

Workshop for Educators

The Perfect Storm: Exploring how sea level rise and storms intersect

Greg Berman

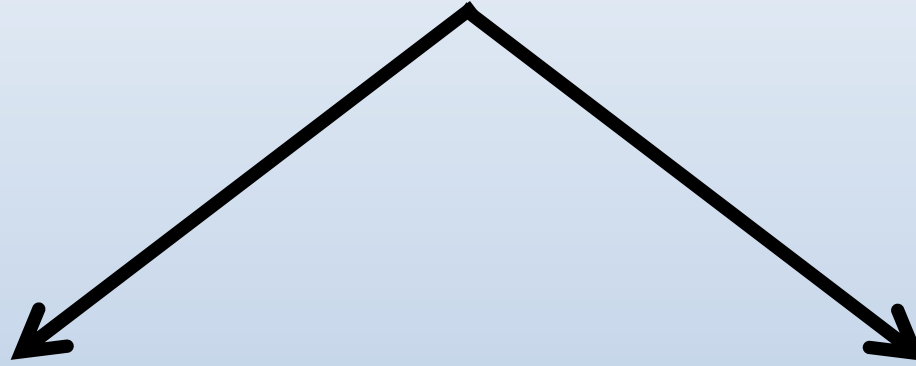
(WHOI Sea Grant & Cape Cod Cooperative Extension)



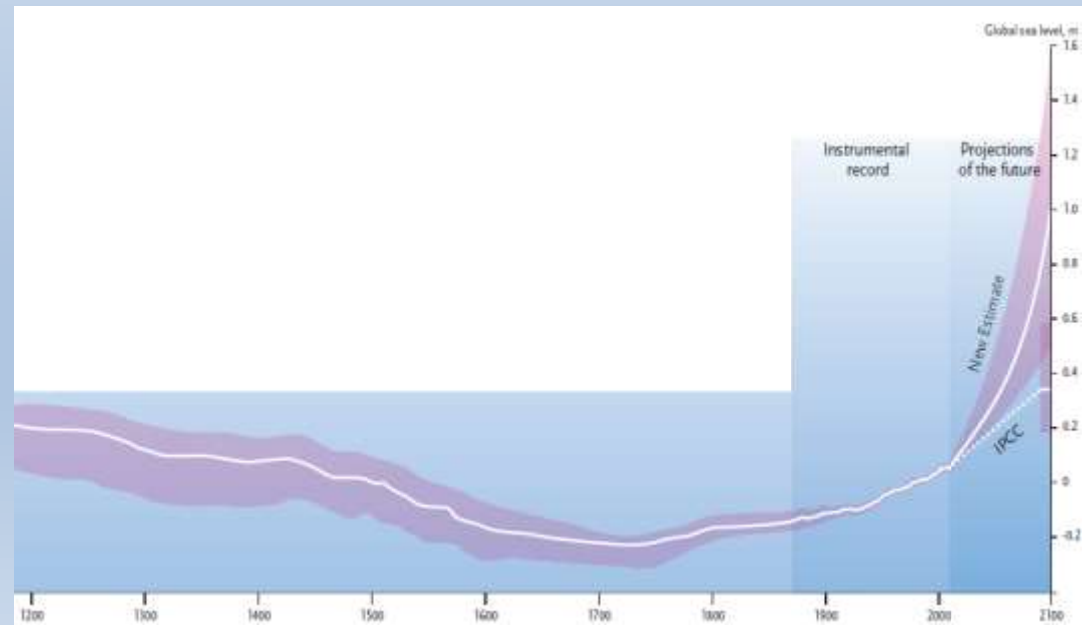
July 15, 2022



Climate Change Impacts In Coastal Environments



5



The Perfect Storm: Exploring how sea level rise and storms intersect

Outline:

Broken up into 4 sections:

- What is Climate Change?
- What are the drivers of SLR?
- What is Storm Surge?
- What are the ways in which SLR and Storms Interact?



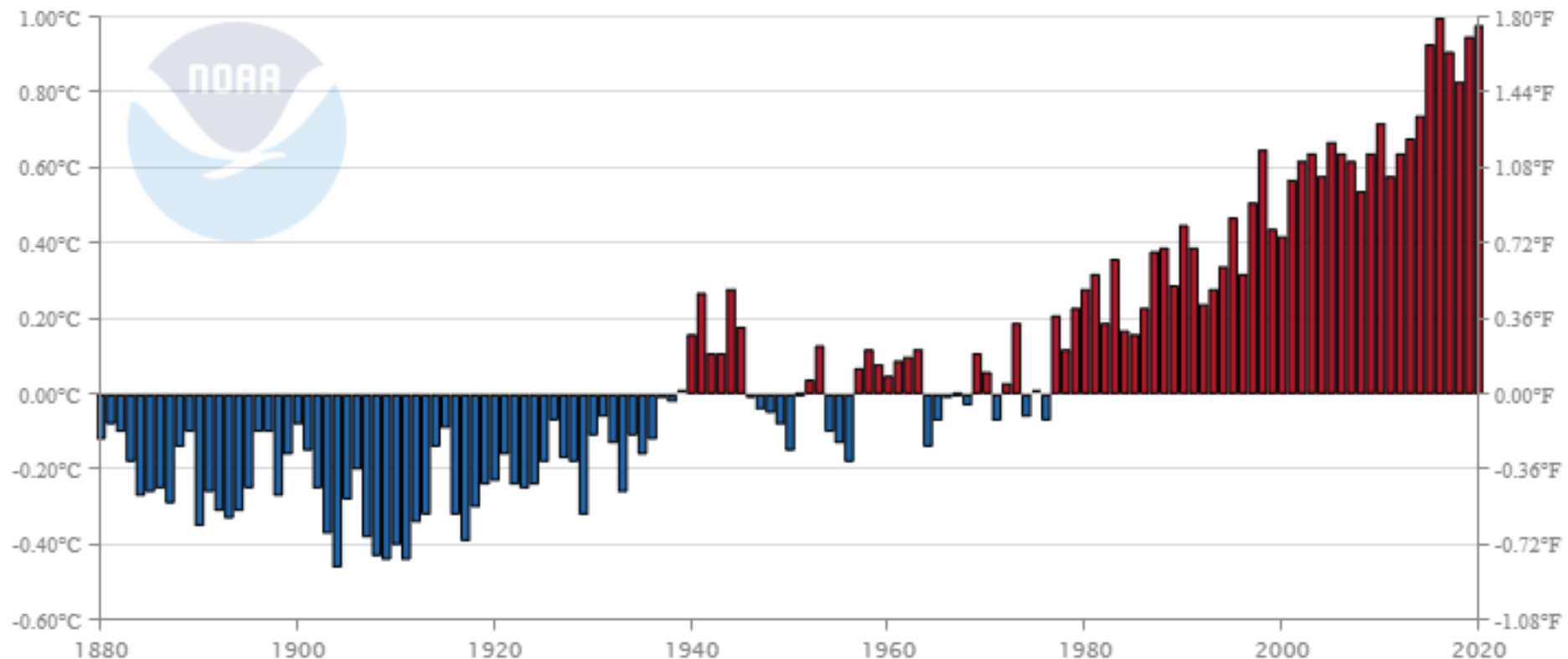
Section 1

What is Climate Change?

Anyone younger than 40 has **ONLY** seen rising temperatures **EVERY** year

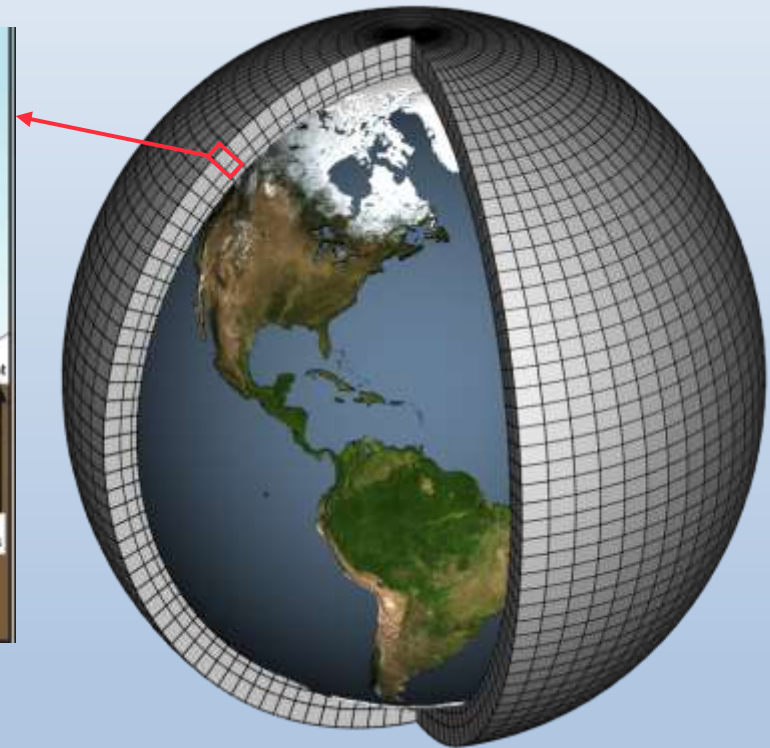
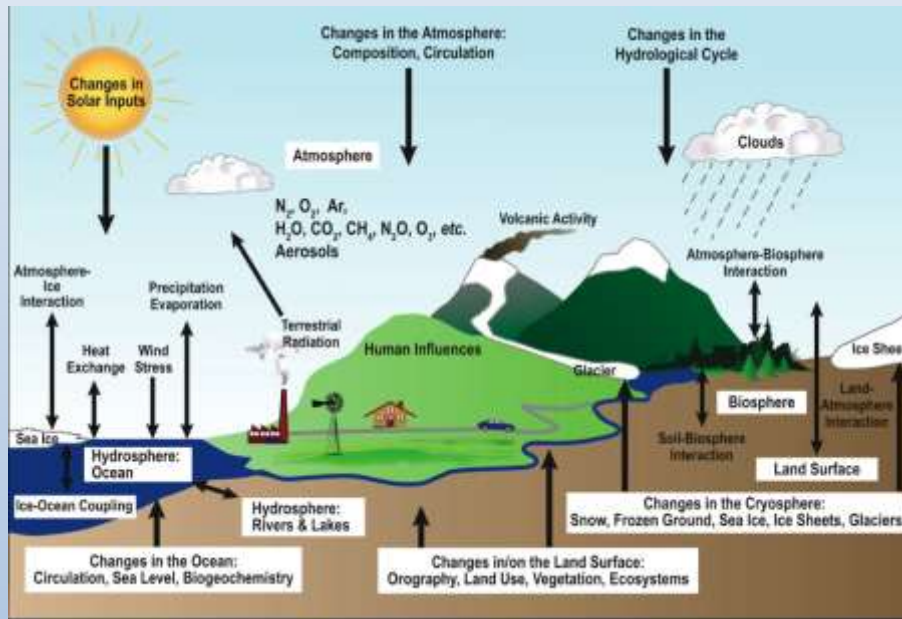
88

Global Land and Ocean
January–December Temperature Anomalies



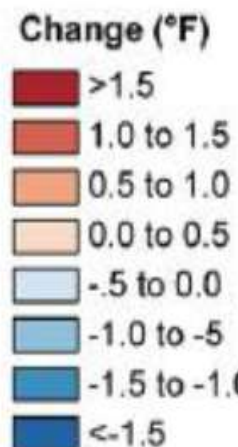
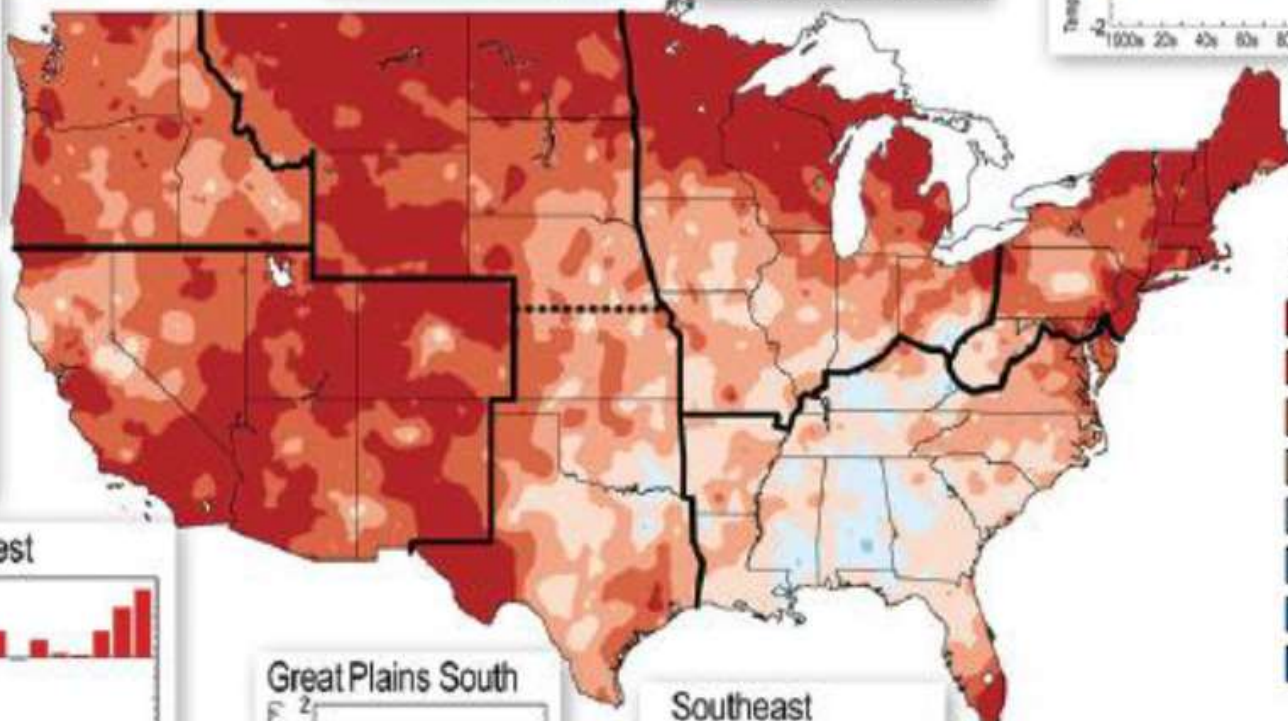
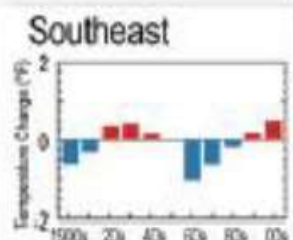
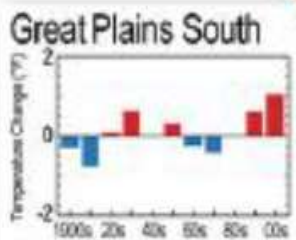
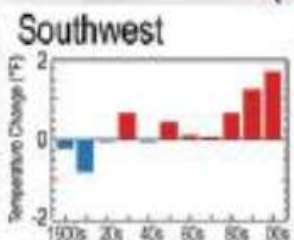
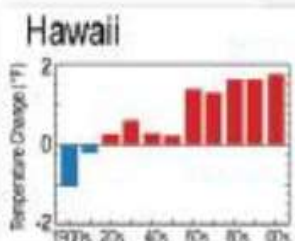
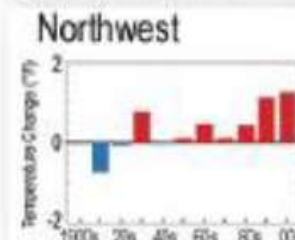
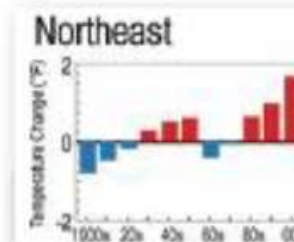
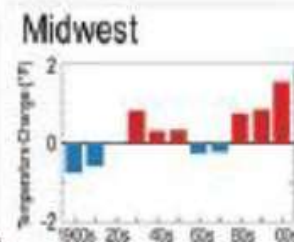
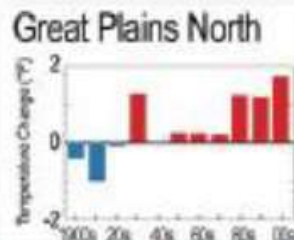
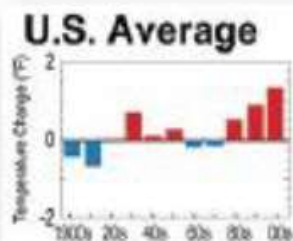
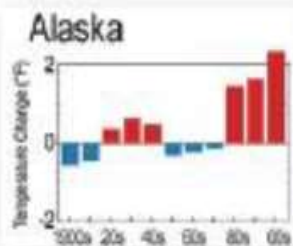
warmest decades on record for the globe, surface temp above the 20th century average
(2011–2020) surface temp of 1.48°F > (2001–2010) value of 1.12°F

Scientists apply that knowledge to a scaled-down, computer simulation of the planet: **a global climate model**

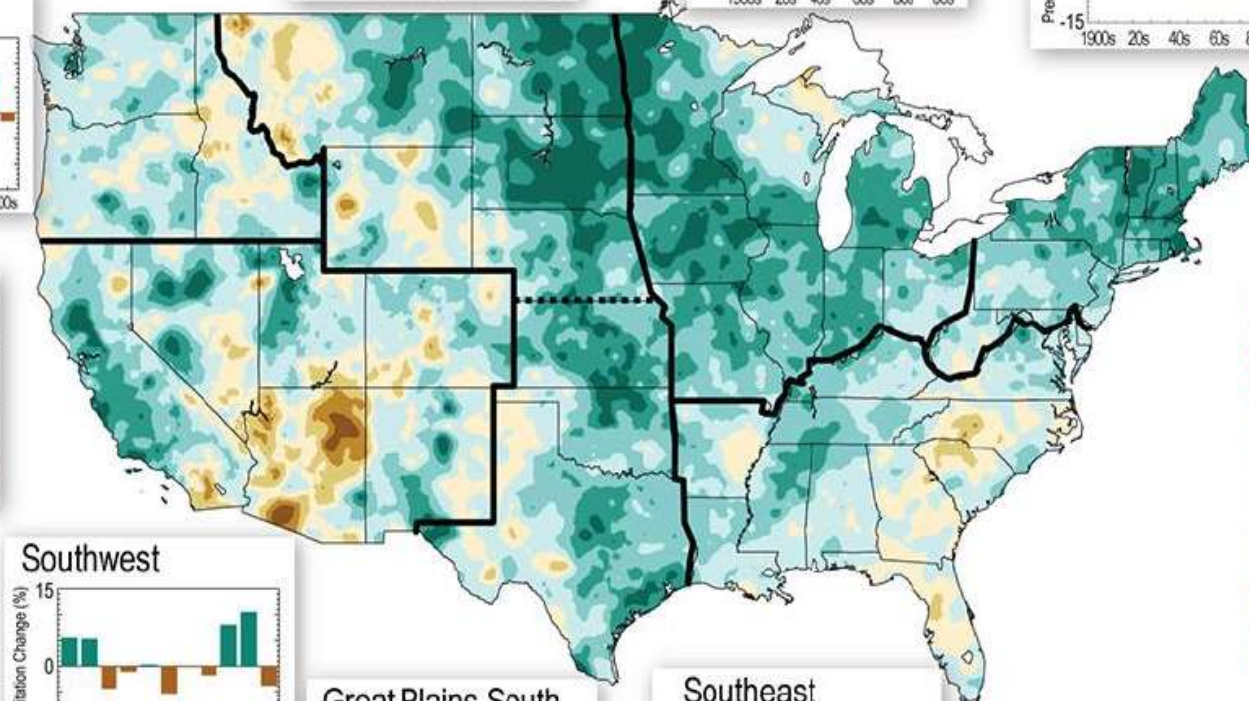
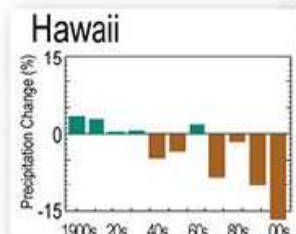
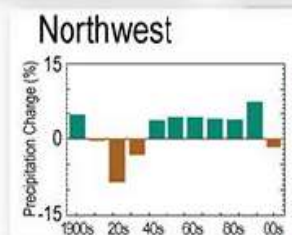
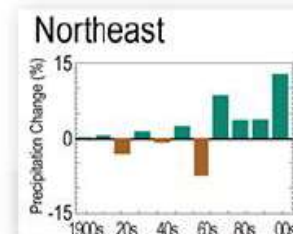
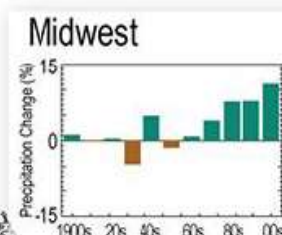
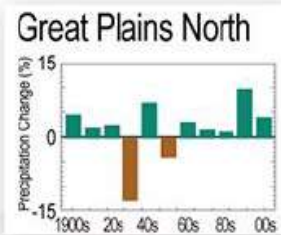
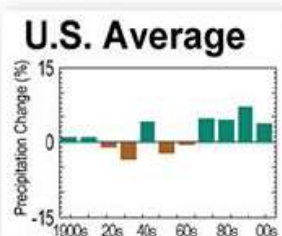
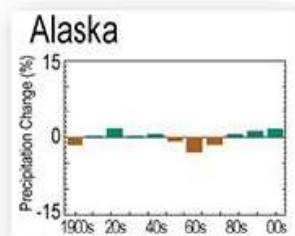


Modelers represent Earth's surface and atmosphere as a virtual world made up of interacting, three-dimensional boxes.

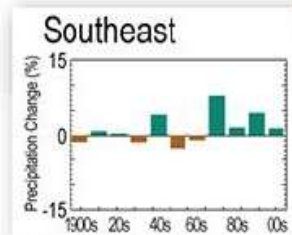
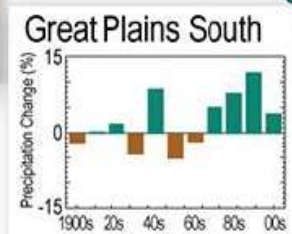
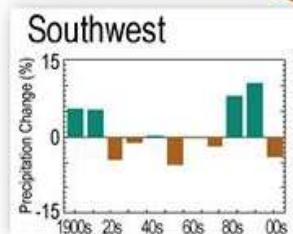
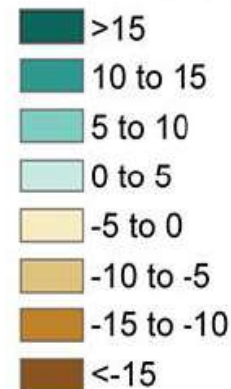
“All models are wrong, but some are useful” – George Box, 1976



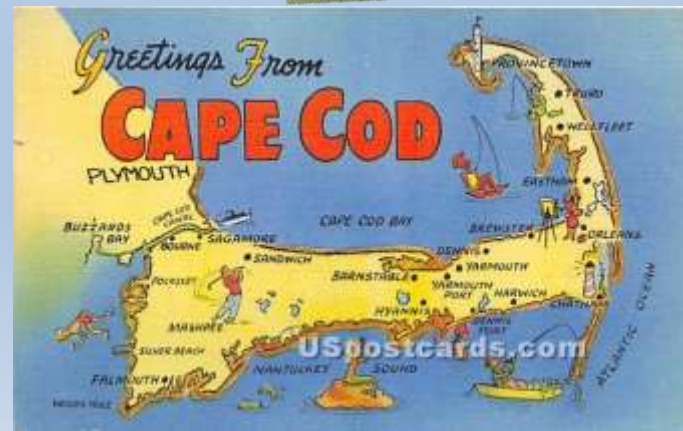
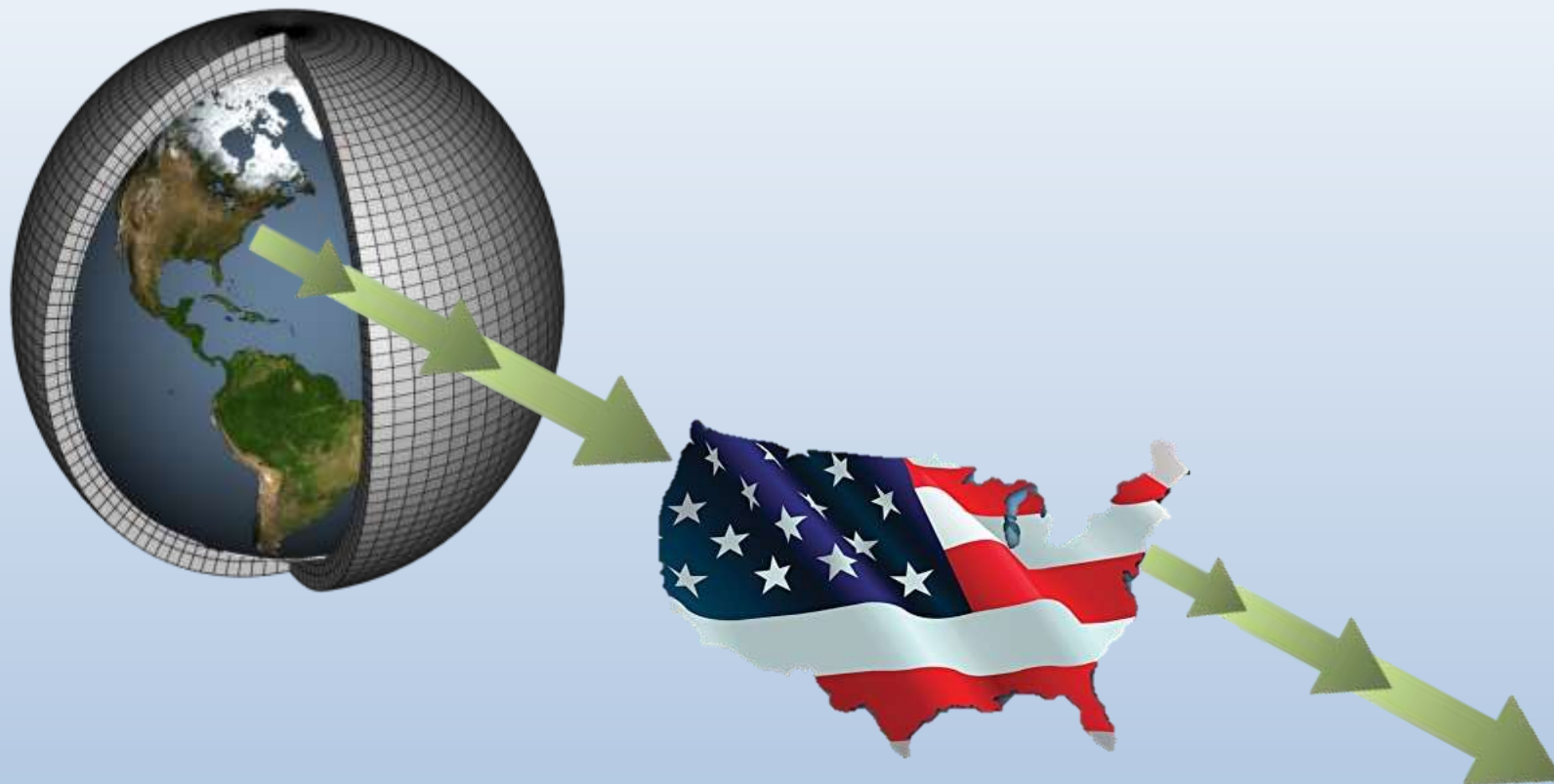
U.S. Precipitation Trends



Percent Change



Down-scaling Climate Models



“All models are wrong, but some are useful”

– George Box, 1976

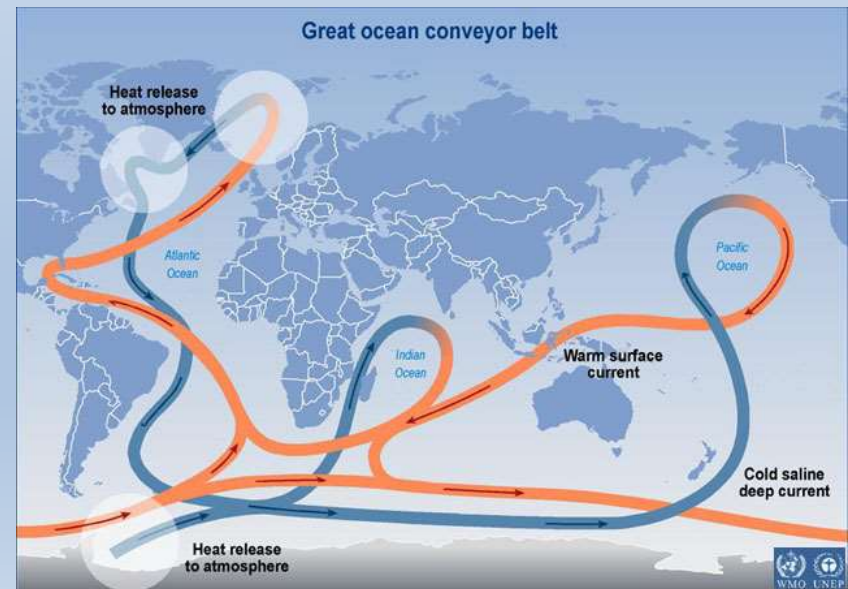
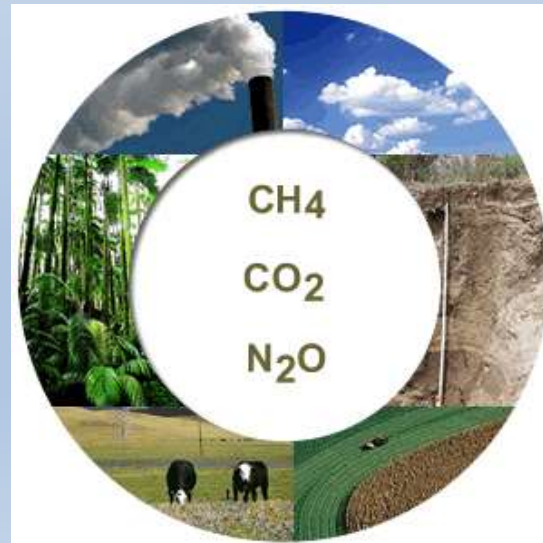
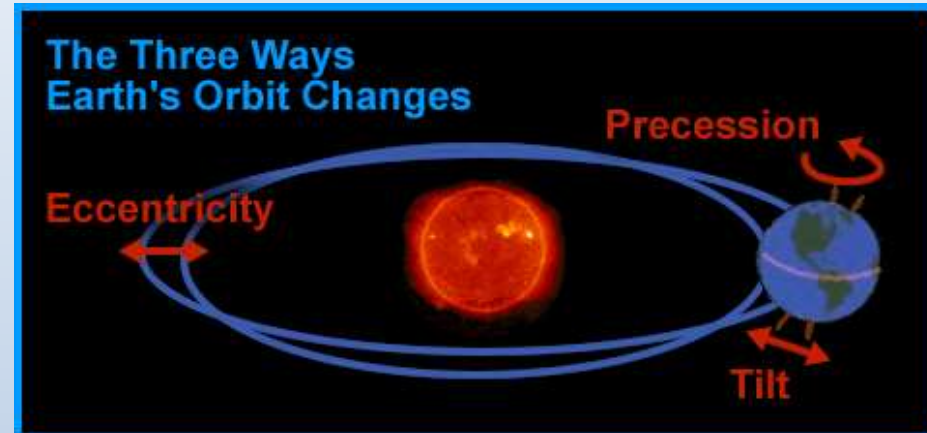
Is Sea Level Rise / Climate Change Happening?



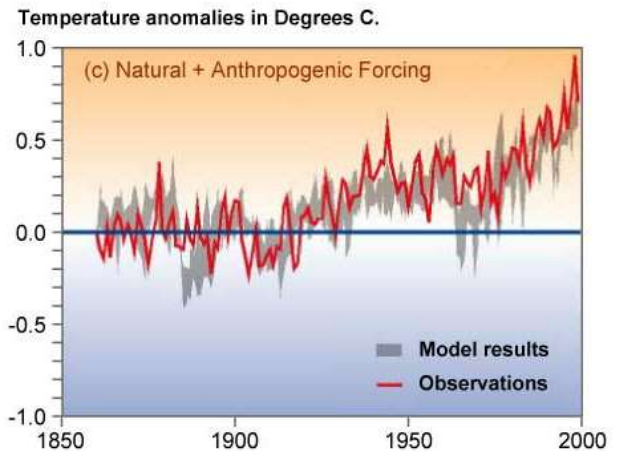
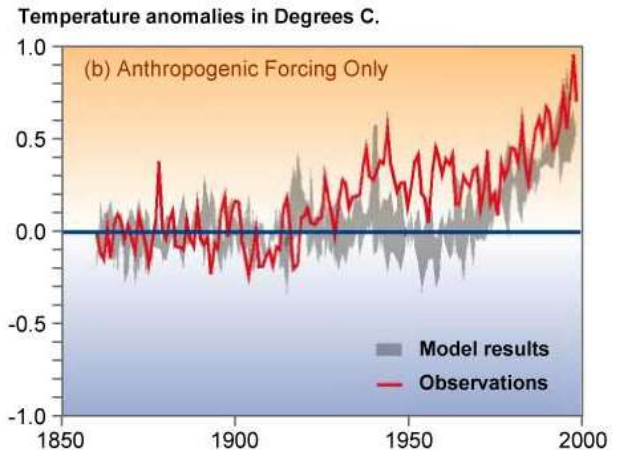
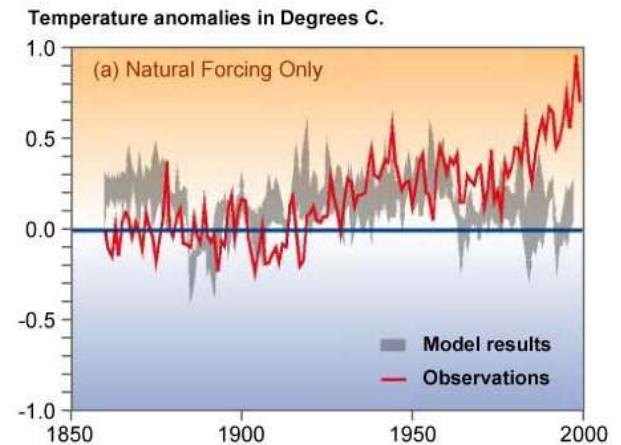
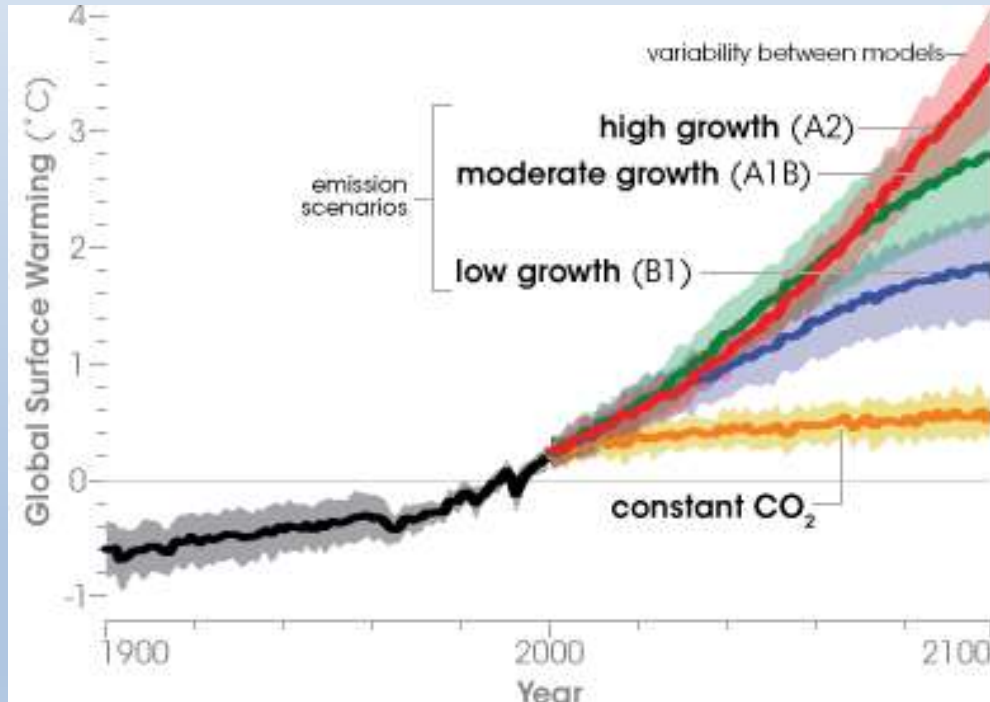
Pasterze Glacier, Austria
Change between 1875 and 2004

<http://www.worldviewofglobalwarming.org/pages/glaciers.html>

- Climate forcings
 - Changes in the Earth's orbit and the sun's intensity
 - Volcanic Eruptions
 - Change in Ocean Currents
 - Changes in Greenhouse Gas Concentrations

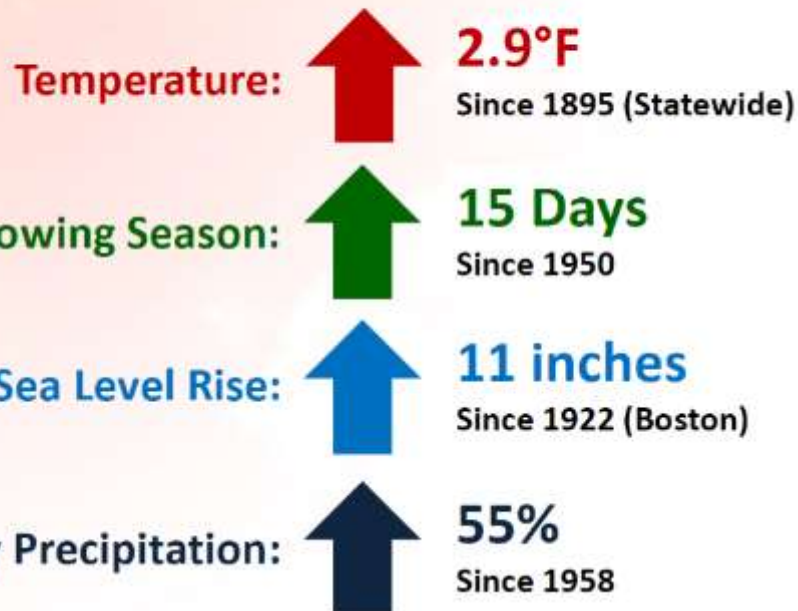


What do the climate models based on Paleoclimate data say?

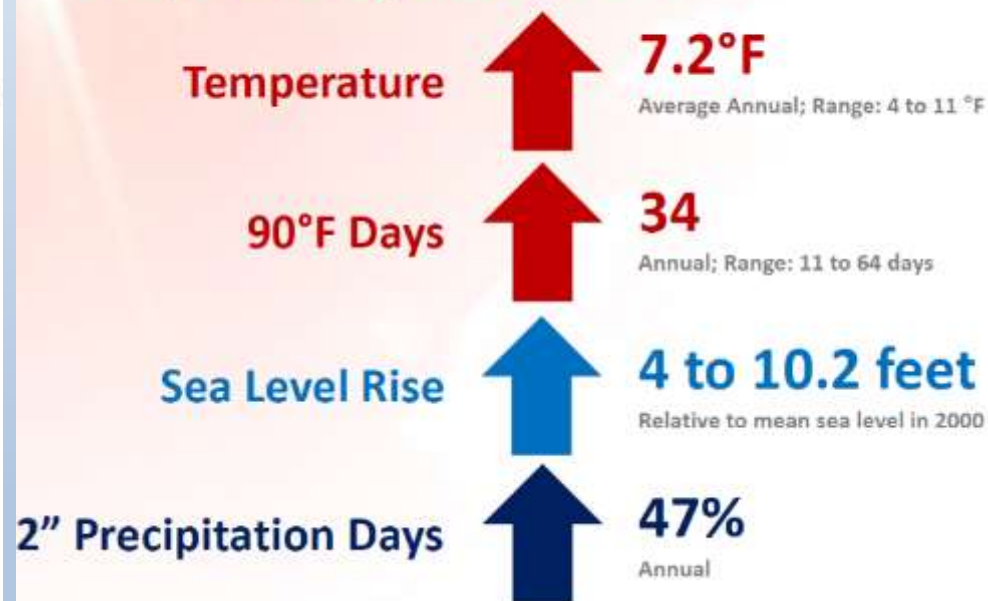


Massachusetts Climate Change Projections (2018)

Massachusetts Observed Climate Changes



Massachusetts Climate Changes Projected by the 2090s



Section 2

What are the drivers of SLR?

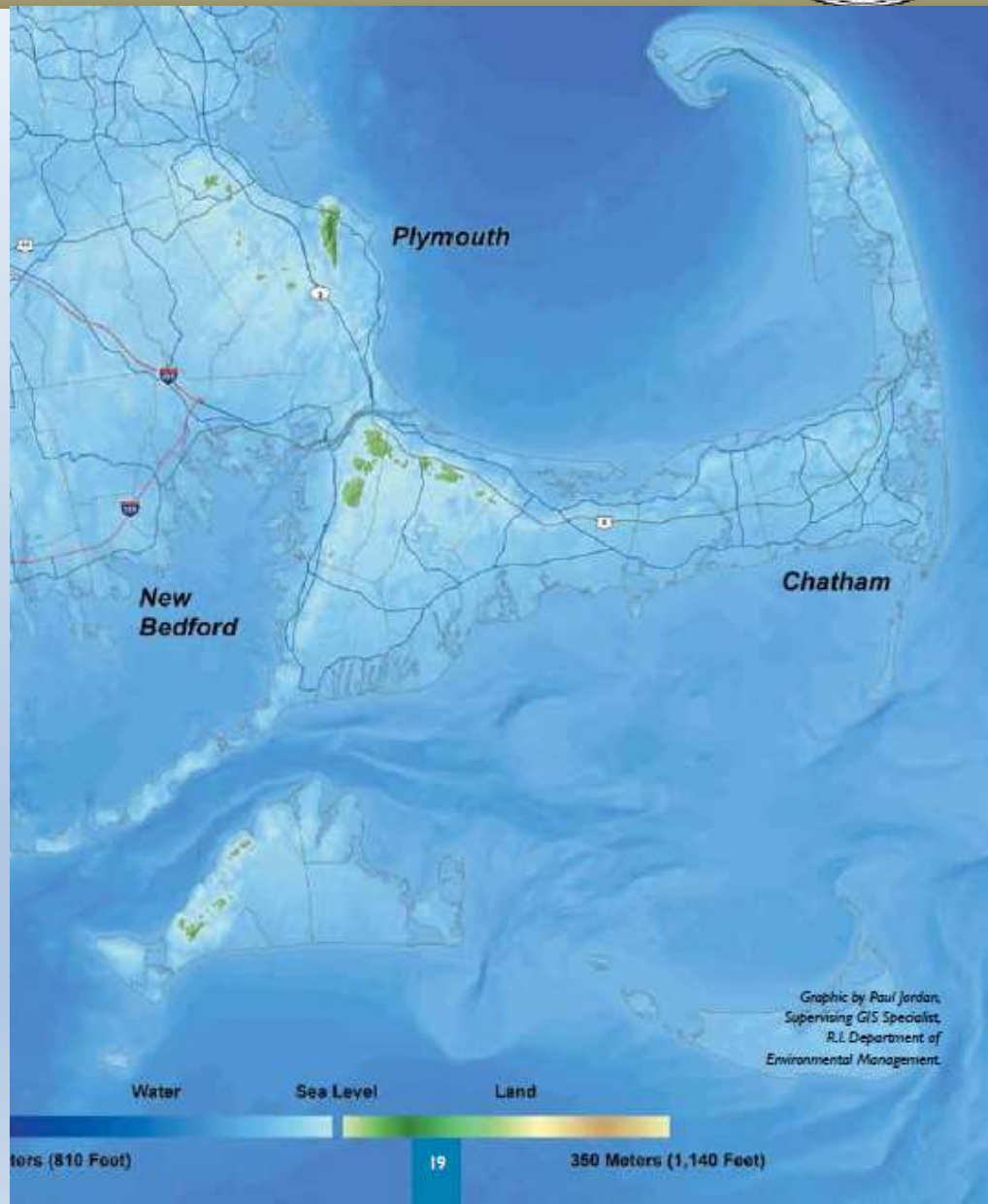


What might this mean for the future?

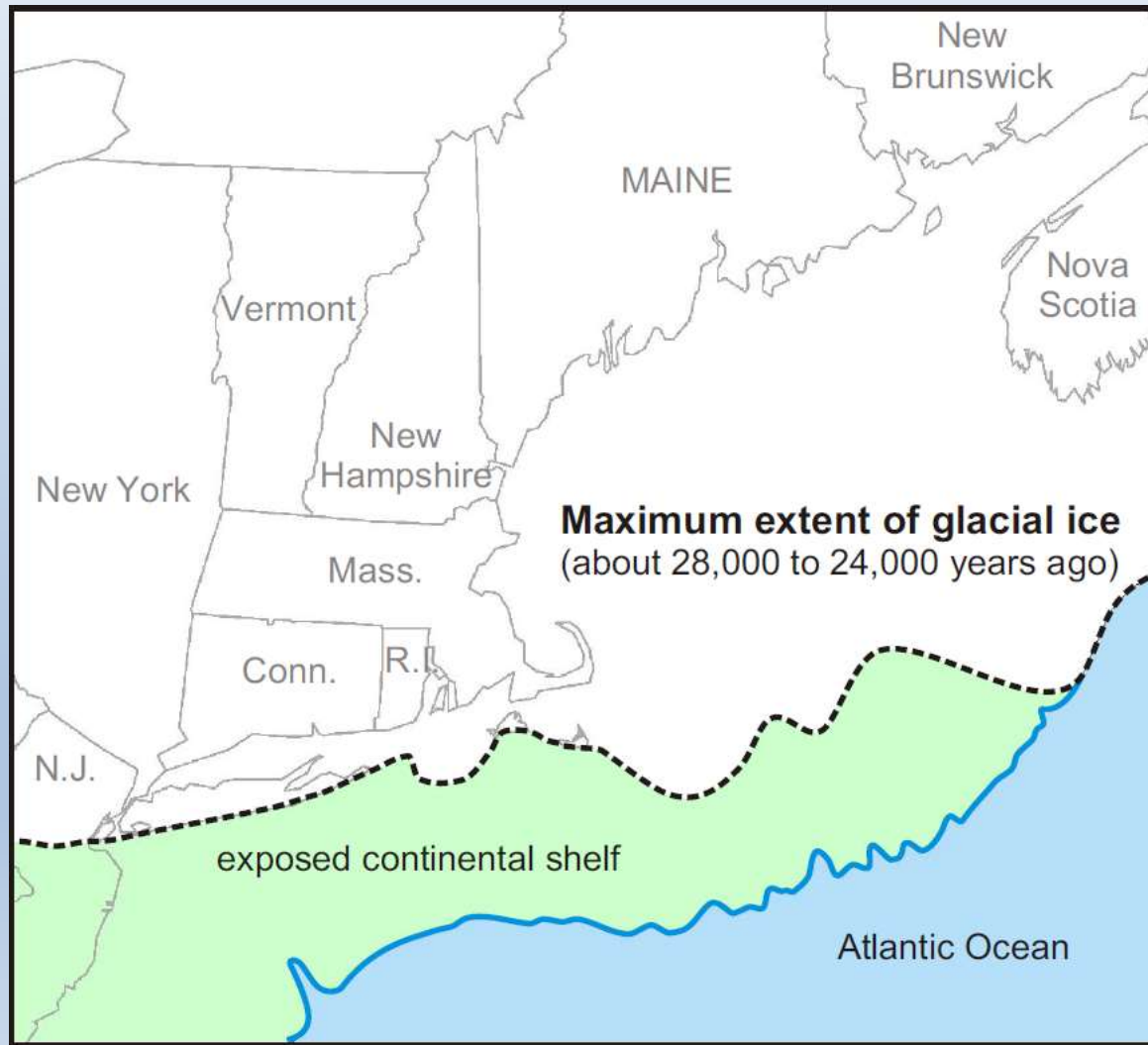
**What if all the polar ice melted?
SLR approx. 220 feet**

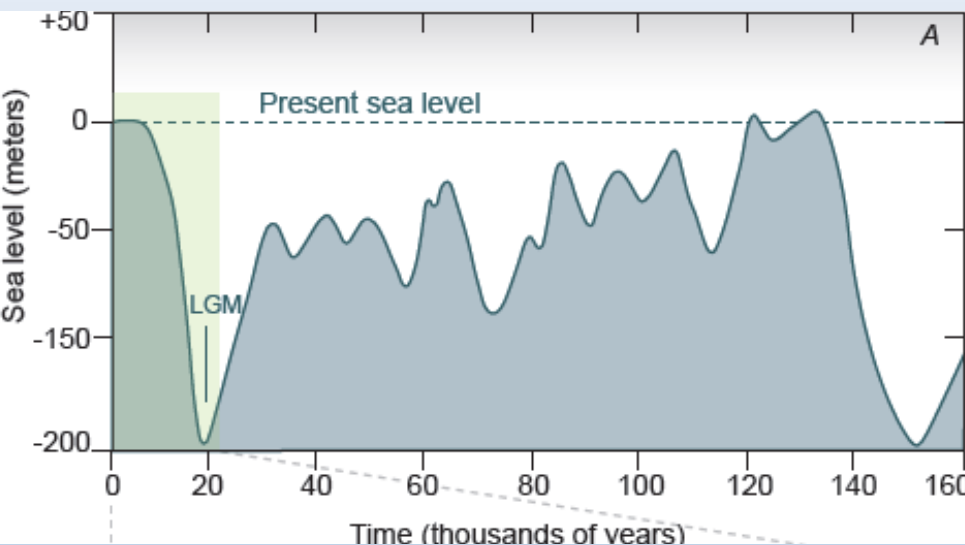


If only I
could
swim !!!



Advance and retreat of the last continental ice sheet (Laurentide - Canada) and the rise in SL that followed the retreat of the ice sheet.





25,000 yr ago
400' below SL, ~1 mile thick
By ~ 15,000 ice was gone.

11,000 years ago

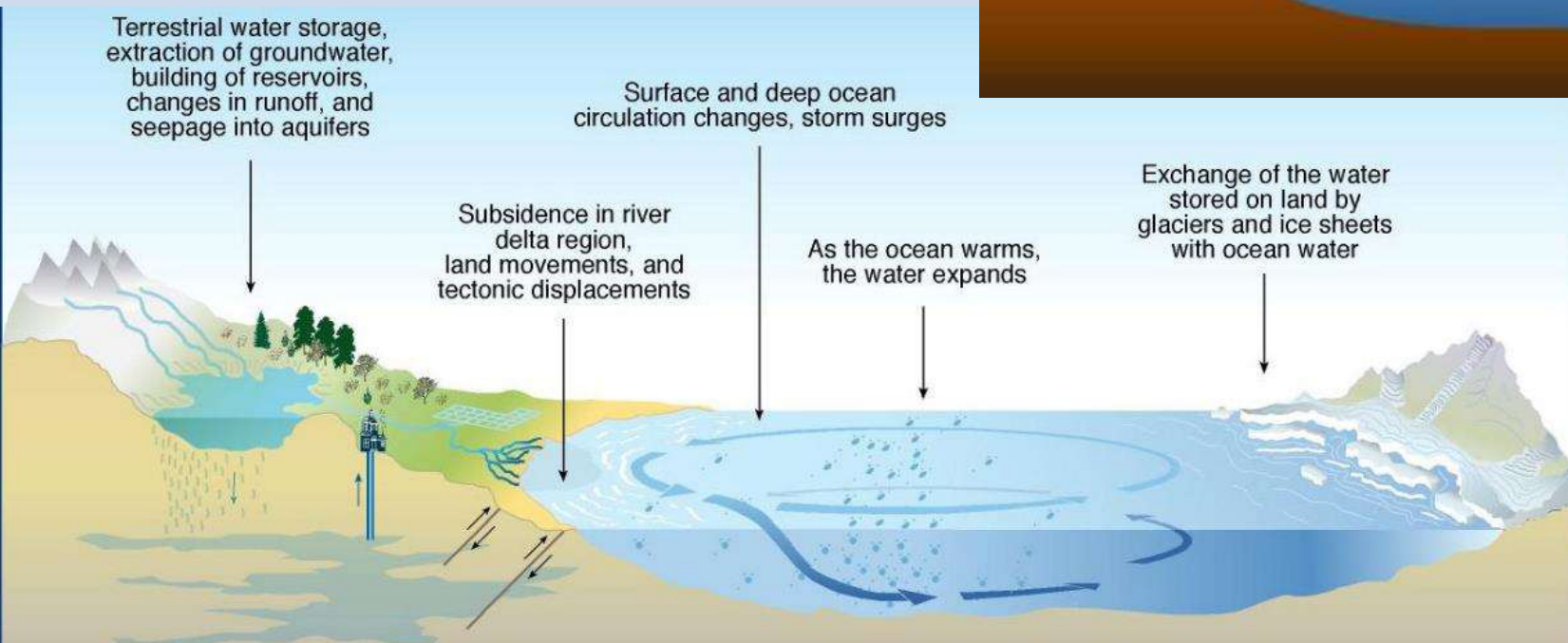
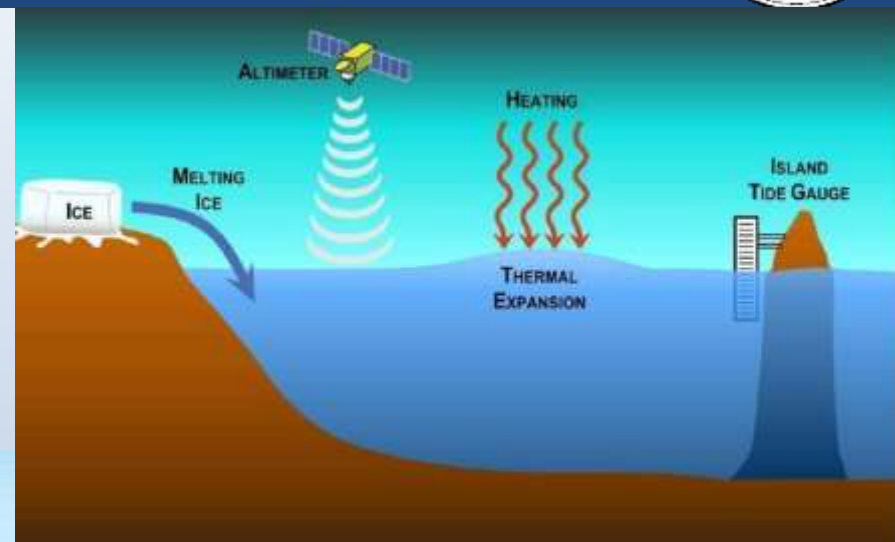


6,000 years ago



Present Day





Global Avg. Sea Level Observations:

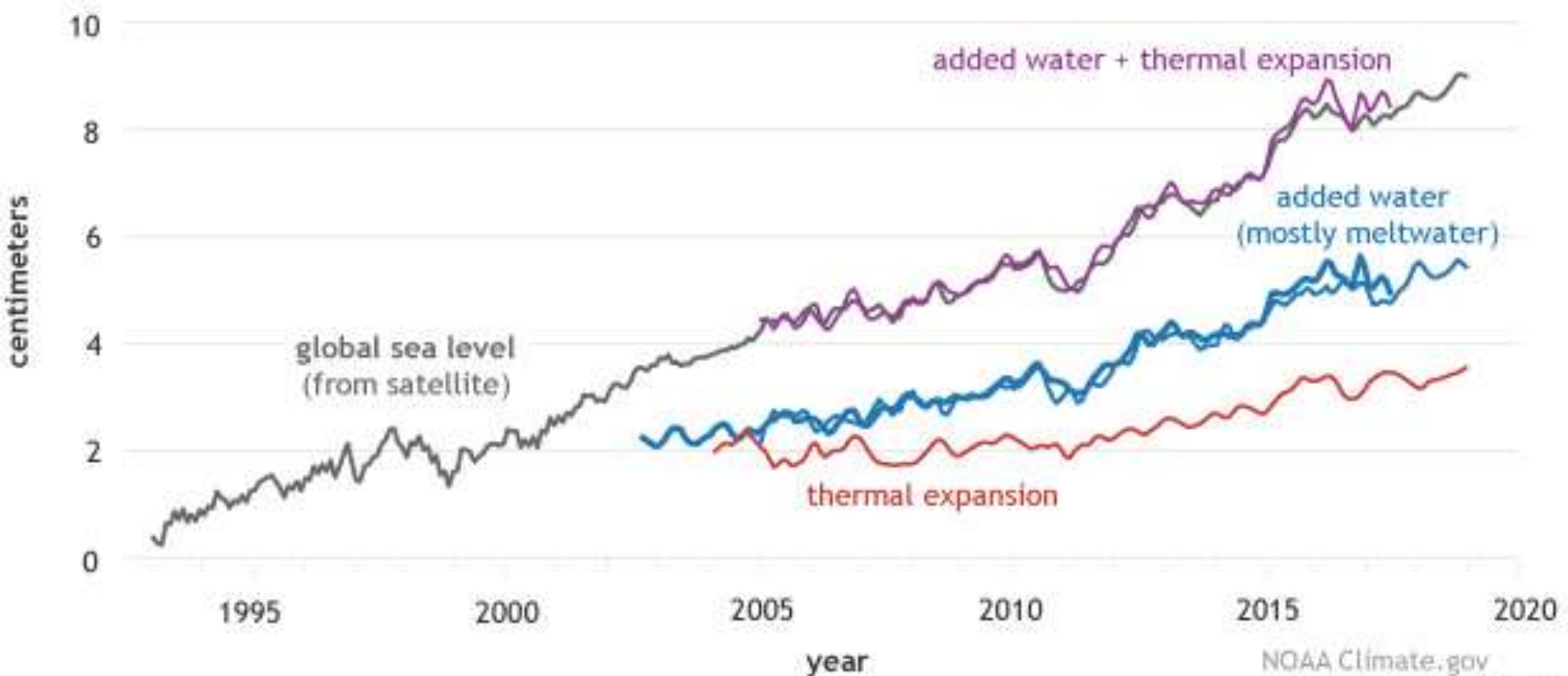
20th century rate: 1.7 ± 0.5 mm/yr

1993 to 2003 rate: 3.1 ± 0.7 mm/yr

thermal expansion 1.6 ± 0.5 mm/yr

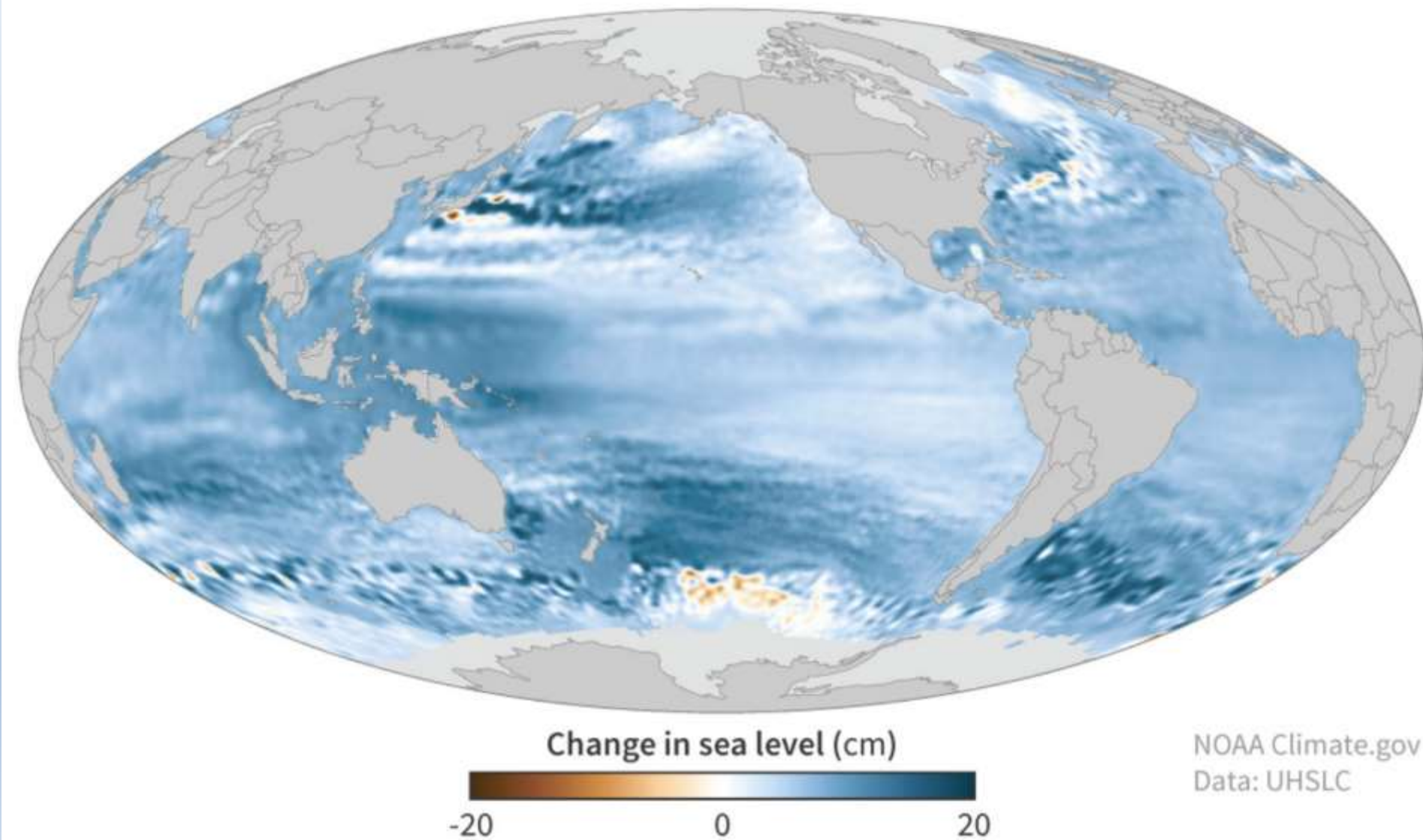
changes in land ice 1.2 ± 0.4 mm/yr

Contributors to global sea level rise (1993-2018)

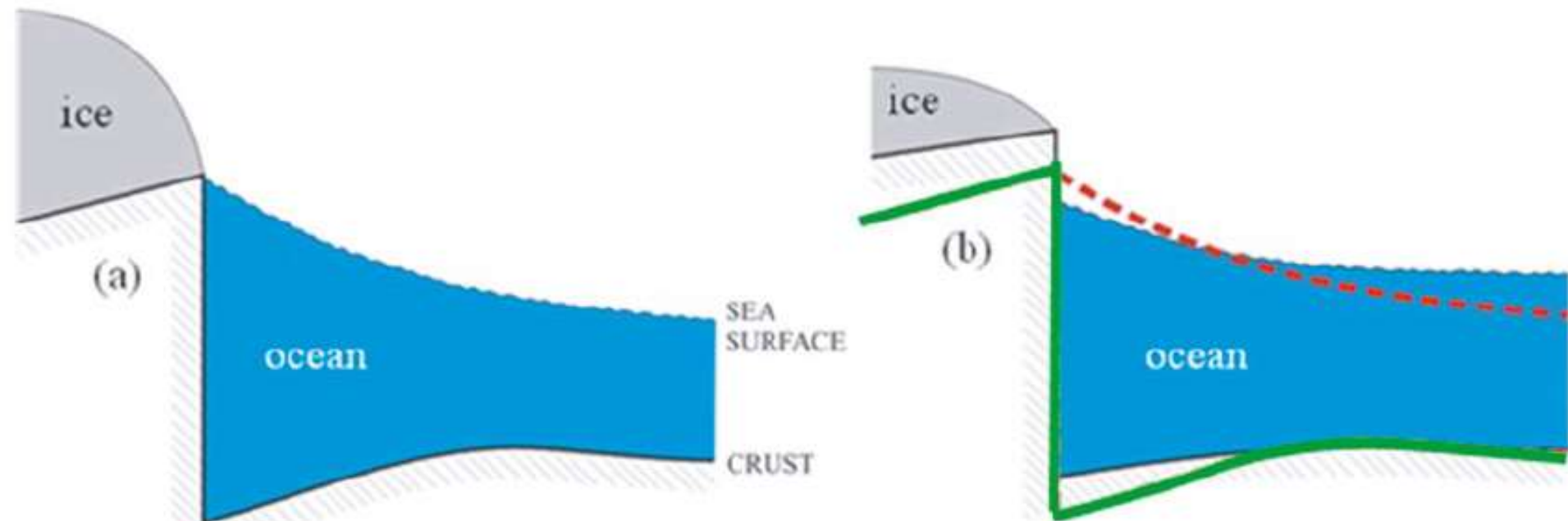


Glacial Isostatic Adjustment (GIA) and sea-level change

SEA LEVEL CHANGE (1993-2019)



Glacial Isostatic Adjustment (GIA) and sea-level change



Glacial isostatic adjustment and sea-level change. State of the art report. Pippa Whitehouse, Durham University. April 2009

**SLR in California and Florida
generated by the melting of the
Antarctic ice sheet is up to 52%
greater than its average effect on
the rest of the world.**

<https://climate.nasa.gov/news/2626/evidence-of-sea-level-fingerprints/>

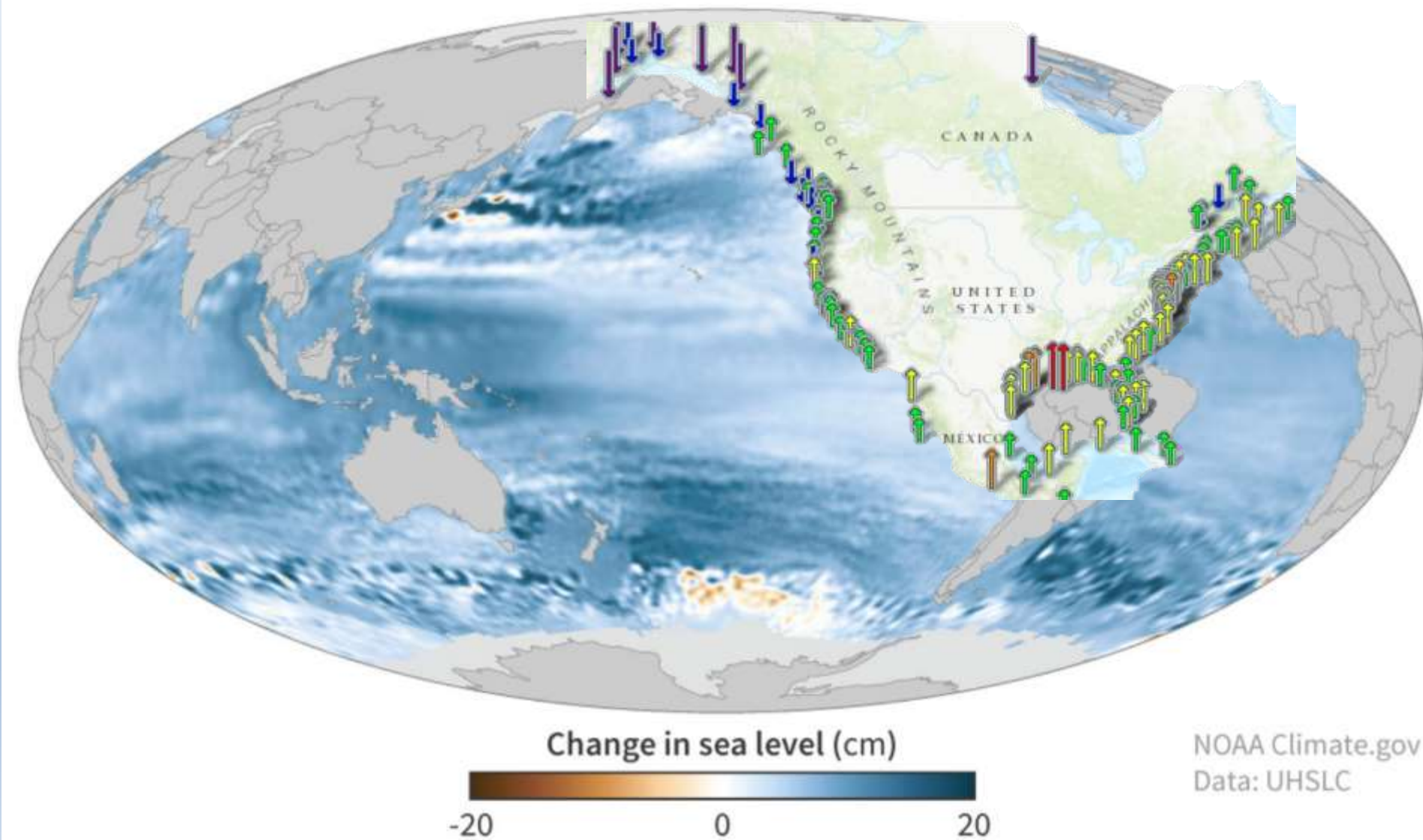
Greenland



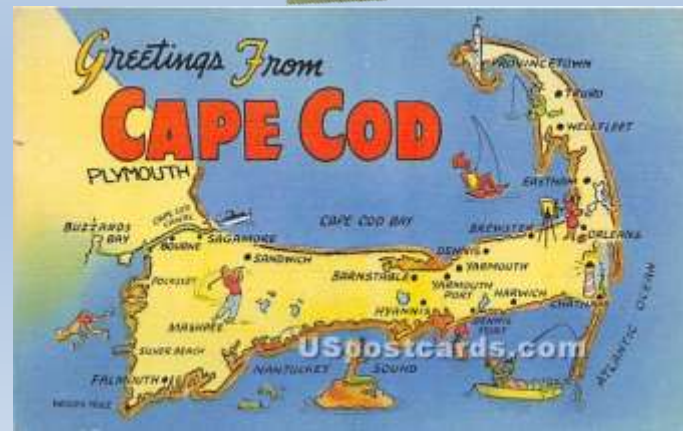
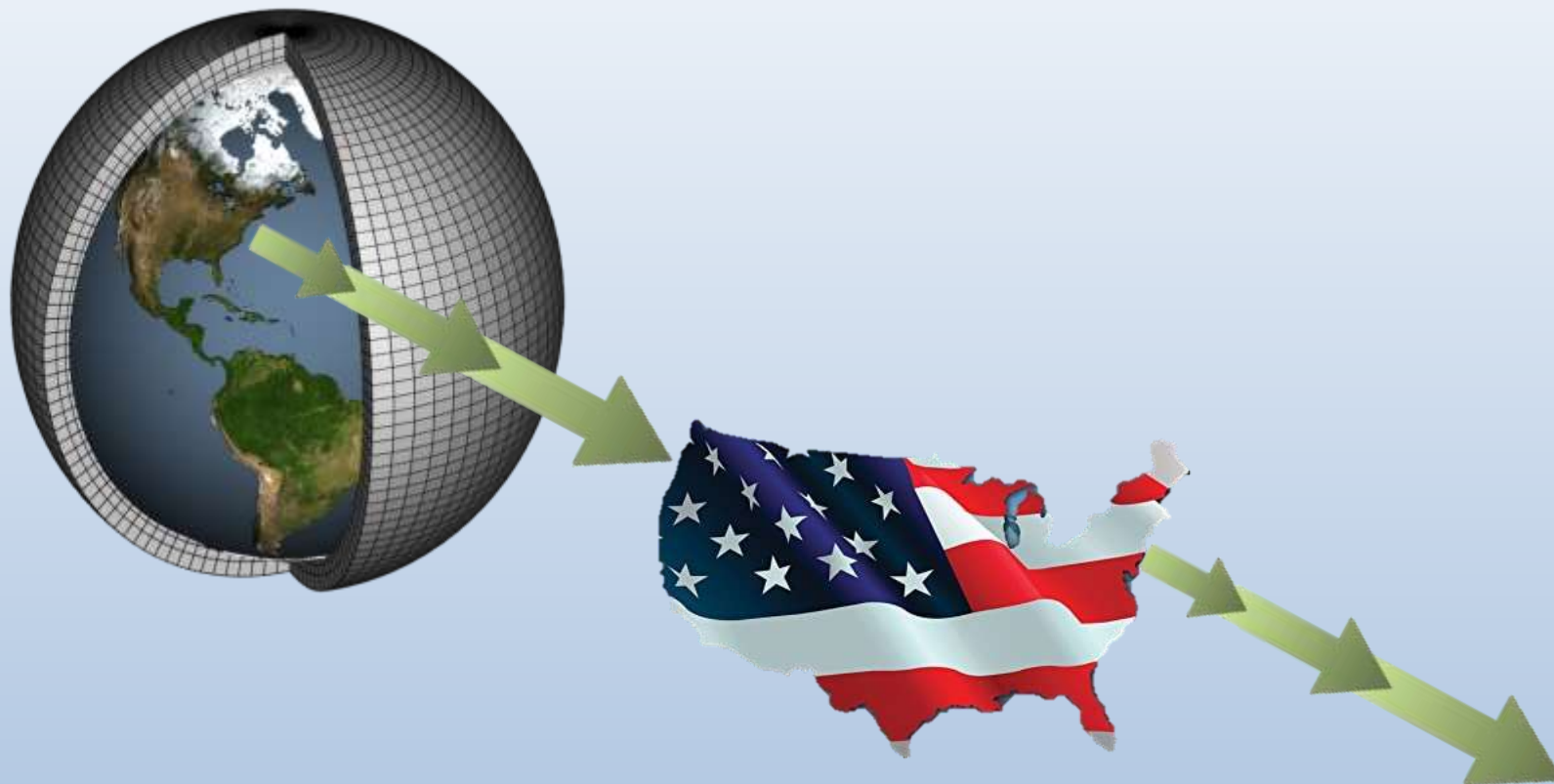
Antarctic



SEA LEVEL CHANGE (1993-2019)



Down-scaling Climate Models



“All models are wrong, but some are useful”

– George Box, 1976

Atmospheric CO₂

April 2022

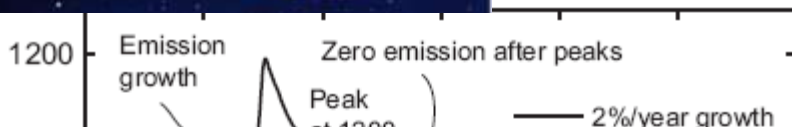
420.23

parts per million (ppm)

Mauna Loa Observatory, Hawaii (NOAA)

Preliminary data released May 5, 2022

Global warming commitment: Irreversibility by any other name



Decade
2003 – 2012

Annual Rate of Increase

2.07 ppm per year

1.67 ppm per year

1.52 ppm per year

1.37 ppm per year

0.90 ppm per year

January 1959 - January 2022

Atmospheric CO₂

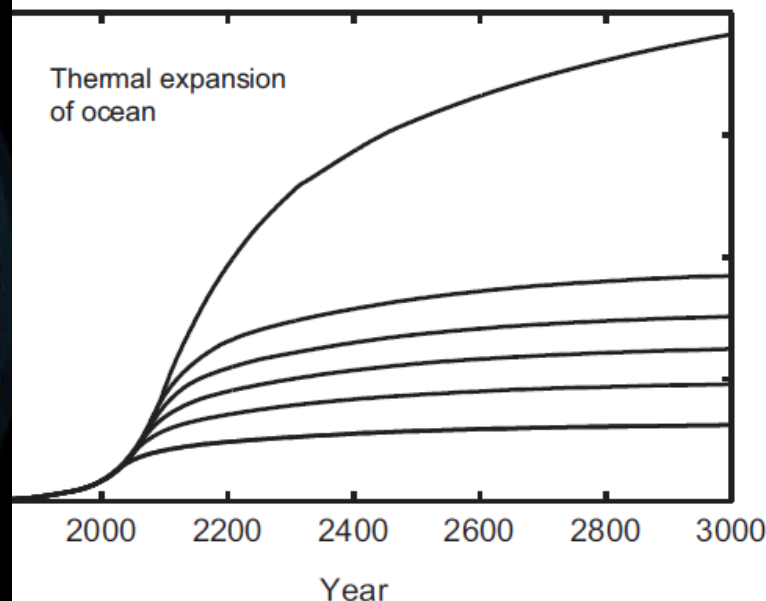
January CO₂ | Year-on-Year | Mauna Loa Observatory



CO₂-earth

Featuring Scripps data of February 4, 2022

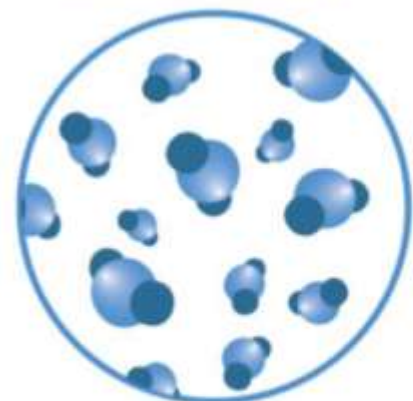
Thermal expansion
of ocean



Solomon et al. 2009, PNAS and <http://co2now.org>

Intergovernmental Panel on Climate Change Sixth Assessment Report

CO₂
concentration



Highest

in at least

2 million years

Sea level
rise



Fastest rates

in at least

3000 years

Arctic sea ice
area



Lowest level

in at least

1000 years

Glaciers
retreat



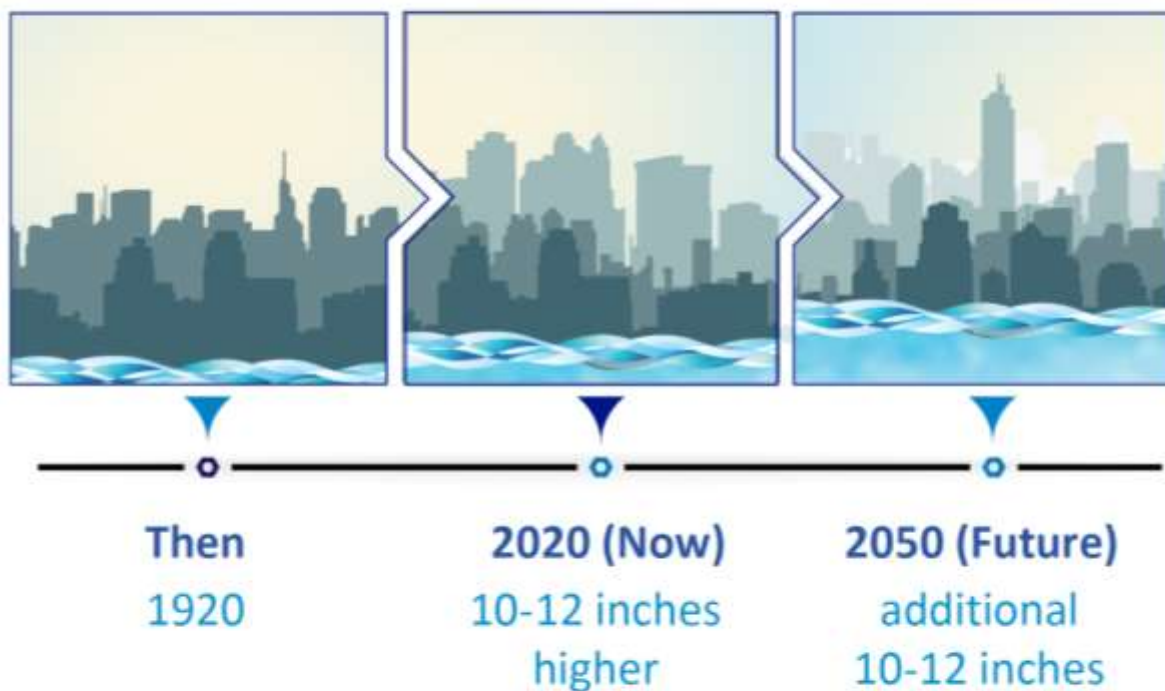
Unprecedented

in at least

2000 years



National Sea Level Rise



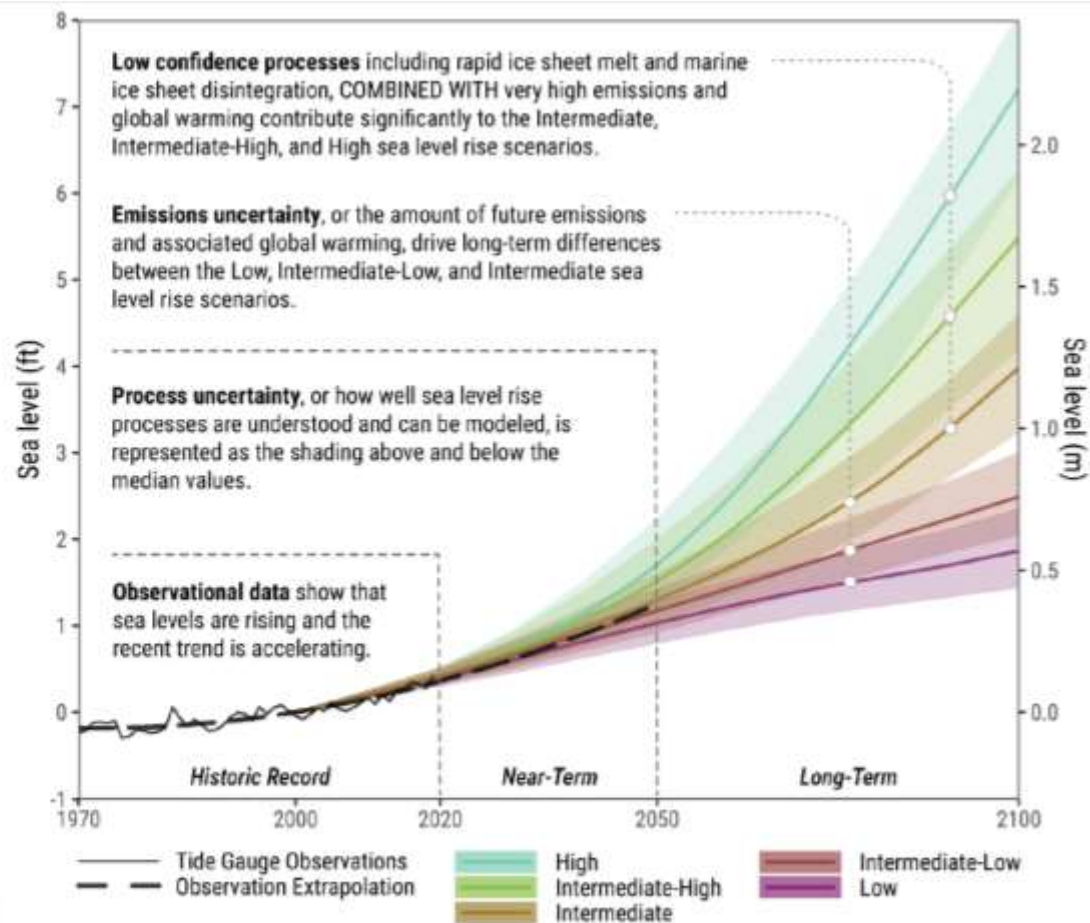
- Projections vary by location.
- 10-12 inch rise in last 100 years; same amount of rise projected in next 30 years.
- Results: profound shift in coastal flooding over next 30 years.
- Results: damaging floods projected 10+ times as often.



Uncertainty factors are related to current science regarding natural processes (process uncertainty) and future emissions and impacts (emissions uncertainty). Scientists account for this by developing many projections that span the likelihood spectrum.

Sea Level Rise Data Past, Present, Future

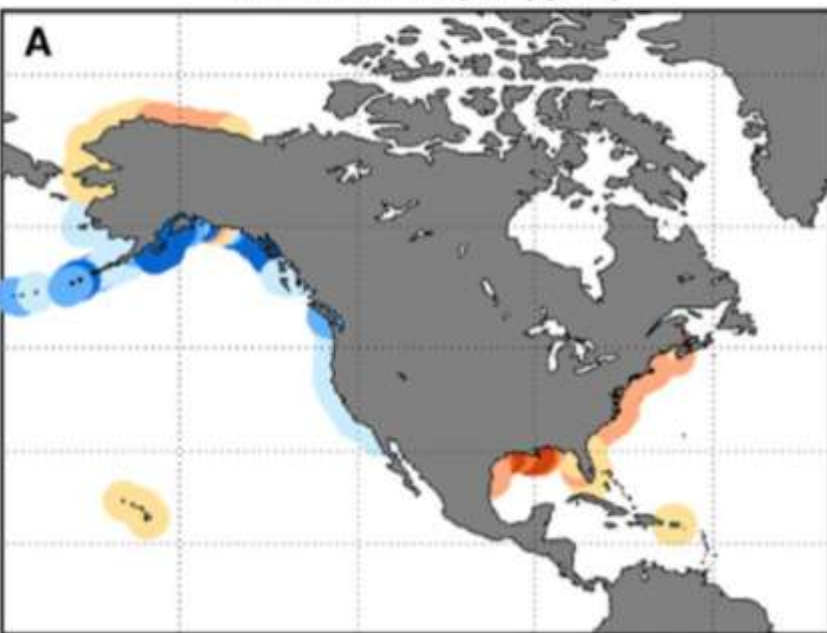
- Greater certainty than previous projections for the next 30 years
- Uncertainty increases after 2050, and is highly dependent on future emissions
- Emissions matter: likely at least two additional feet by 2100 due to current emissions alone



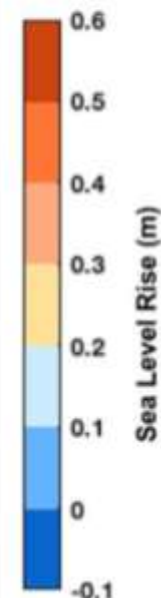
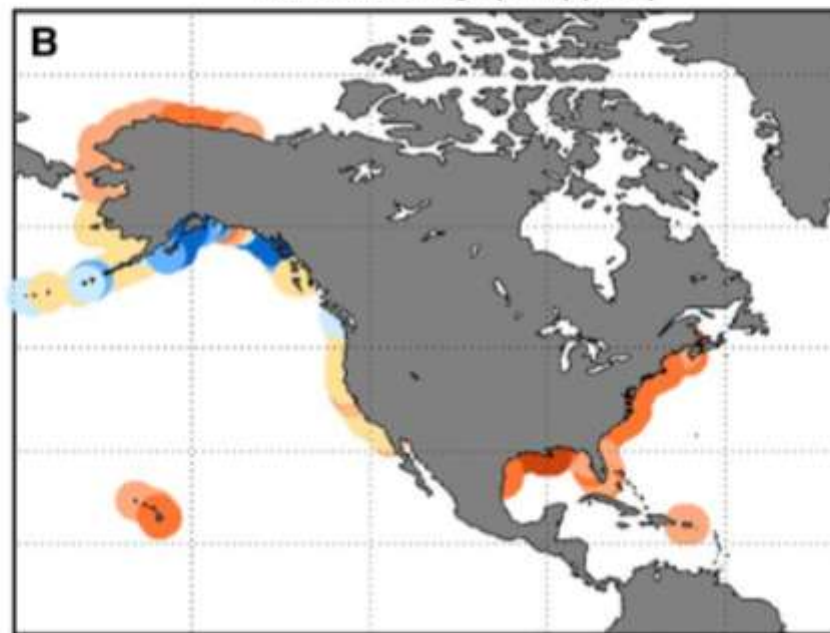
Contiguous U.S.A. Projections

Near-Term Sea Level Change (2020-2050)

Intermediate Low (0.5m) (2050)



Intermediate High (1.5m) (2050)





Sea Level Rise Technical Report

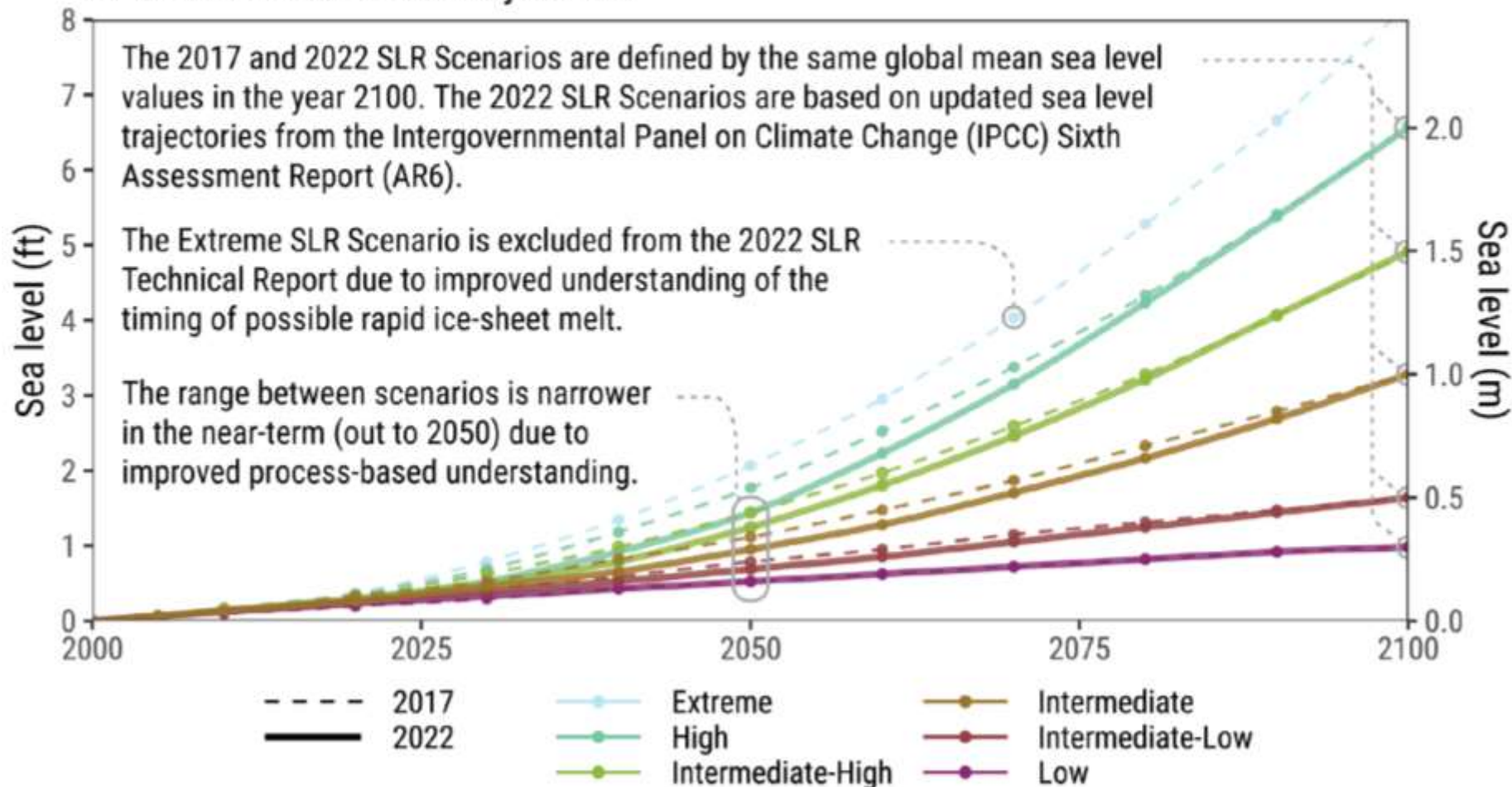
Comparing 2017 and 2022 Scenarios

- Global scenarios for 2100 stayed the same, but the timing changed; less acceleration in scenarios until after 2050
- 2022 report provides a greater understanding of future sea level trends in the near term (next 30 years)



What has changed from 2017?

Global Mean Sea Level Projections





KEY TAKEAWAYS

U.S. coast: average 10-12" SLR in next 30 years.

- Equals change seen over past 100 years.
- Rates will be lower or higher in different regions.

Results: More extreme tides and damaging storm surges.

Results: Profound shift in coastal flooding over next 30 years. By 2050, “moderate” (typically damaging) flooding likely to occur 10+ times more often.

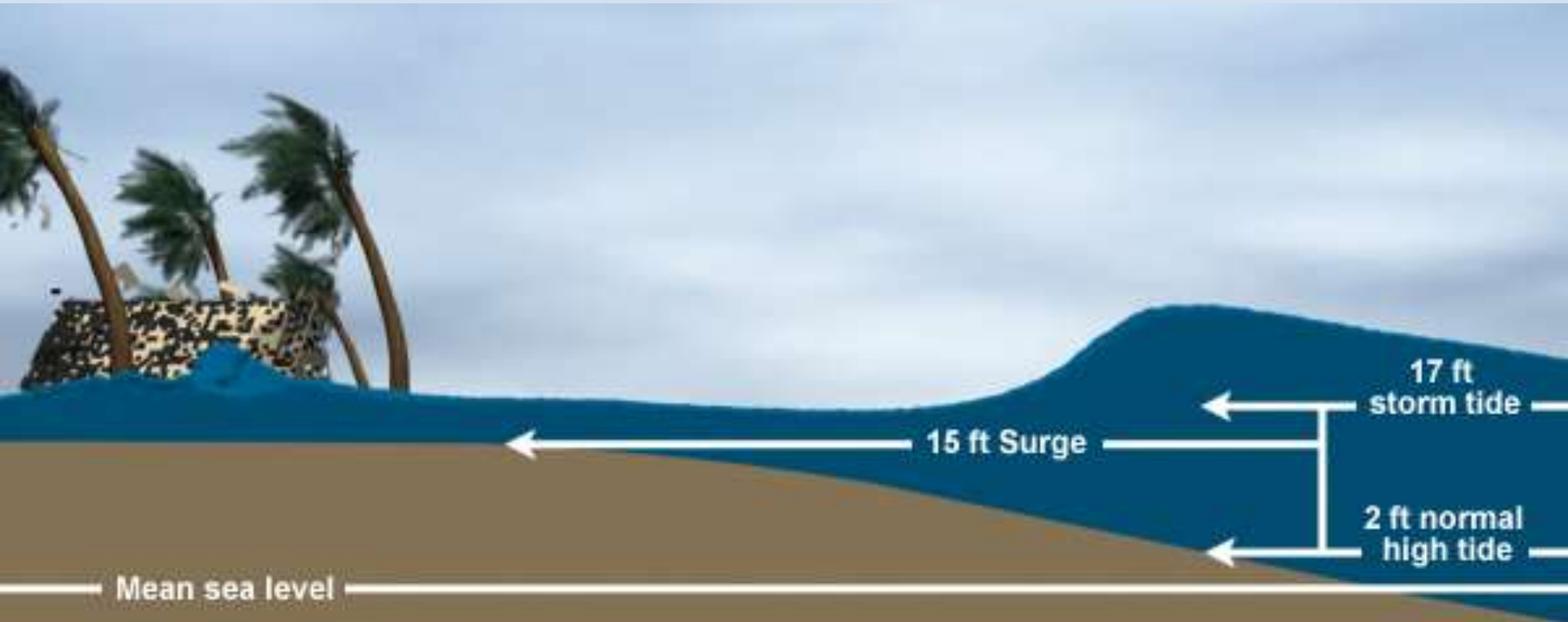
Section 3

What is Storm Surge?



Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

Storm tide is the water level rise during a storm due to the combination of storm surge and the astronomical tide.



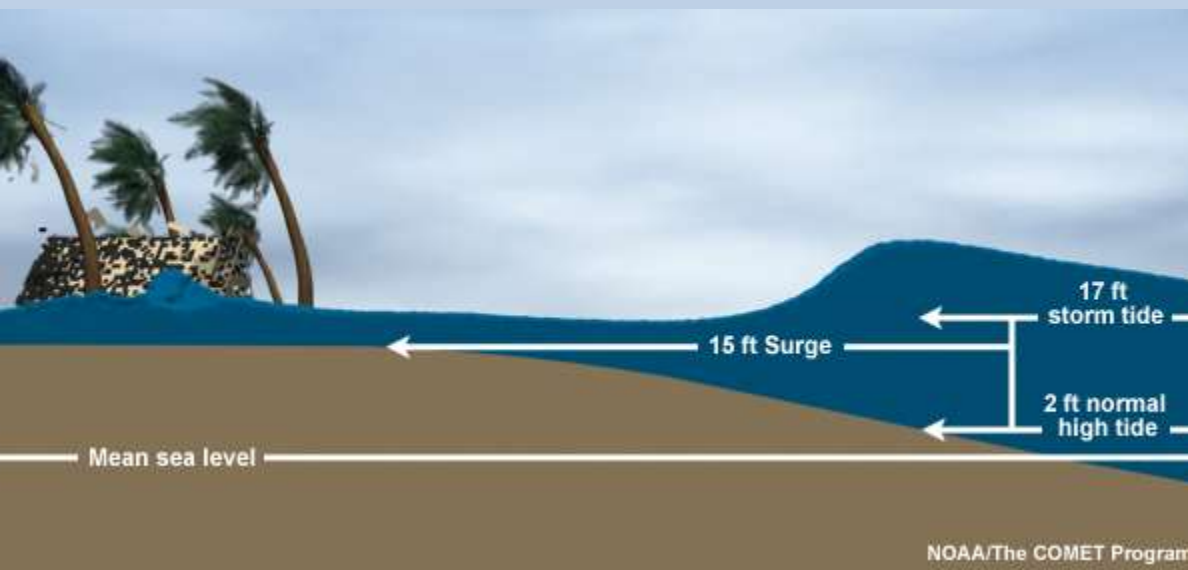
Width and slope of the continental shelf.



A shallow slope will potentially produce a greater storm surge than a steep shelf.

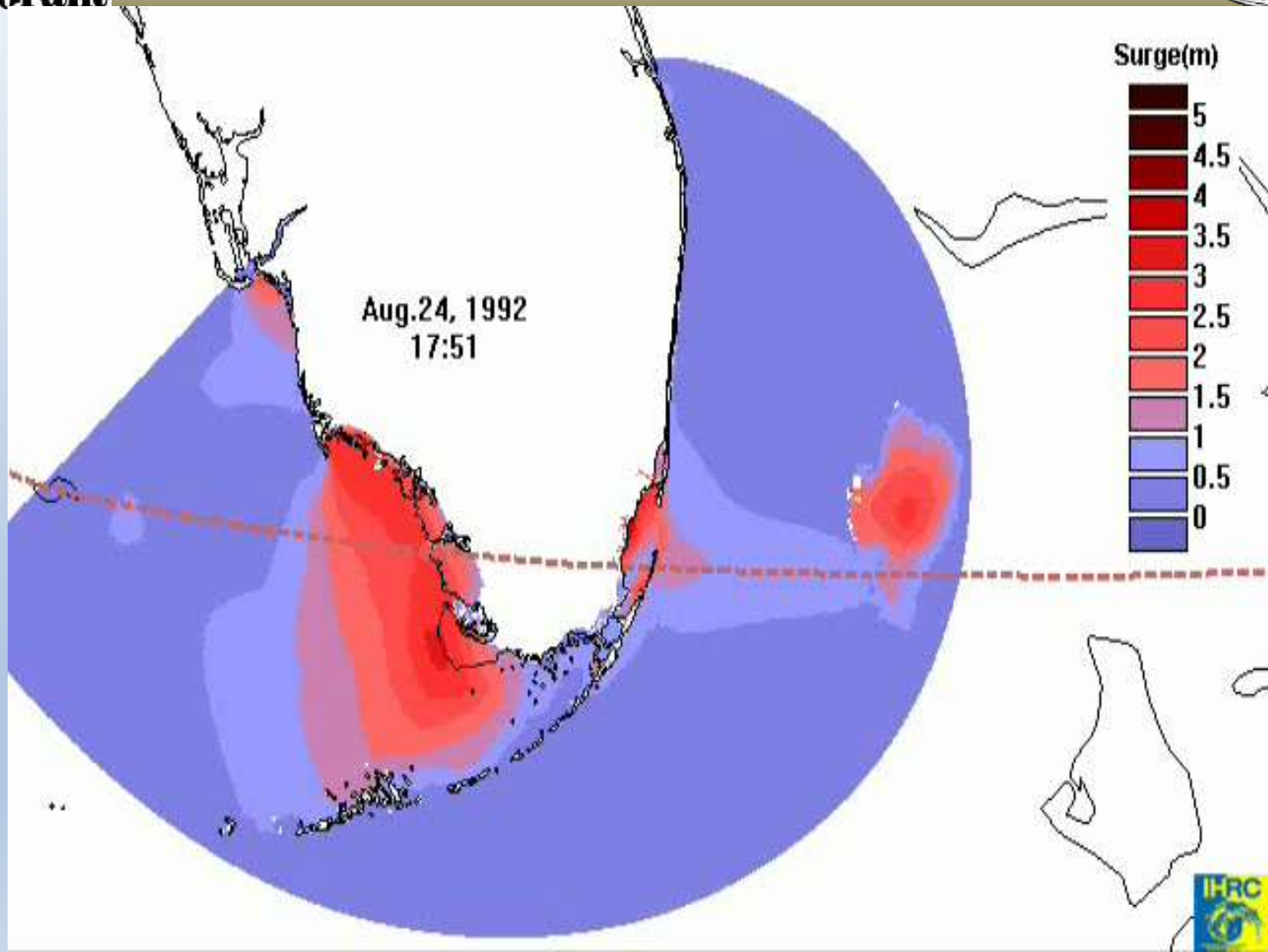


EX. Cat 4 hitting the Louisiana coastline(wide and shallow shelf) may produce a 20' storm surge, in Miami Beach, (shelf drops off quickly) might see an 9' surge.



What is Surge?

(Hurricane Andrew - Cat. 4 @ landfall)



Estuaries can focus surge

HURRICANE Bob
NOV-18
6:13 PM
6:38 AM EDT
NOV-18 13

Surge is a function of:

- Storm Intensity
- Storm Track
- Land Geometry / Bathymetry



Bob (1991).....Cat.2

US: 6 deaths and
\$680 million in
damage in the
United States

MA: Storm surges
of 10 to 15 ft

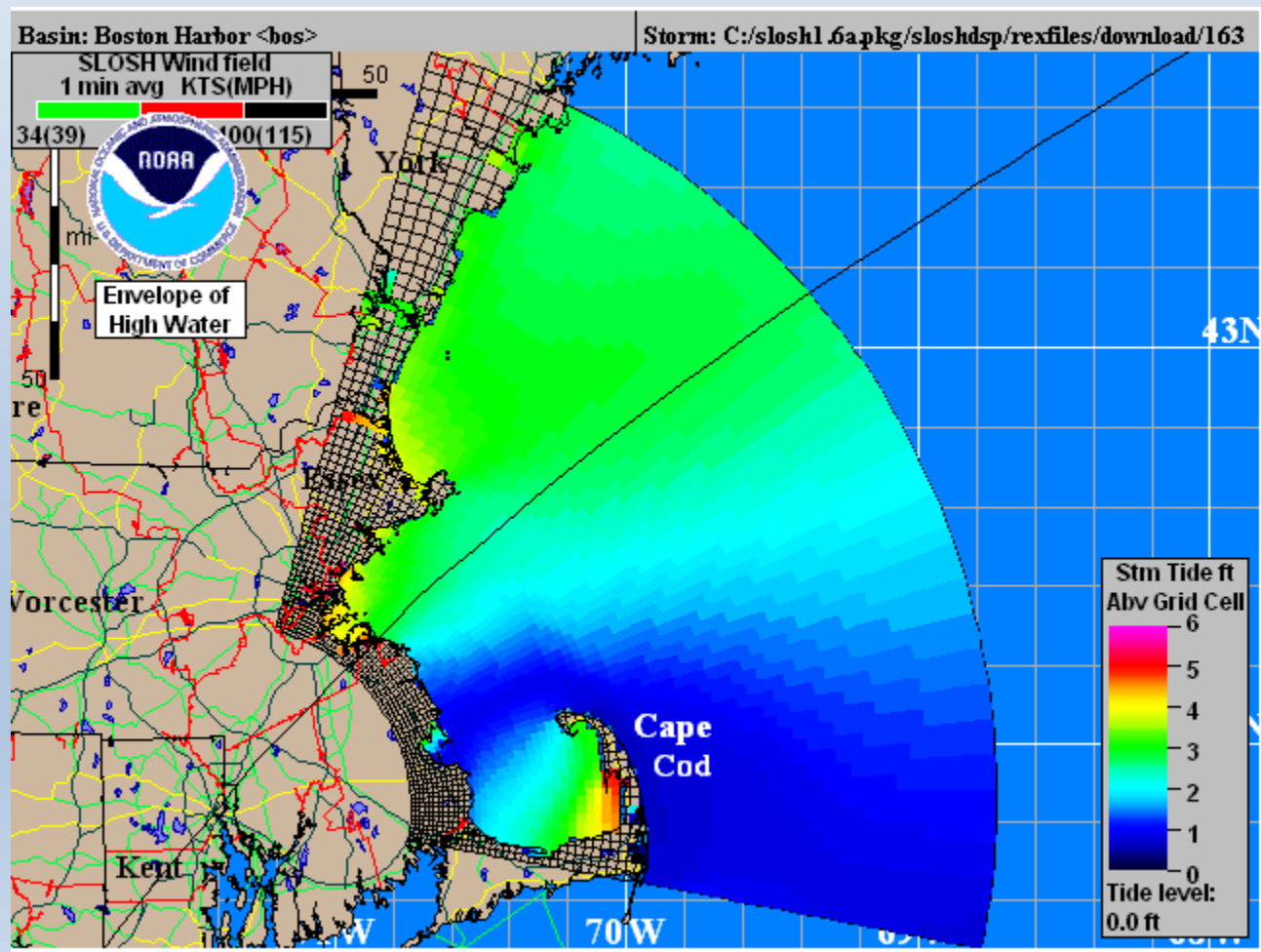
*Will it hit at:
MLW or MHW?*

Great Colonial Hurricane of 1635

("The big one" ~Cat.3)

US: ??? deaths and \$??? million in damage in the United States

MA: Storm surges of >6 ft



Storm surges of >>>>> 6 ft

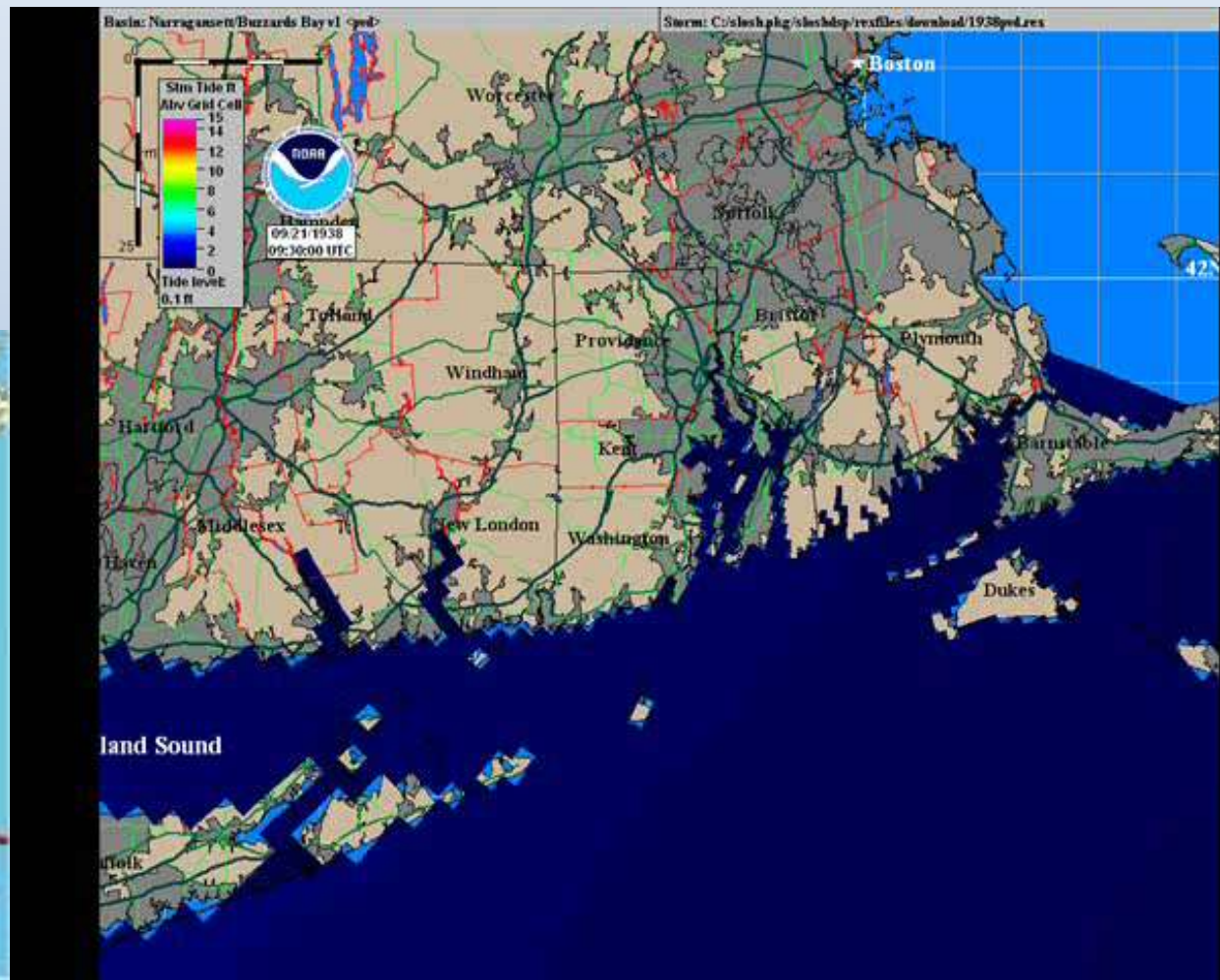
The grand opening of the
Cape Cod Canal was
July 29, 1914

New England Hurricane 1938

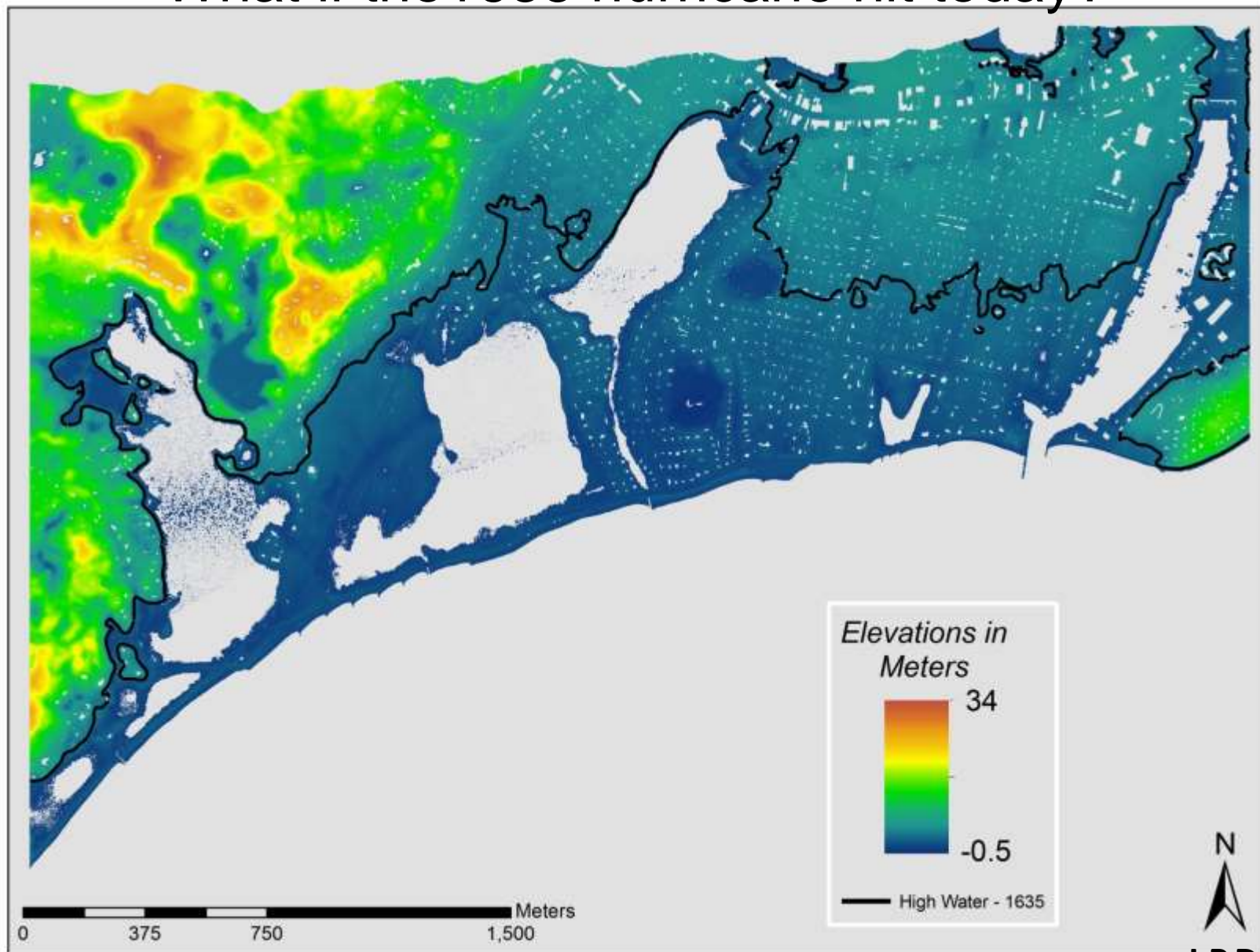
(Puerto Rico- Cat.5....NE- Cat.3@ landfall)

US: 600 deaths and \$308 million in damage in the United States

MA: Storm surges of 10 to 12 ft



What if the 1635 hurricane hit today?



Section 4

What are the ways in which SLR and Storms Interact?

PEARLS BEFORE SWINE

by Stephan Pastis



Nor'Easter (January 2018)

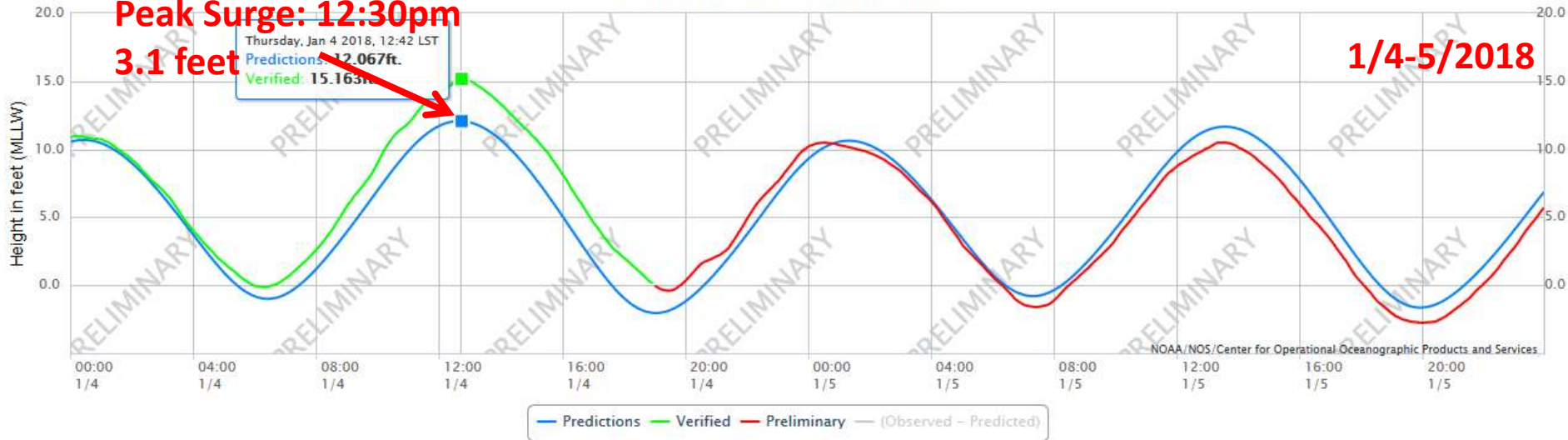
High Tide: 12:30pm

Peak Surge: 12:30pm

3.1 feet

NOAA/NOS/CO-OPS
Observed Water Levels at 8443970, Boston MA
From 2018/01/04 00:00 LST to 2018/01/05 23:59 LST

1/4-5/2018



Nor'Easter (January 2018)



Hurricane Sandy (10/29-30/2012)

Predicted High WL = **10.3** MLLW

Actual High WL = 12.8 MLLW

Max Surge: 4.5'

High Tide Surge: 2.5'

Nor'easter Nemo (2/8-2/9/2013)

Predicted High WL = **10.0** MLLW

Actual High WL = 13.0 MLLW

Max Surge: 3.9'

High Tide Surge: 3.0'

Nor'easter Grayson (1/4-5/2018)

Predicted High WL = 12.1 MLLW

Actual WL = **15.2** MLLW

Max

High

SL has risen ~4.5" in the
40 years since 1978....so
SLR is the reason the
record was broken!!!

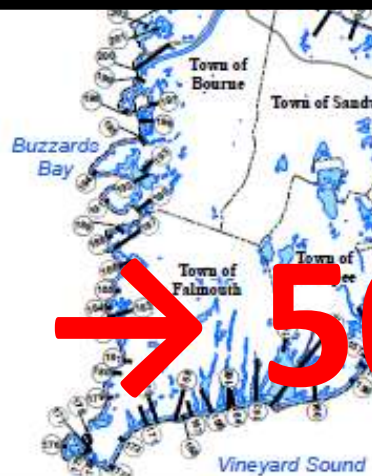
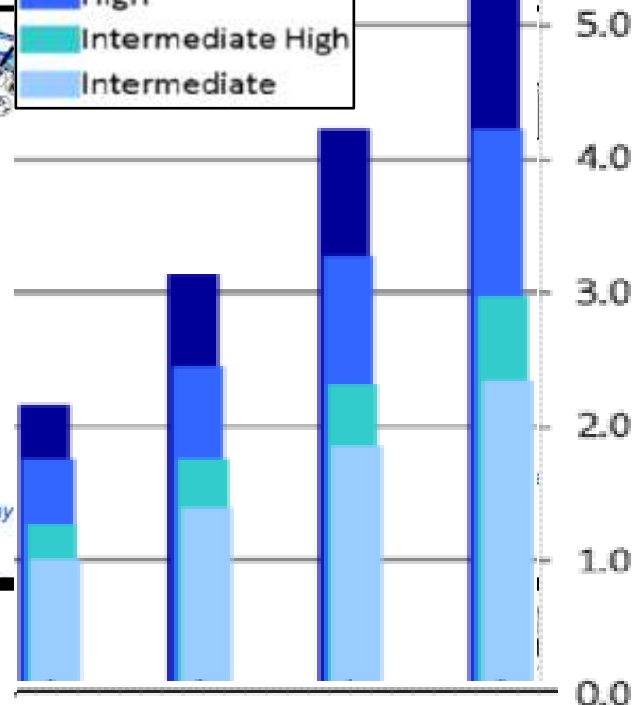
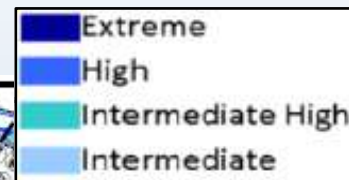
In Boston, a storm tide of 15.16' was recorded which beat the record set by the Blizzard of 1978 (15.0').

Changing the return period of flooding

TABLE 10 – TRANSECT DATA – 2013 COASTAL STILLWATER ELEVATIONS (FEET NAVD88³)

TRANSECT	10- PERCENT- ANNUAL- CHANCE	2- PERCENT- ANNUAL- CHANCE	1- PERCENT- ANNUAL- CHANCE	0.2- PERCENT- ANNUAL- CHANCE
032	9.6	10.6	10.9	12.0
033	9.6	10.6	10.9	12.0

1.3'



Cape Cod Bay

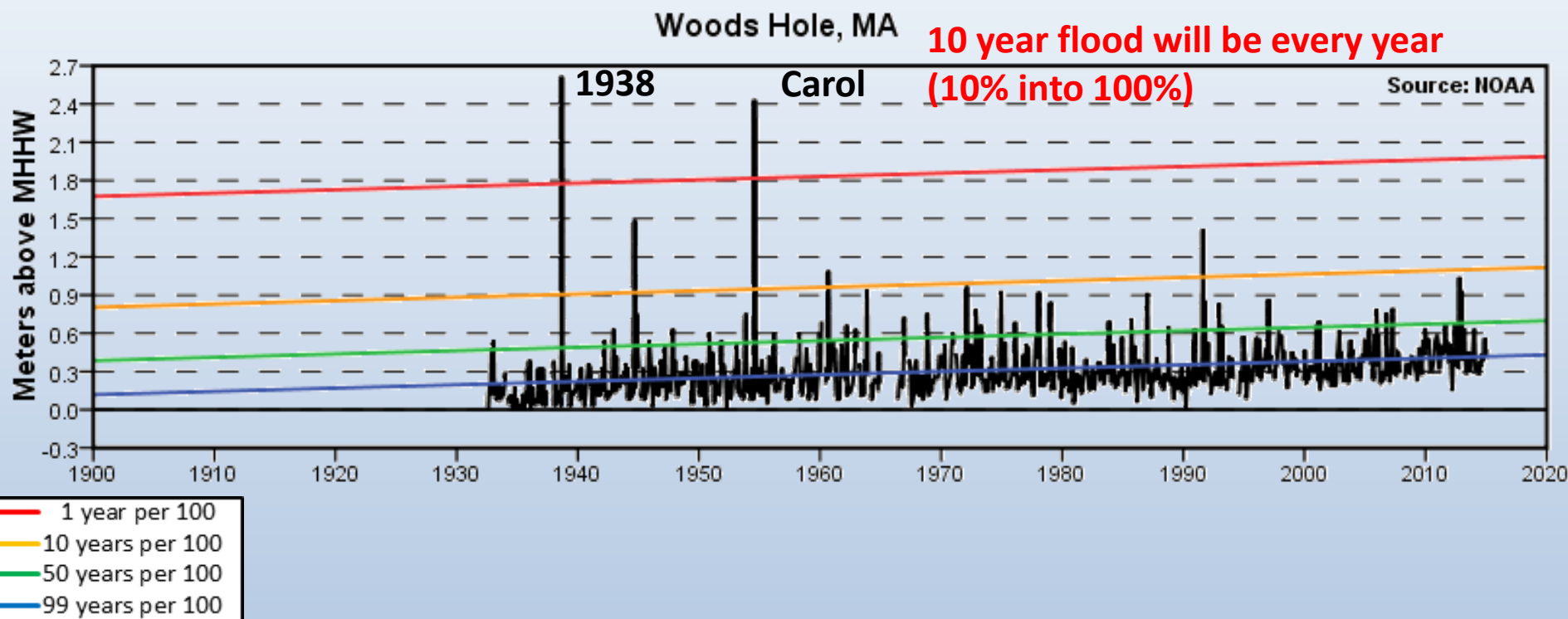


FIGURE 2

FEDERAL EMERGENCY MANAGER
BARNSTABLE COUNTY
(ALL JURISDICTIONS)

500 yr → 50 yr

100 yr → 10 yr



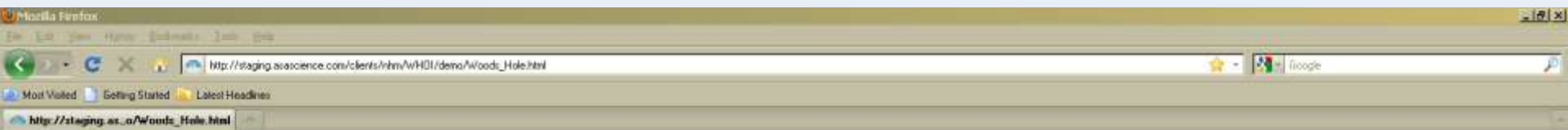
Top Ten Highest Water Levels for long-term stations in feet above MHHW (as of 1/2015)

* --- Inferred Level

! --- Last Recorded Level

--- High Water Mark

Station Number	Station Name	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
8447930	Woods Hole, MA (since 1932)	9/21/1938 # 8.58	8/31/1954 * 7.98	9/14/1944 * 4.88	8/19/1991 4.65	9/12/1960 3.58	10/29/2012 3.42	2/19/1972 3.18	11/30/1963 3.08	12/27/2012 3.07	12/2/1974 3.06



Condition

Calm

Hurricane

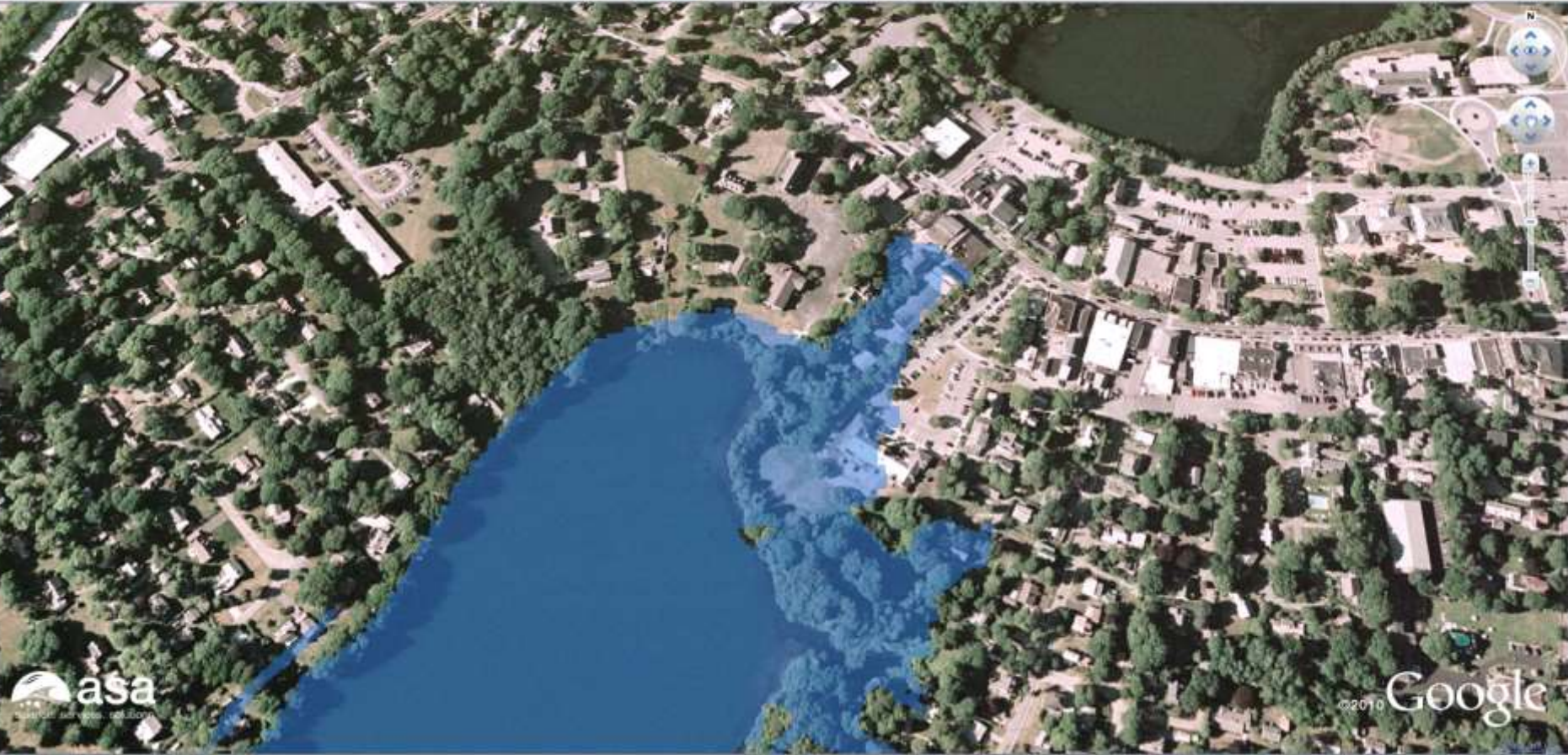
with 1 foot of

Sea Level Rise

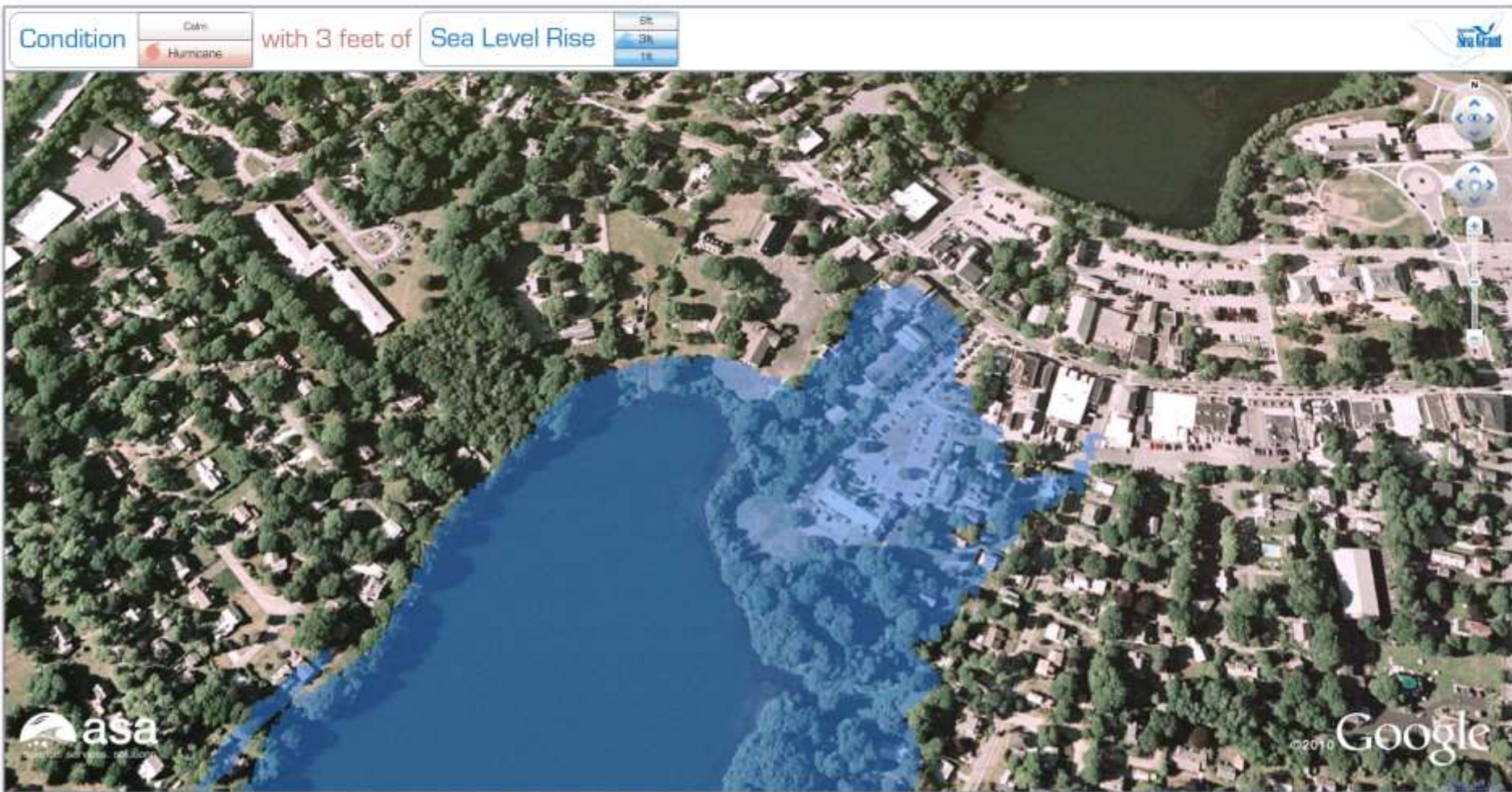
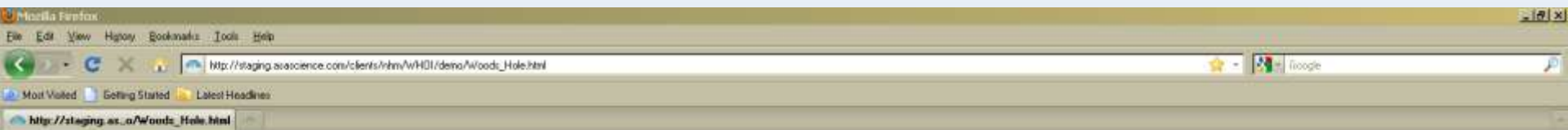
5ft

3ft

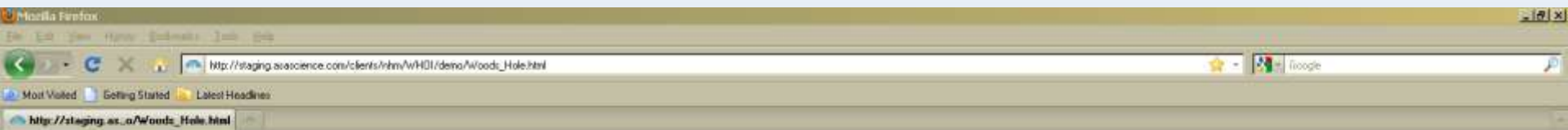
1ft



2D Visualization – Town Hall



2D Visualization – Town Hall



Condition

Calm

Hurricane

with 6 feet of Sea Level Rise

6ft

3ft

1ft

Sea Grant

N

30°

60°

90°

120°

150°

180°

210°

240°

270°

300°

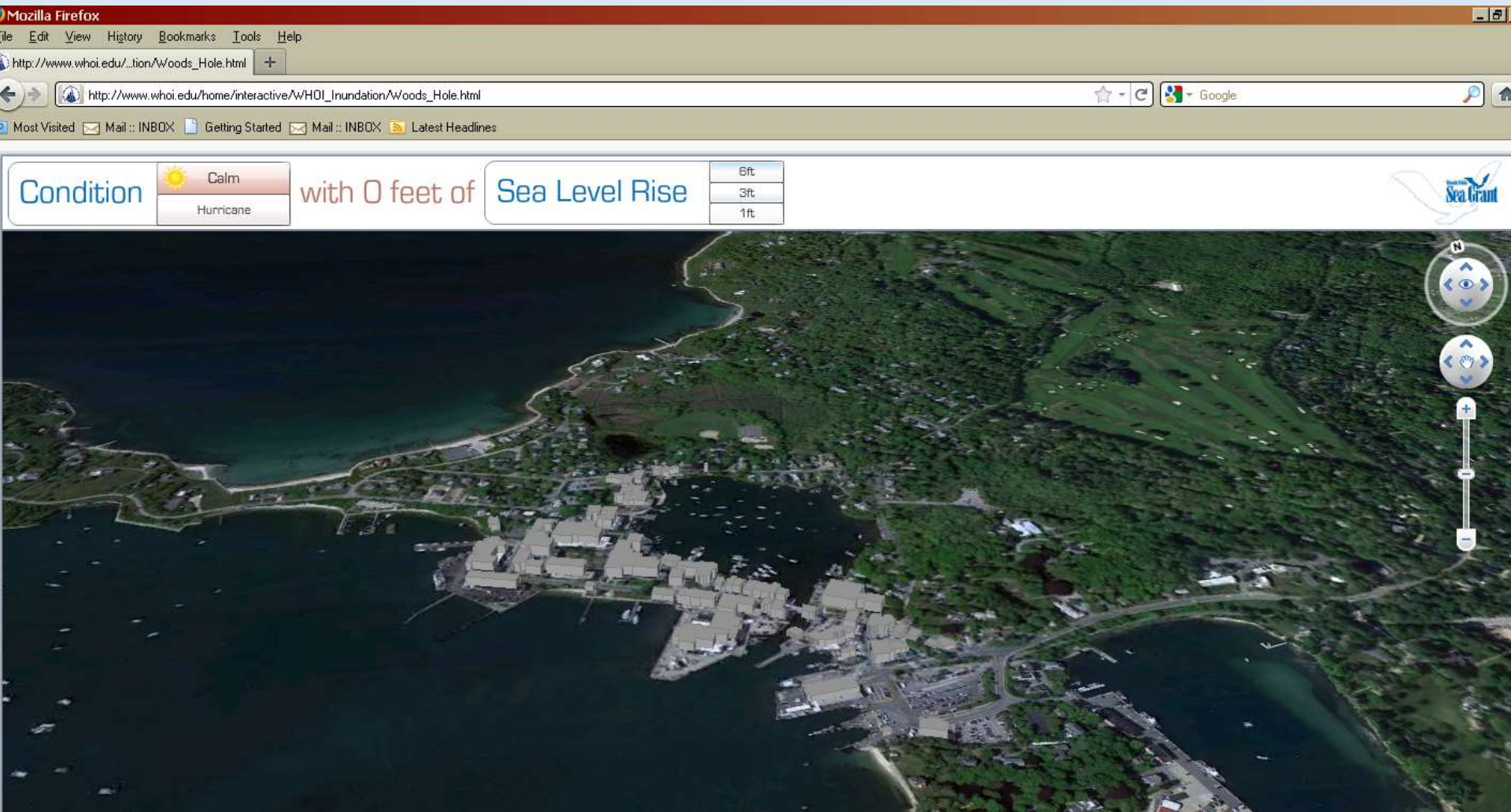
330°

360°

asa
scientific solutions

©2010 Google

BETA



Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.whoi.edu/...tion/Woods_Hole.html

http://www.whoi.edu/home/interactive/WHOI_Inundation/Woods_Hole.html

Google

Most Visited Mail :: INBOX Getting Started Mail :: INBOX Latest Headlines

Condition  Calm
Hurricane

with 3 feet of Sea Level Rise

6ft
3ft
1ft



Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.whoi.edu/...tion/Woods_Hole.html

http://www.whoi.edu/home/interactive/WHOI_Inundation/Woods_Hole.html

Google

Most Visited Mail: INBOX Getting Started Mail: INBOX Latest Headlines

Condition

Calm

Hurricane

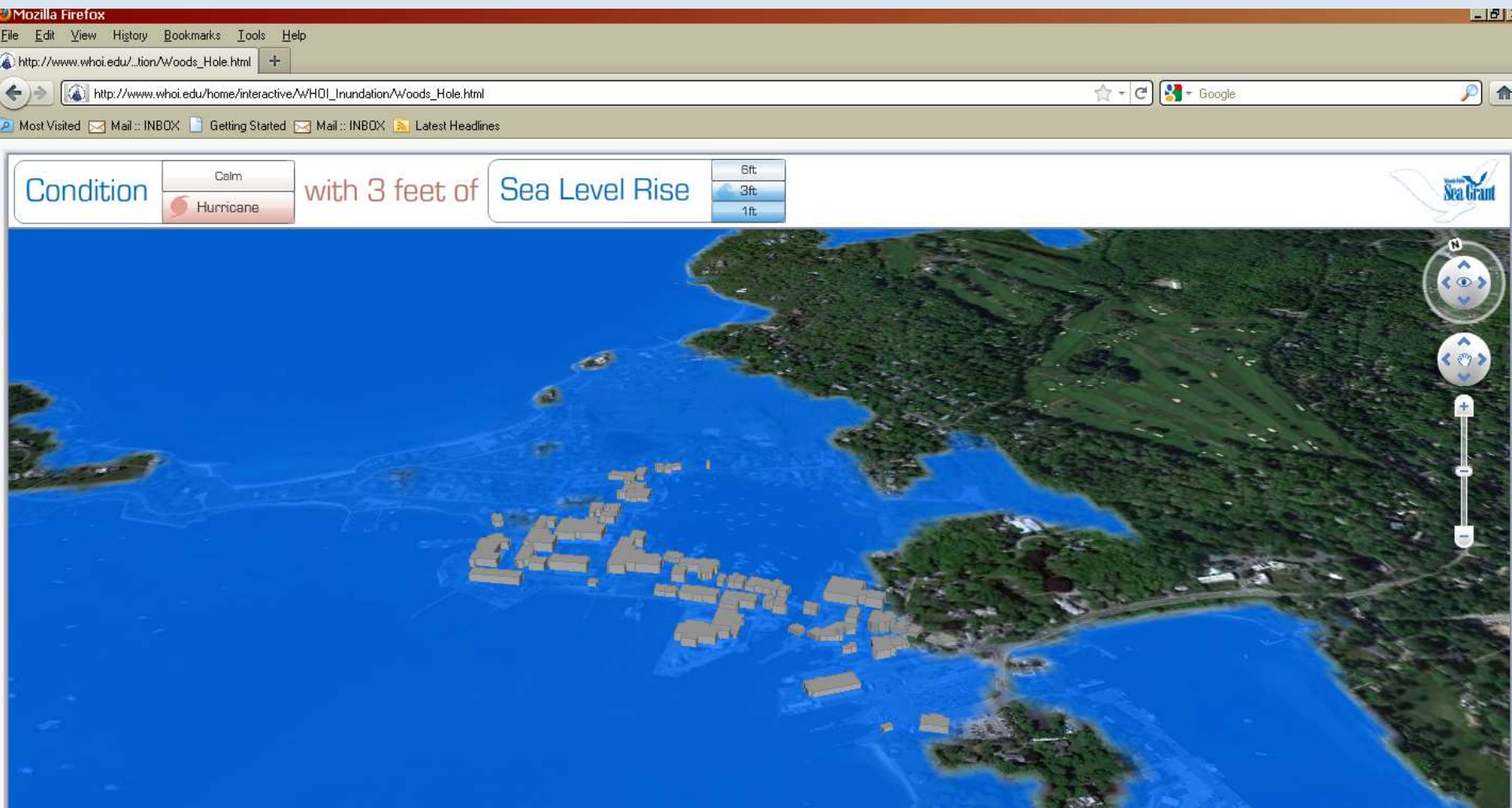
with 0 feet of Sea Level Rise

6ft

3ft

1ft





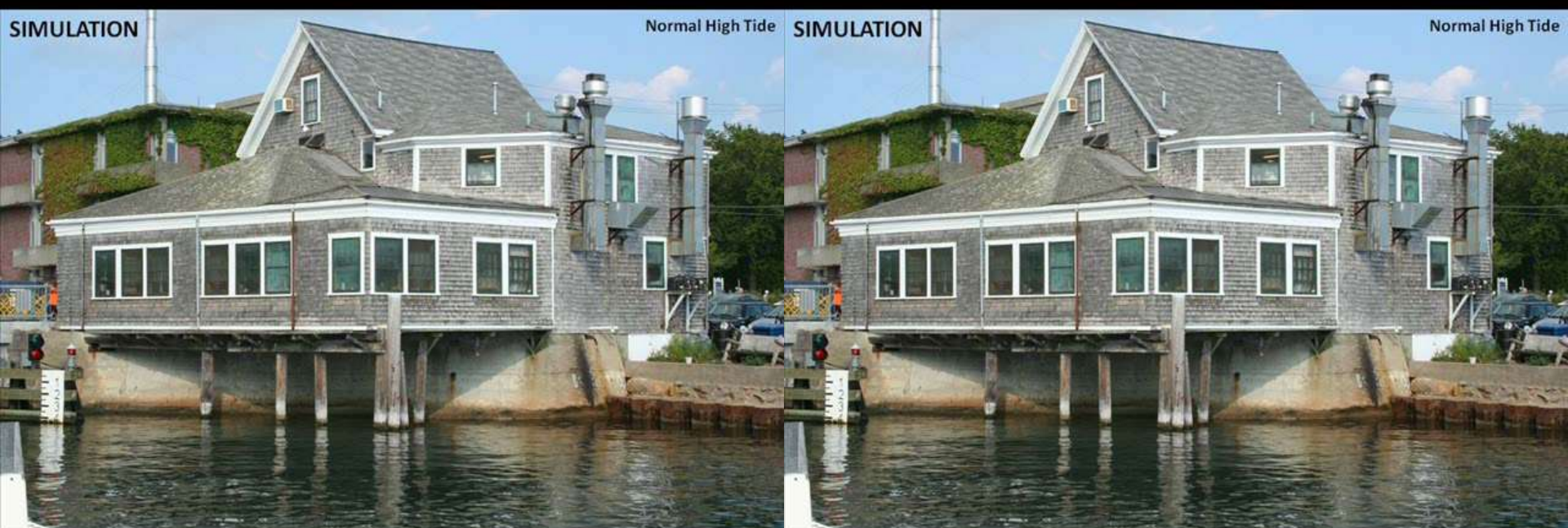
SIMULATION

Normal High Tide

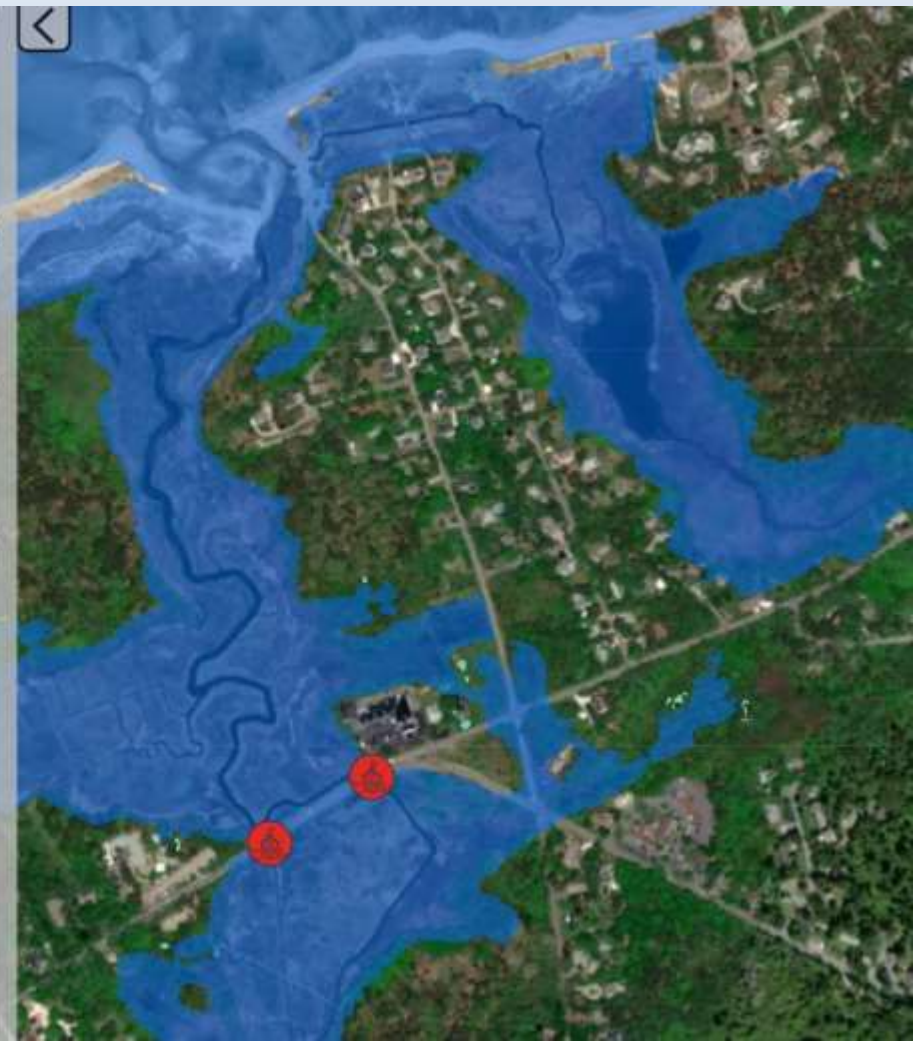
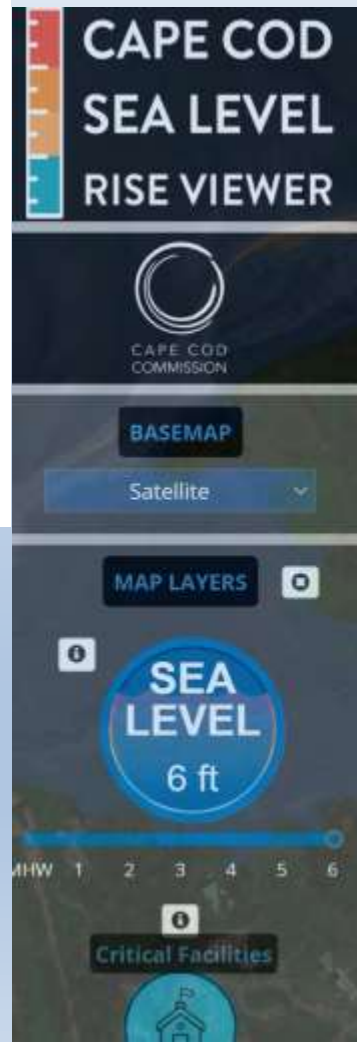
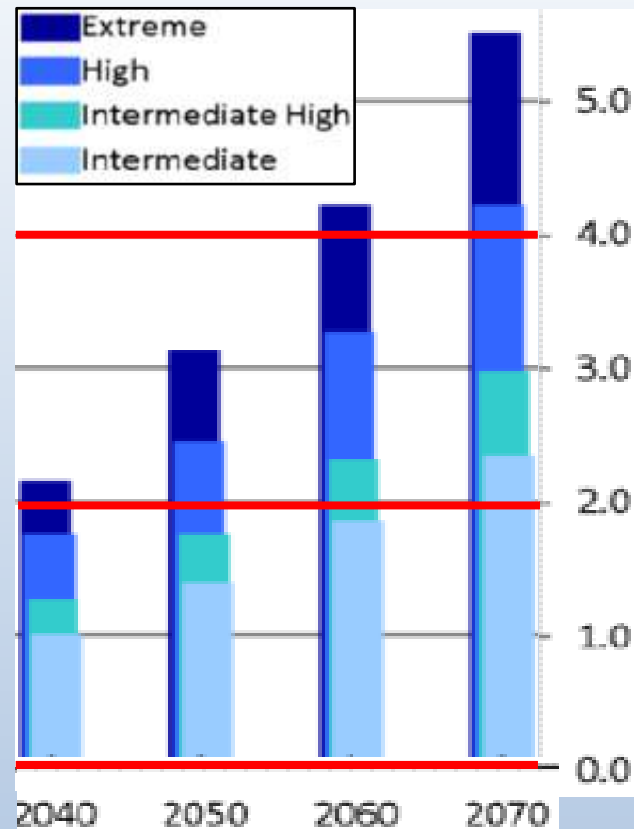


Just SLR

SLR & Storm Event

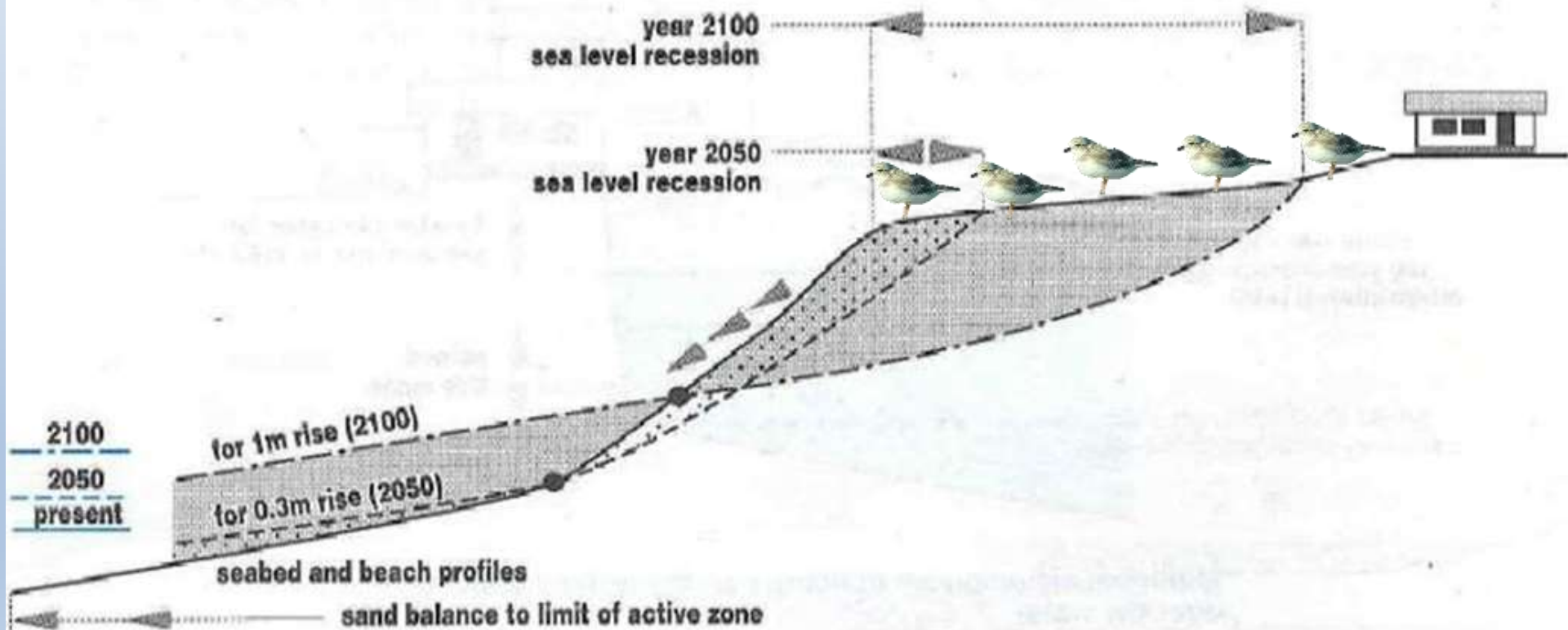






SLR leads to Erosion

- The “Bruun rule” predicts recession of sandy coasts with changed water levels



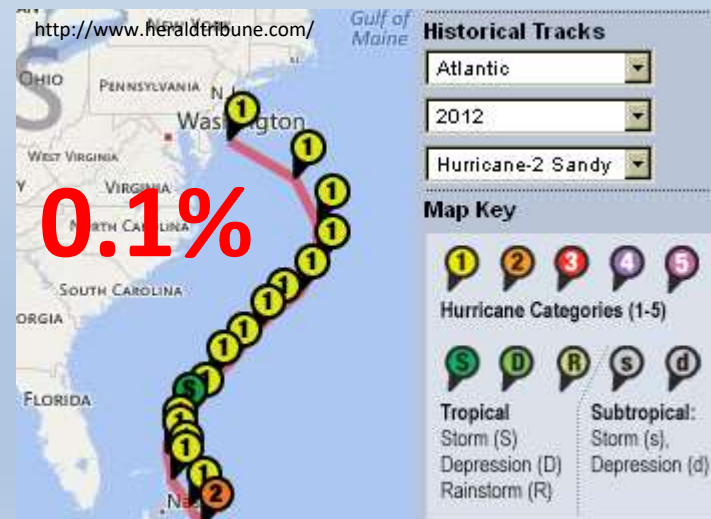
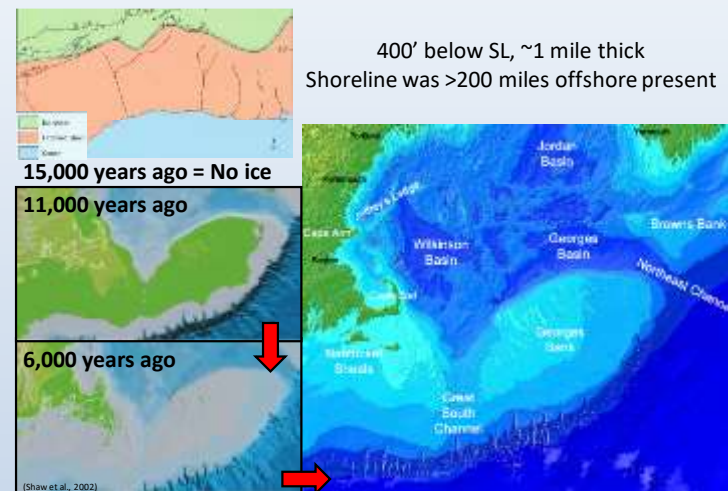


➤ Sea level has risen for tens of thousands of years...it's not stopping anytime soon, and it's projected to accelerate.

➤ Regarding storms...we've been lucky for a long time.

➤ Need to plan/adapt “while the sun is shining”!

➤ Erosion & Flood management is going to become even more effective as costs + dangers ↑↑↑



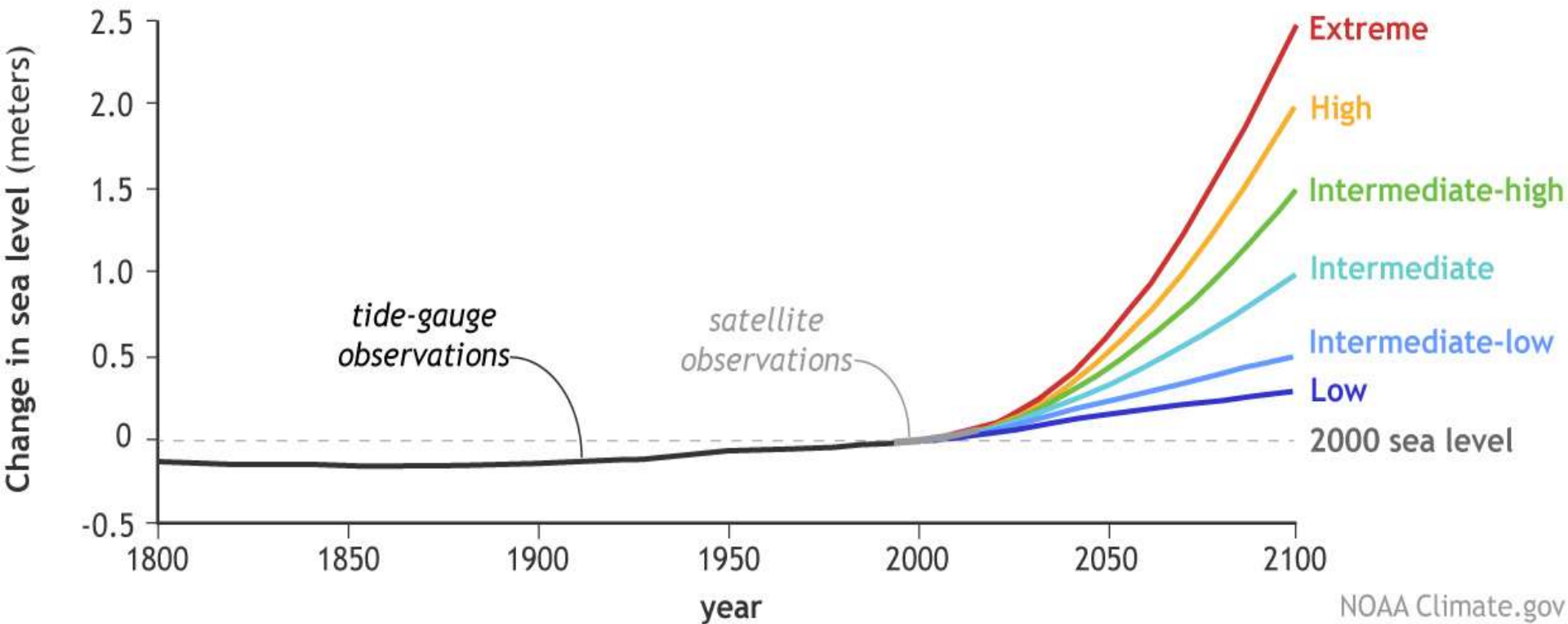


Land-use change, population 4.75x 1950s



Our Choices Matter !!!

Possible future sea levels for different greenhouse gas pathways



2017 National Institute of Building Sciences (NIBS) study looked at 23 years of federally funded mitigation grants provided by the FEMA, EDA and HUD and found mitigation funding **can save the nation \$6 in future disaster costs, for every \$1 spent** on hazard mitigation. Original 2005 study had 4:1 ratio.

