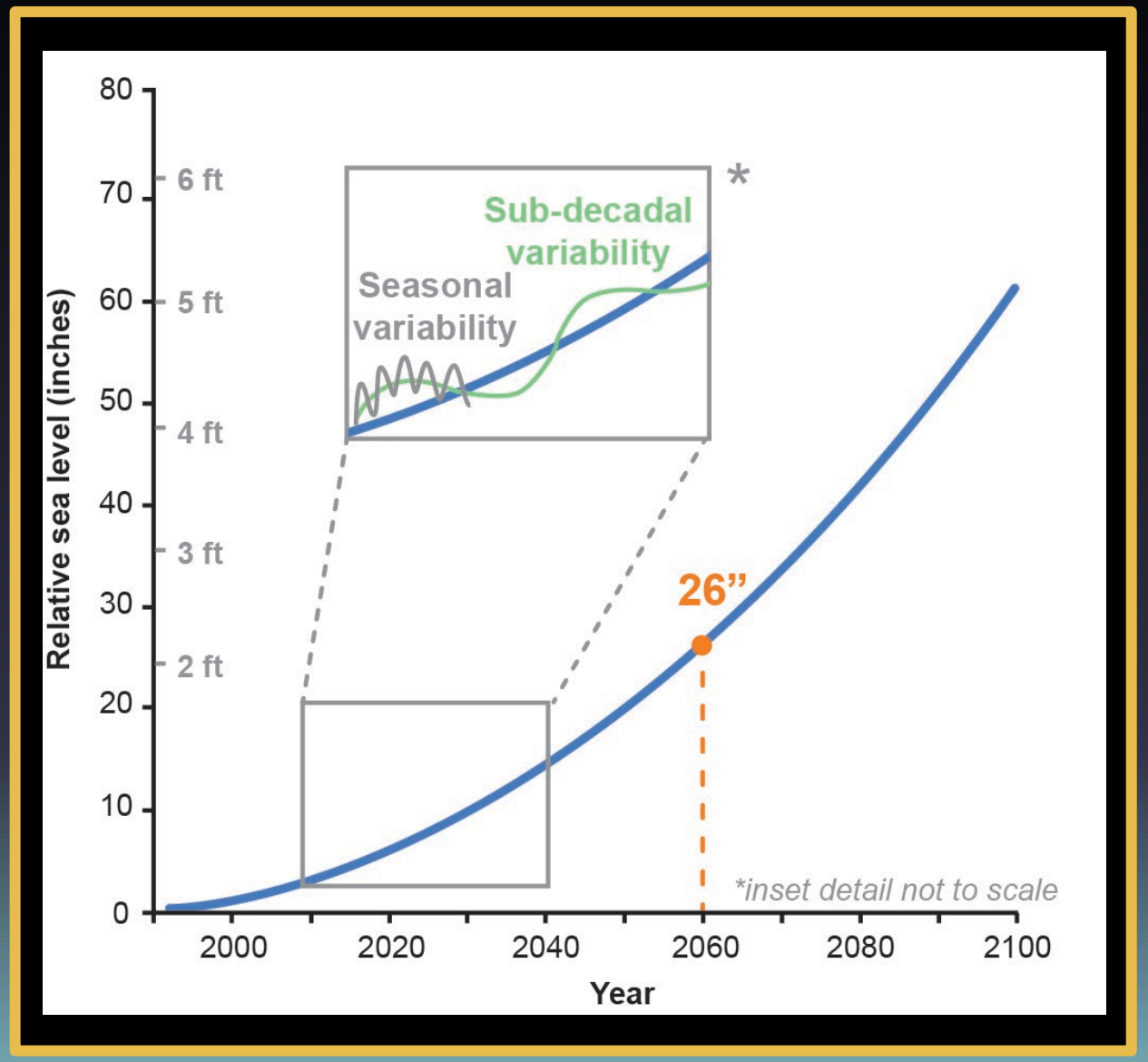
Such short-term accelerations can occur anywhere along the U.S. Atlantic coast due to the interaction of two large climate oscillations: El Niño and the North Atlantic Oscillation.

Hot Spots of Accelerated Sea Level Rise



Valle-Levinson et al. (2017) *Geophysical Res. Letters*

Sub-decadal variability modifies projections



Mitchum et al. (2017) *Florida’s Climate*

Lessons from Recent Sea Level Trends

- Hot spots of sea level rise are a threat to the entire eastern seaboard of the United States.

- These hot spots can produce high rates of sea level rise (~1” per year) over at least several years.
  (present rate of sea level rise is ~12” per century)

- Implications: need to account for possibility of short-term accelerations (at least 5” on top of existing projections).

- Ongoing research needed to understand how often these can be expected, and how long such hot spots can persist.

Impacts of sea-level rise

- **Inundation**
- **Salt water intrusion**
- **Health issues**
  contaminated and/or standing floodwaters
- **Intense rainfall**
  w/ reduced capacity for runoff
- **Loss of coastal resources**
  erosion, habitat loss, infrastructure
- **Social inequality**
  lack of resources to adapt or move
- **Economic impacts**
  tourism, real estate, coastal industries

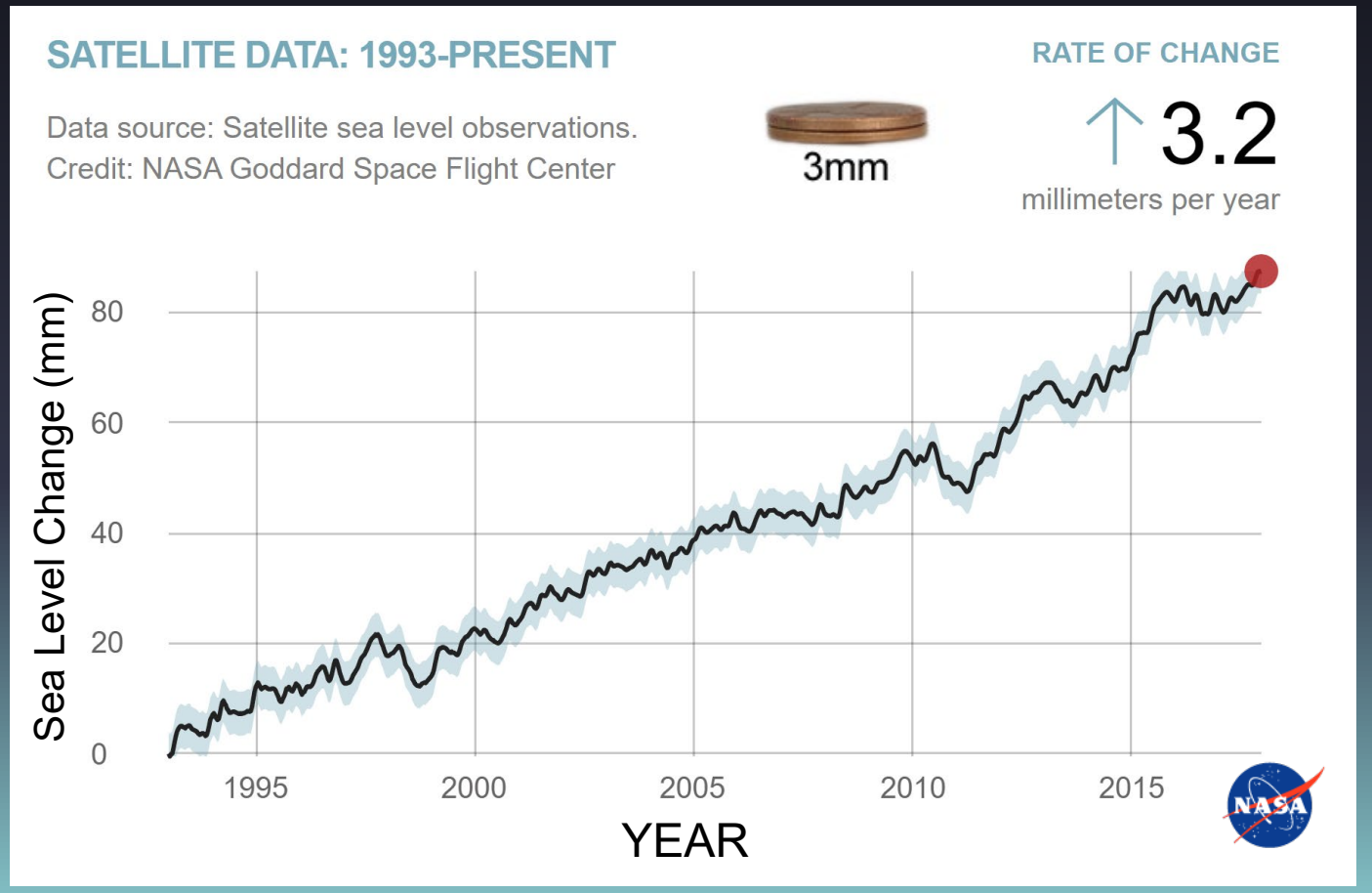
NJ coast post-Sandy (top), Heavy rains in Miami Beach (bottom)

Message #1:

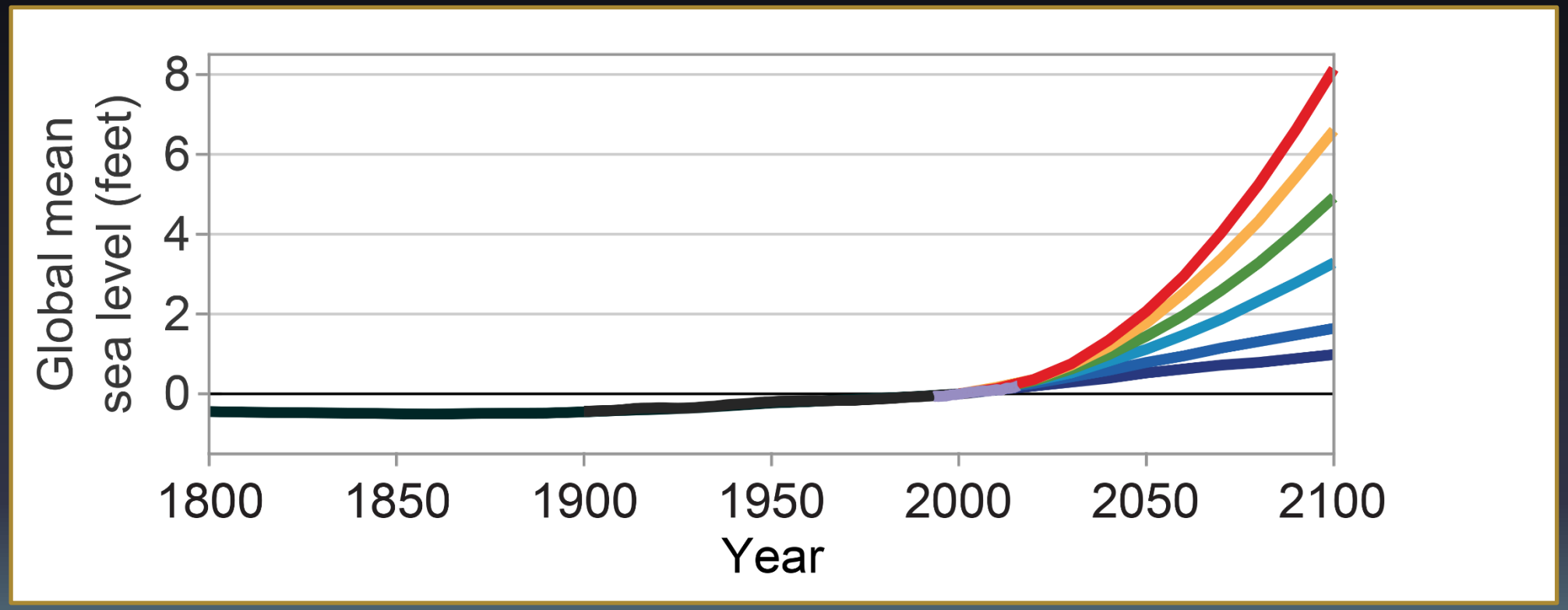
The impacts of sea-level rise are not gradual

Corollary:

Sea level projection curves are misleading



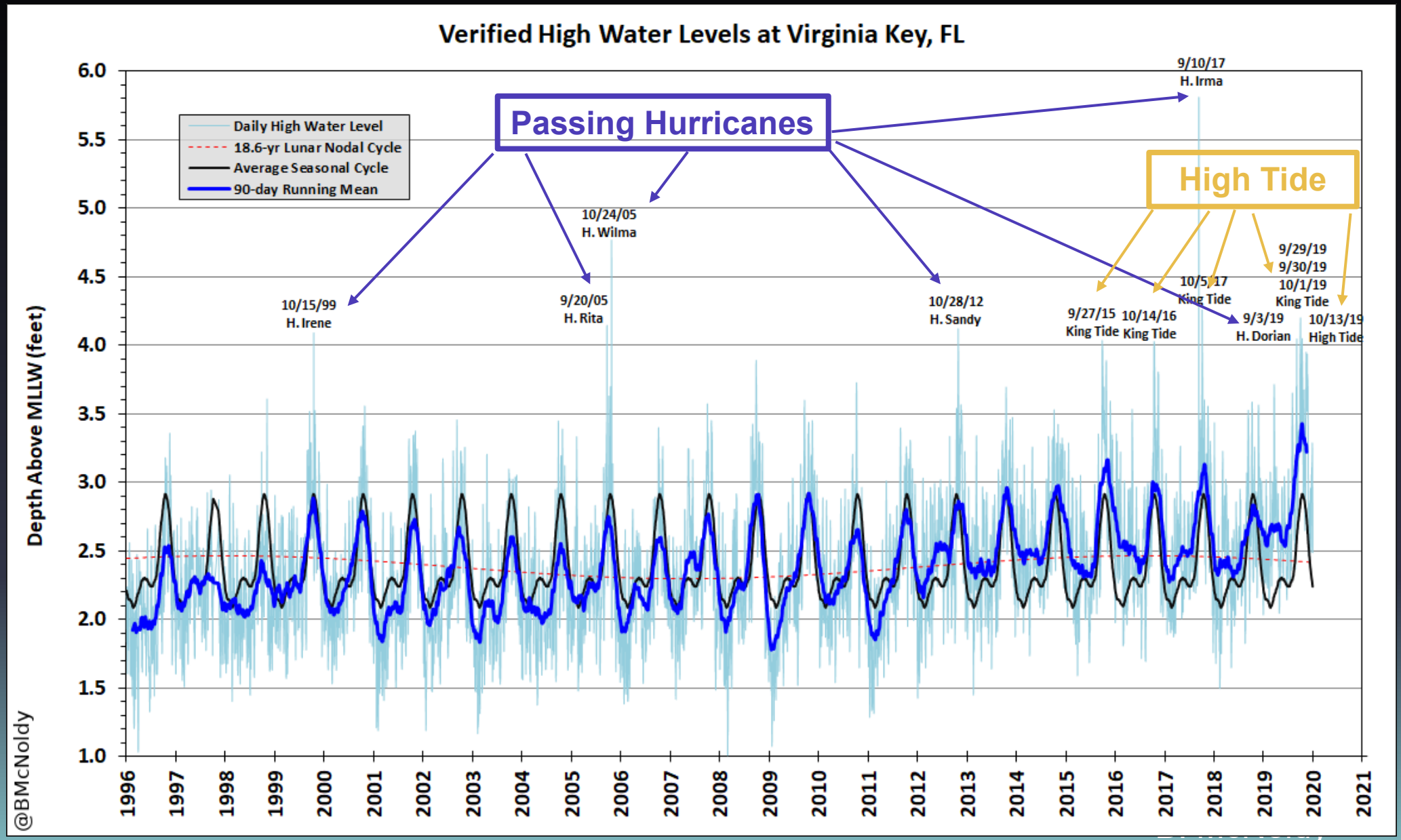
Communication: Framing the Problem



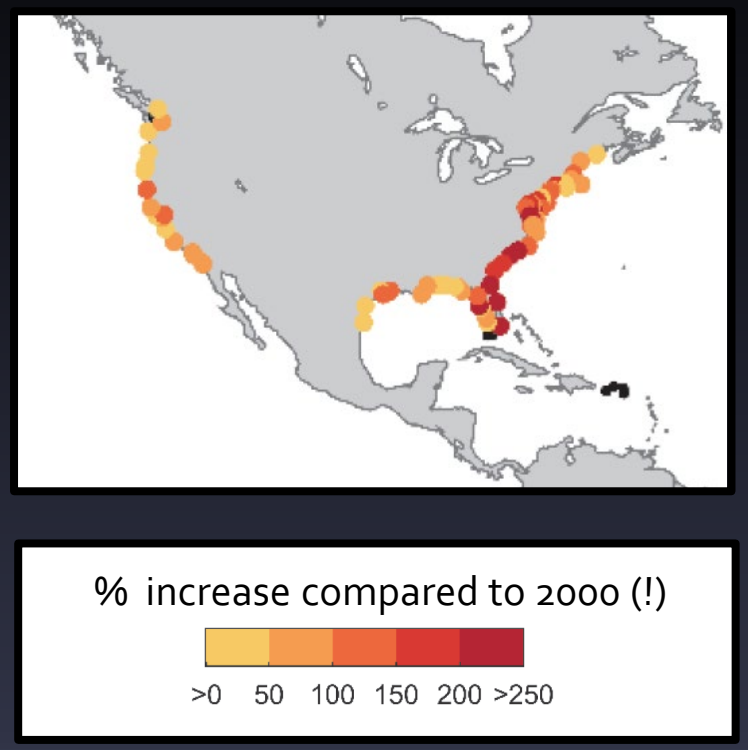
National Climate Assessment (2017)

These are useful projections, but I can guarantee you that sea level rise will NOT look like any of these curves.

What will future sea-level rise look like?



Frequency of Coastal Flooding



Sweet et al. (2018) NOAA

The frequency of coastal flooding from high tides has doubled in the U.S. in just 30 years.

In 2017, more than a quarter of the tide gauge locations tied or broke their records for high tide flood days.

- **Frequency of flooding:**

Sea-level rise will happen sooner than most think it will

Message #2:

Providing the facts about sea-level rise is not enough to help us prepare and respond to this challenge

Message #3:

We cannot 'just build our way out of it'

The Army Corps built levees to protect New Orleans, but they are only 4 years away from becoming inadequate due to rising sea levels. (*This quote is from 4 years ago*).

ARMY CORPS

After $14B upgrade, New Orleans levees are sinking

Thomas Frank, E&E News reporter • Published: Thursday, April 11, 2019

New Orleans is ringed by flood defenses like the Lake Borgne Surge Barrier (left) and floodwalls (right). Experts say they might not stop very large disasters. Army Corps of Engineers

E&E News

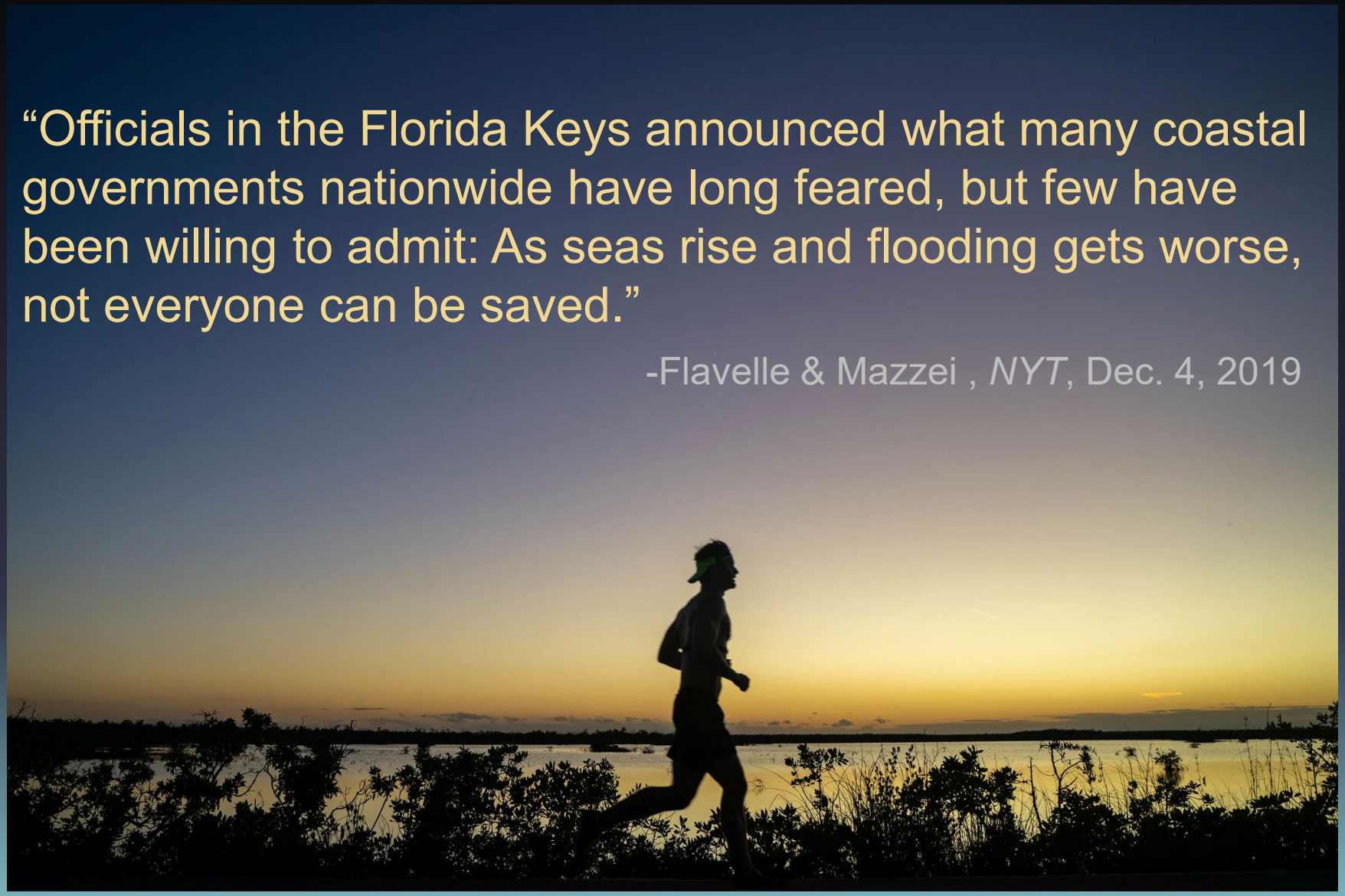
Sugarloaf Key, Florida (a small island 15 miles up Highway 1 from Key West)

To keep a single 3-mile stretch of road at the southern tip of Sugarloaf Key dry year-round in:

2025	would require raising it by	1.3 ft, at a cost of $75 million
2045	…	2.2 ft … $128 million
2060	…	… $181 million

-Flavelle & Mazzei , *NYT*, Dec. 4, 2019

Sugarloaf Key, Florida



The Dangers of Sea Walls

- **Exacerbates existing racial and social inequality.**

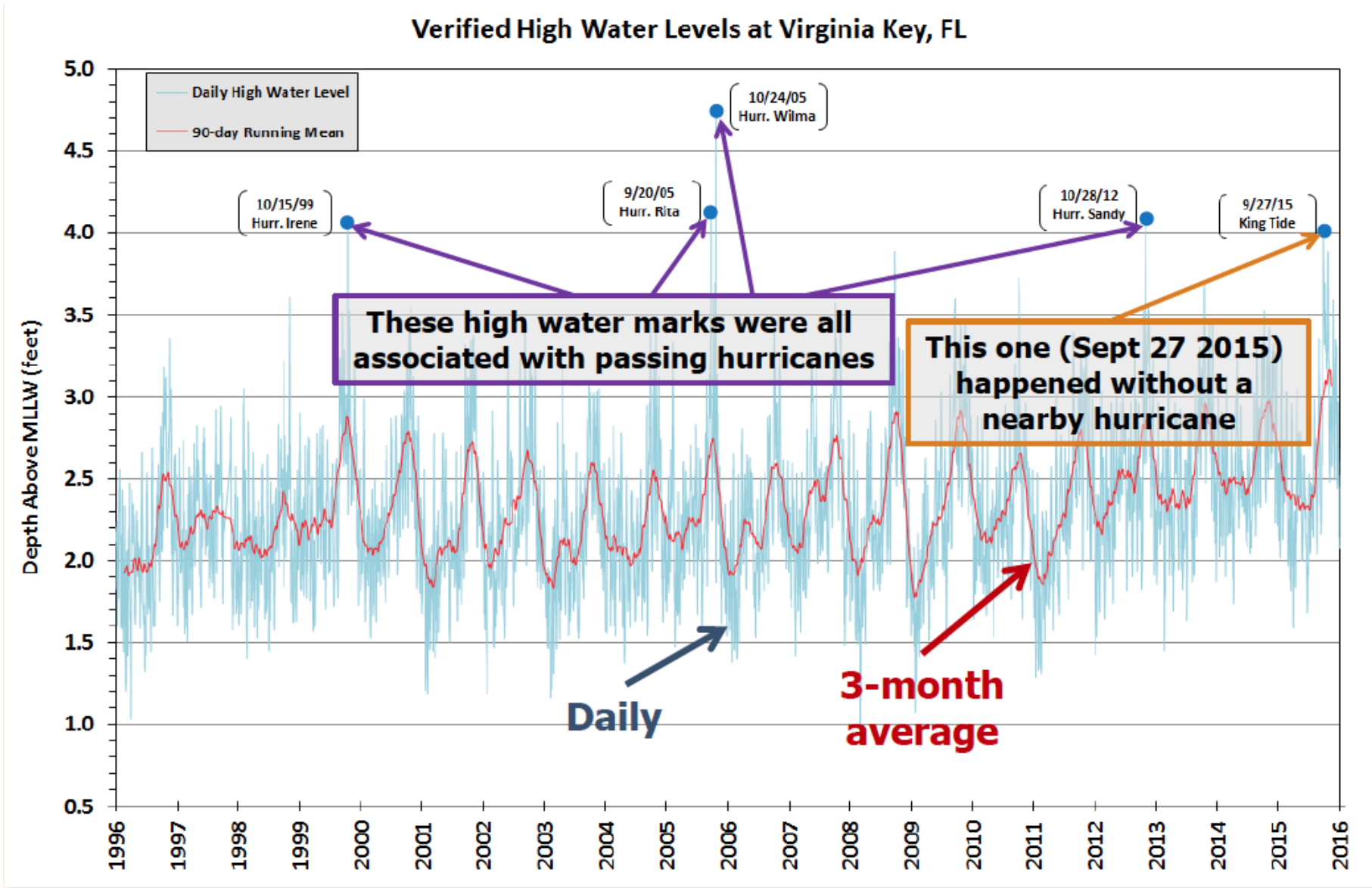
  An analysis of federal flood insurance payments shows that flooding in the U.S. disproportionately harms African American neighborhoods (*E&E News, 2 Jun 2020*).

- **Builds in a false sense of complacency.**

Resiliency & Adaptation are community-wide issues

Mexico Beach, FL after hurricane Michael (2018)

Johnny Milano for *The New York Times*


Verified High Water Levels at Virginia Key, FL
Daily High Water Level
90-day Running Mean
10/15/99
Hurr. Irene
9/20/05
Hurr. Rita
10/24/05
Hurr. Wilma
10/28/12
Hurr. Sandy
9/27/15
King Tide
These high water marks were all associated with passing hurricanes
This one (Sept 27 2015) happened without a nearby hurricane
Daily
3-month average
Depth Above MLLW (feet)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

B. McNoldy