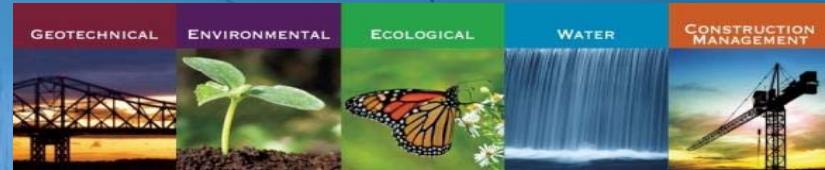


GZA GeoEnvironmental, Inc.

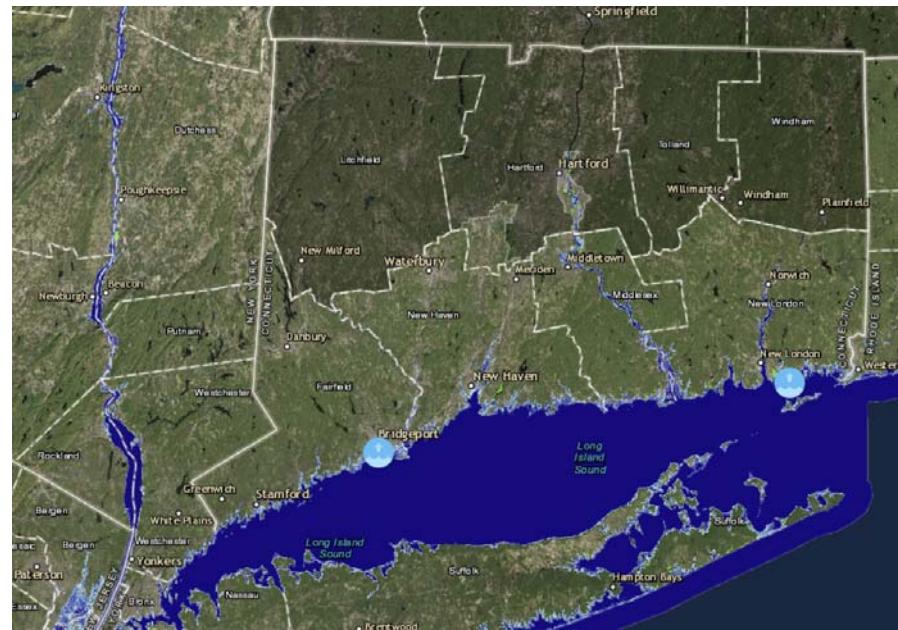


CAFM Conference October 25, 2017

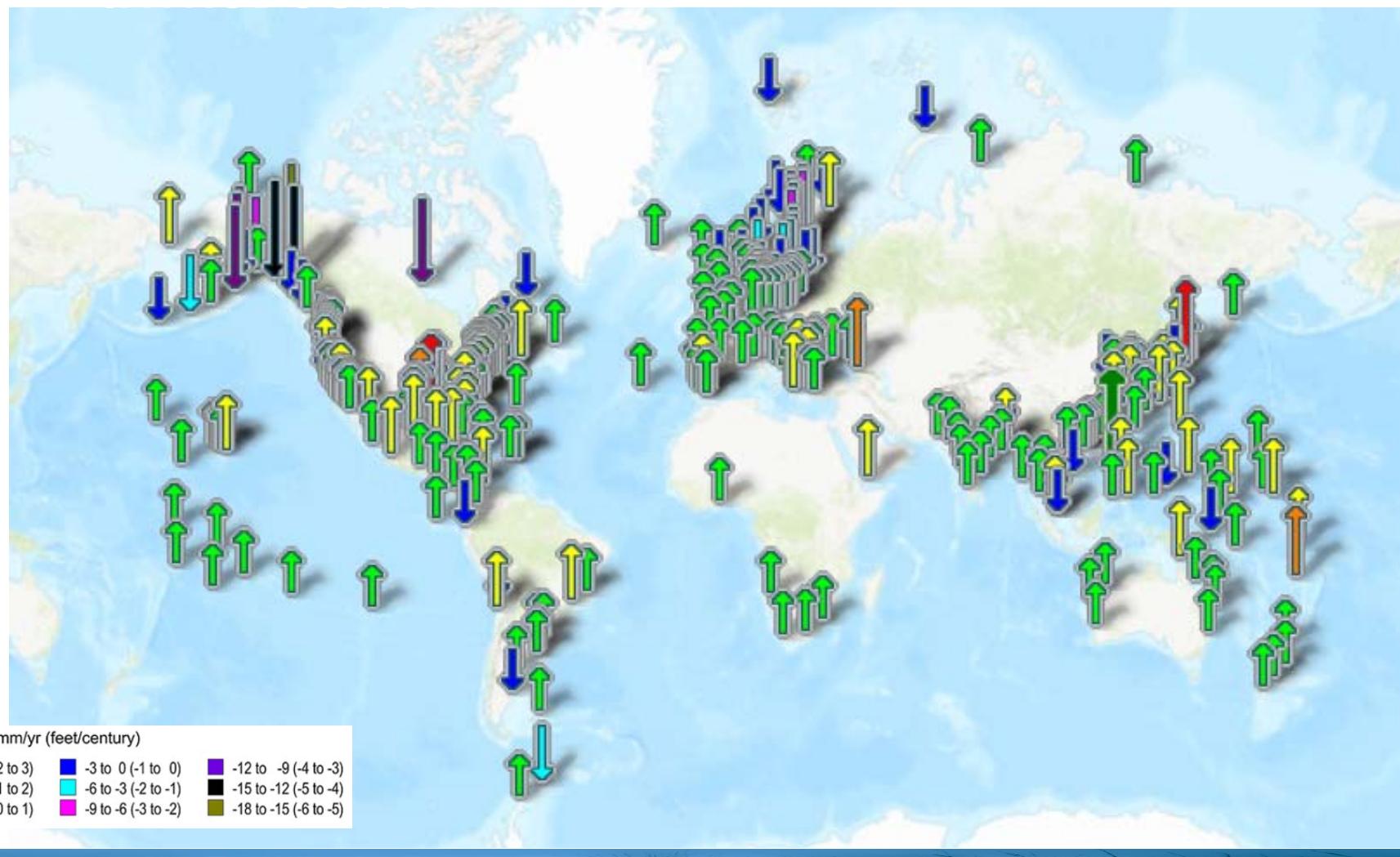
# Sea Level Rise in Connecticut A Risk-Informed Approach

Proactive By Design.  
Our Company Commitment

Bin Wang, P.E.  
Dan Stapleton, P.E.

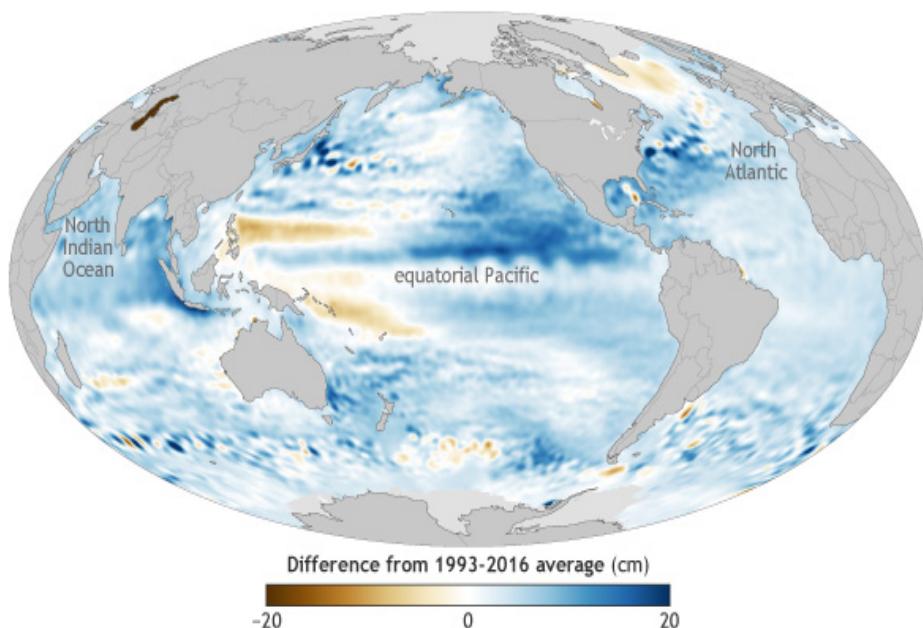


# Global Sea Level Rise Trends Based on Observation

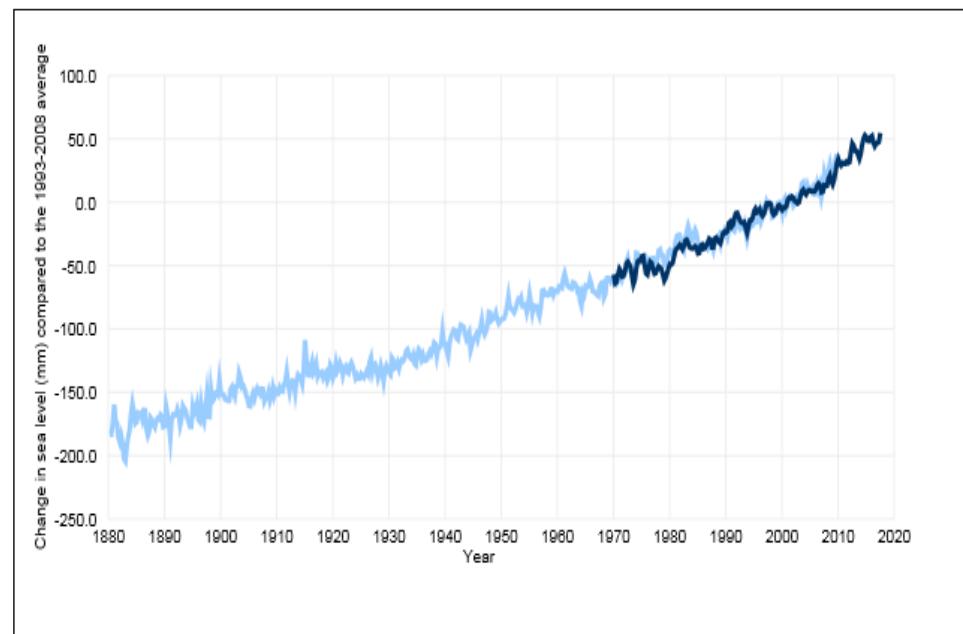


# Global Sea Level Rise Trends Based on Observation

Sea level has been rising over the past century, and the rate has increased in recent decades. In 2016, global sea level was 3.2 inches (82 mm) above the 1993 average—the highest annual average in the satellite record (1993–present).



Sea level in 2016 compared to the 1993–2016 average. NOAA Climate.gov map, adapted from Figure 3.16a in *State of the Climate in 2016*.



Since 1993, SLR rate = 3.4 mm/yr (1/8<sup>th</sup> in/year)

Note: SLR measured using: tide gauges and satellite laser altimeters

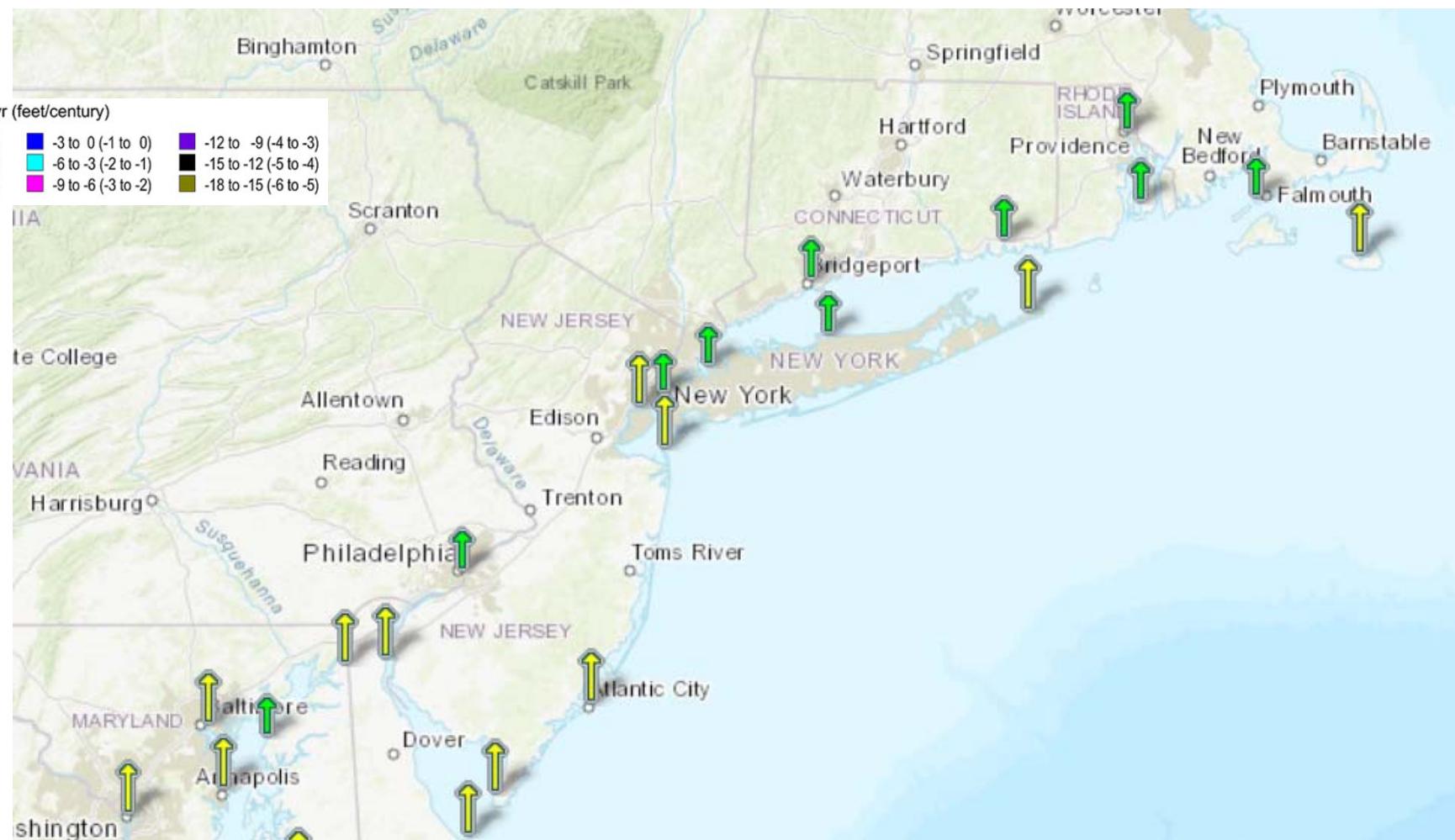
# Sea Level Rise - Why It Matters



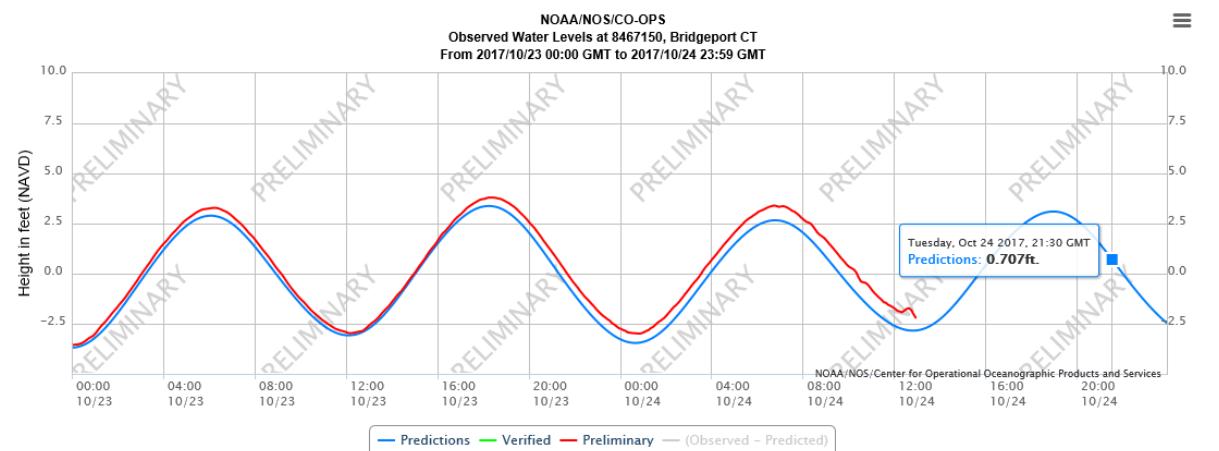
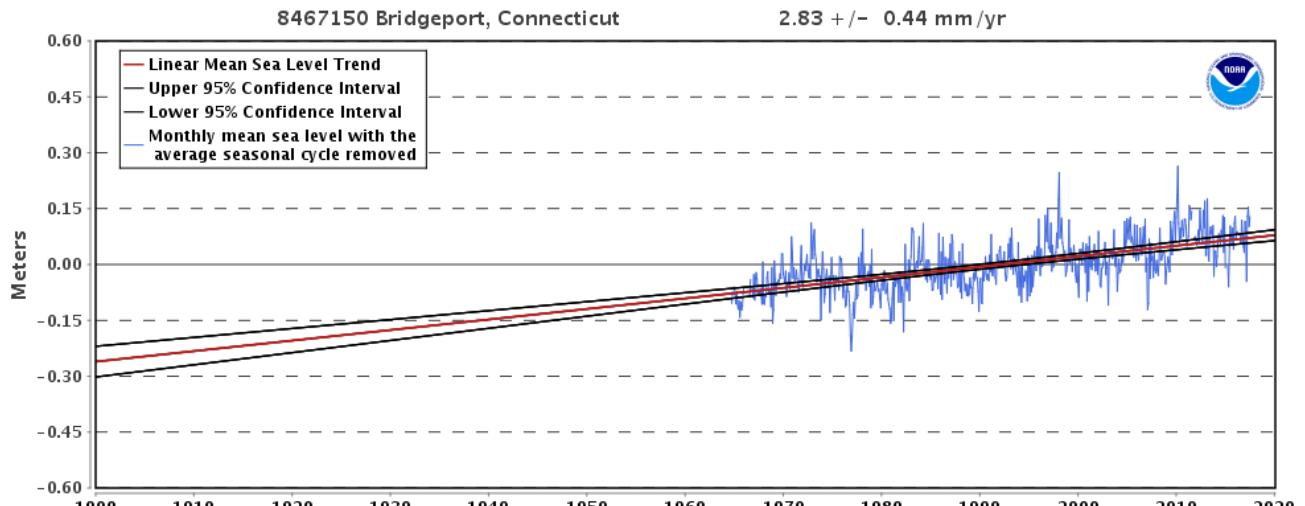
**NOAA Climate.gov**  
science & information for a climate-smart nation

- ✓ 40% of the U.S. population lives in high-density coastal areas
- ✓ 8 Million people live within LIS watershed
- ✓ 8 of 10 of the world's largest cities are near coast
- ✓ U.S Property Exposure:
  - \$16T Coastal Properties Gulf and Atlantic
  - 4.2 million people living in coastal areas (less than 10 feet above sea level rise)
  - 50% in south Florida
  - 13% increase in coastal development (last few years)

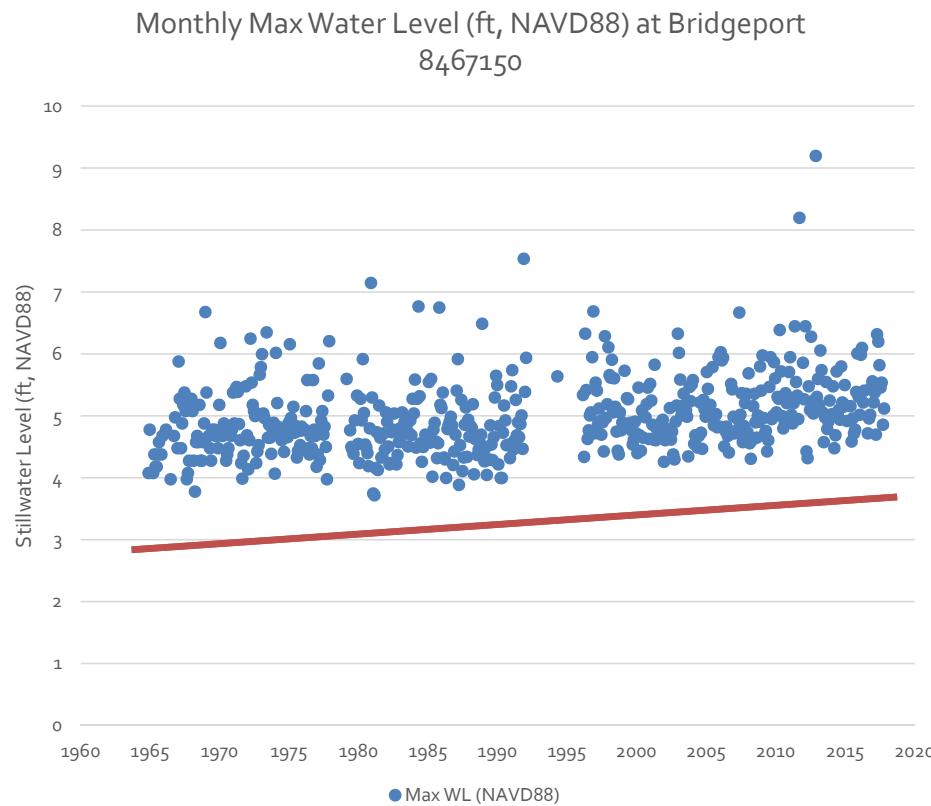
# Connecticut Sea Level Rise Trends Based on Observation



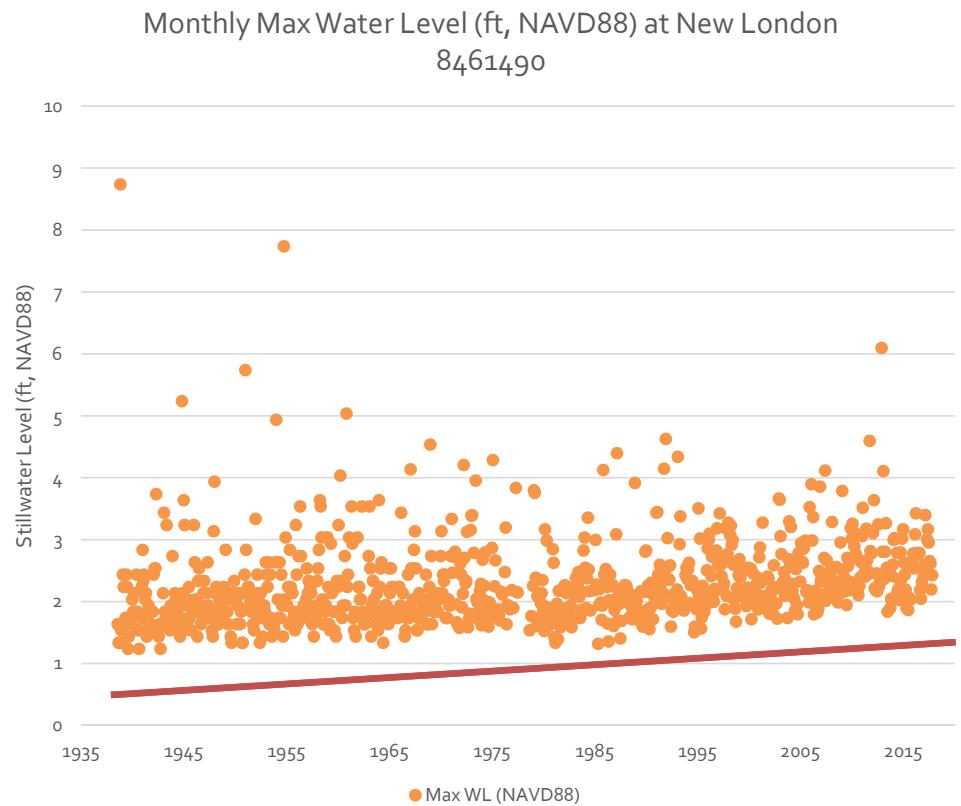
# Connecticut Sea Level Rise Trends Based on Observation



# Connecticut Sea Level Rise Trends Based on Observation

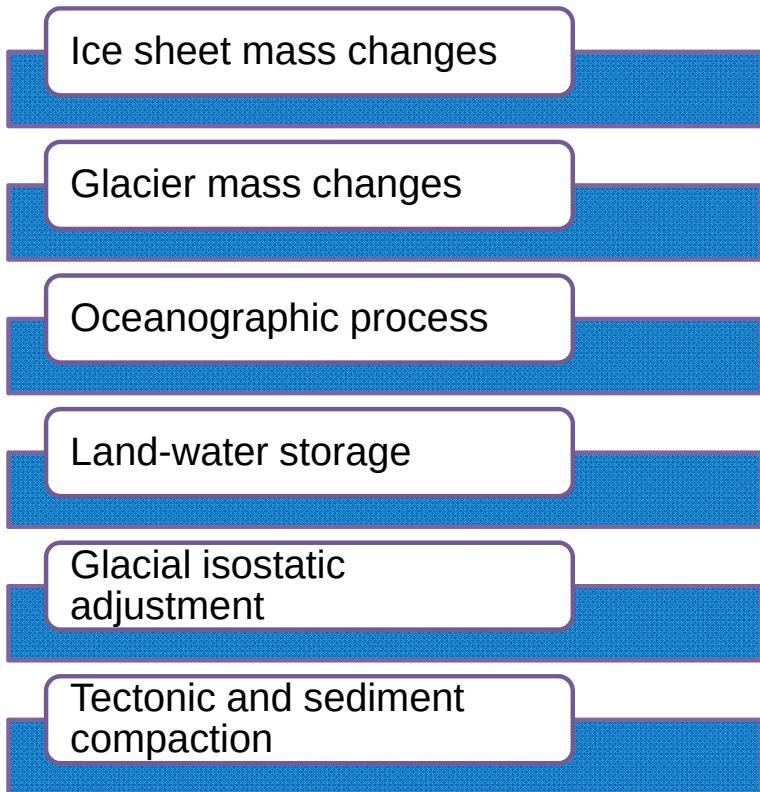


MHHW: 3.48 feet NAVD88  
MLLW: -3.84 feet NAVD88  
MSL: -0.22 feet NAVD88  
Tidal Range: 6.74 feet

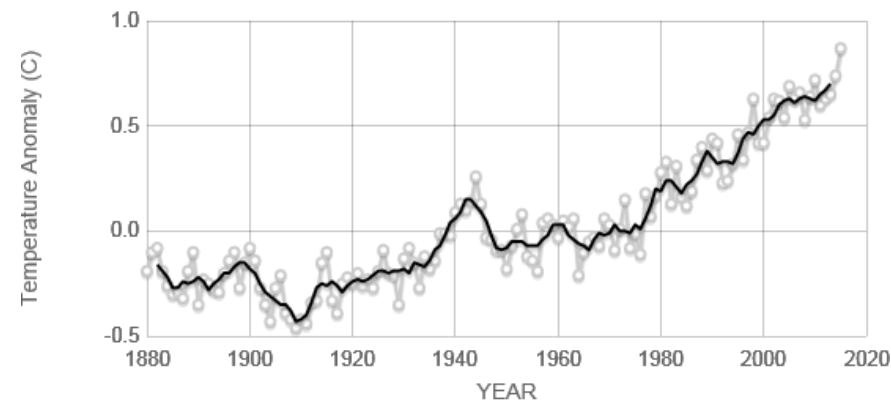


MHHW: 1.21 feet NAVD88  
MLLW: -1.84 feet NAVD88  
MSL: -0.31 feet NAVD88  
Tidal Range: 2.56 feet

# Causes of Sea Level Rise



## Global Temperature



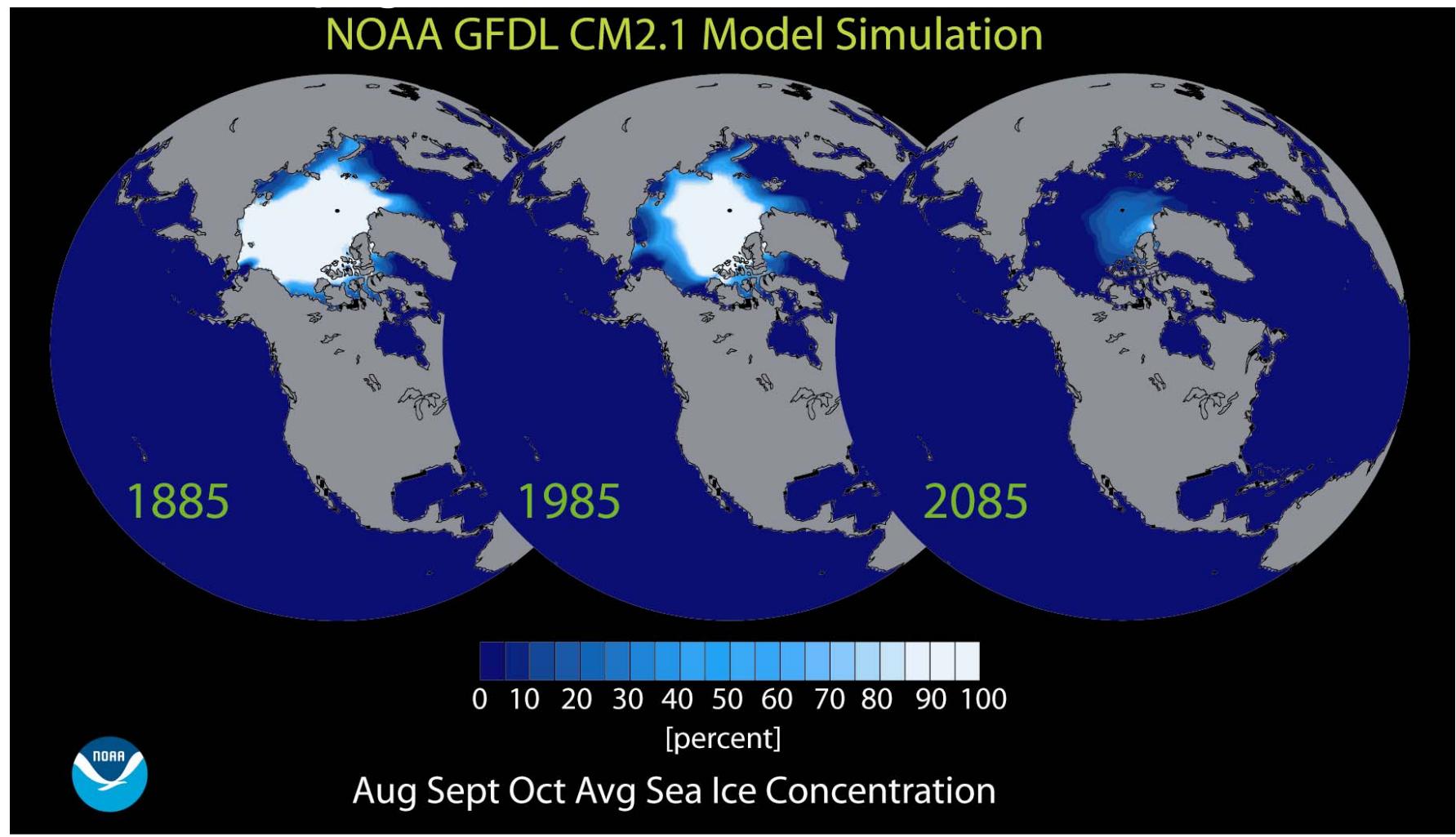
Source: climate.nasa.gov

# Arctic Land and Sea Ice Melt

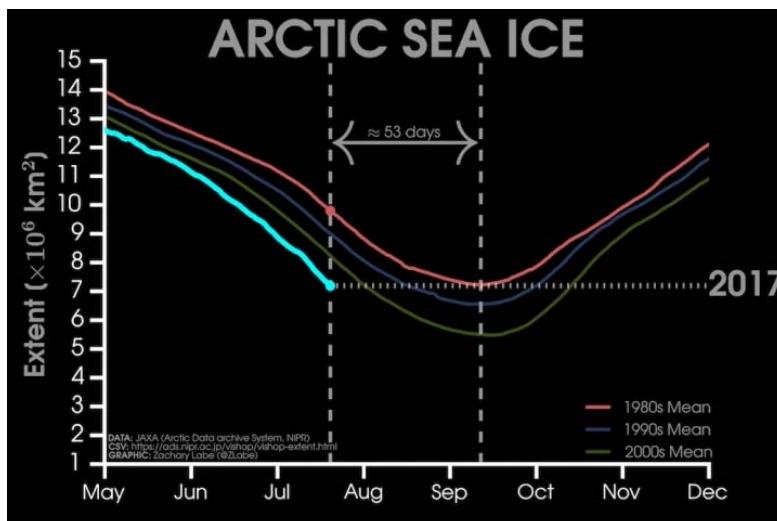
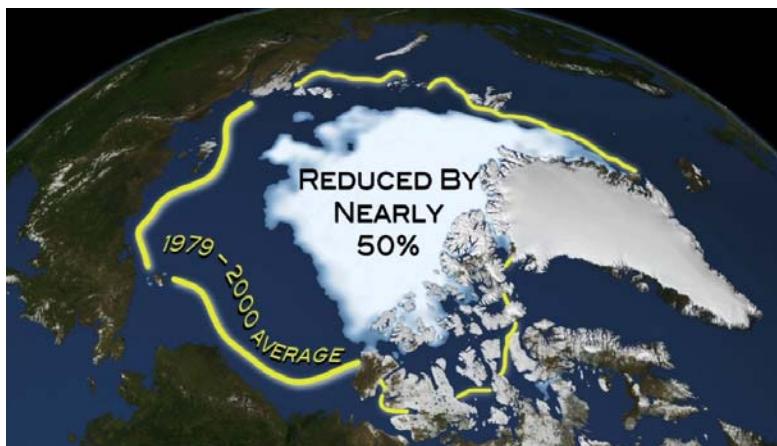
Sep 13, 2017



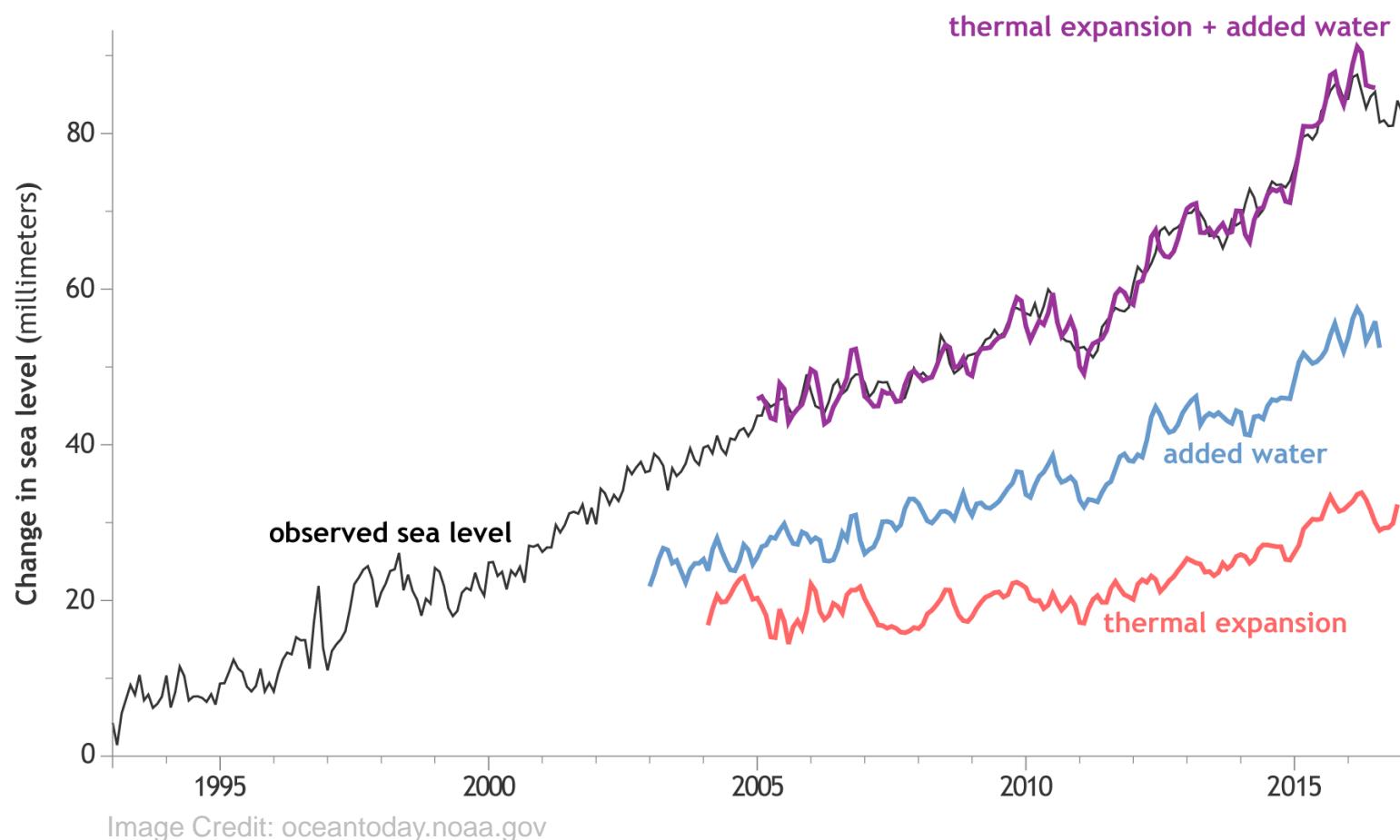
# Arctic Land and Sea Ice Melt



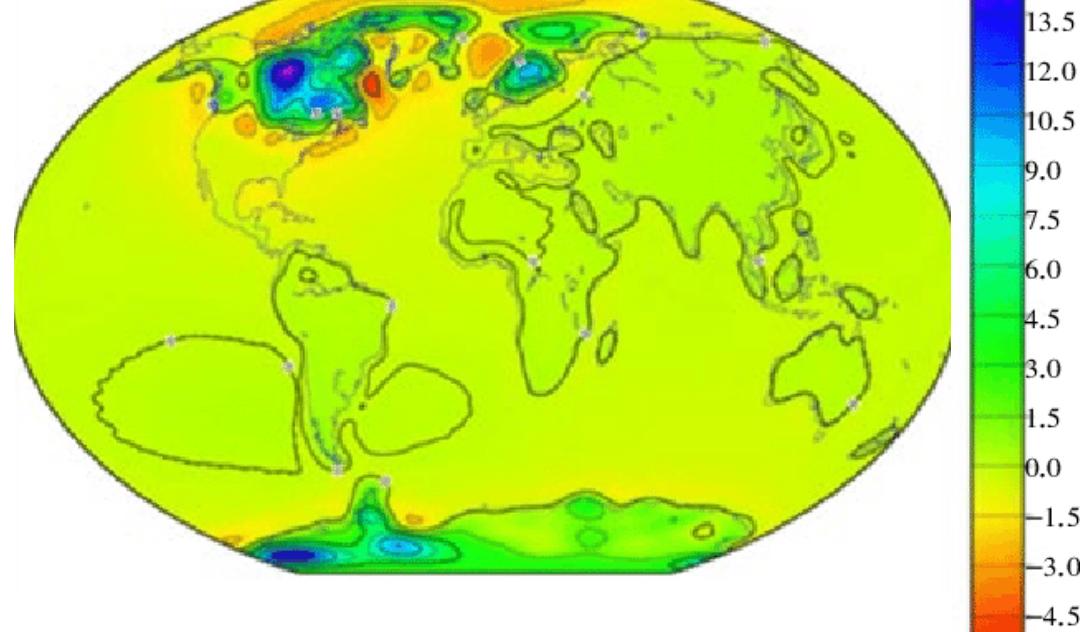
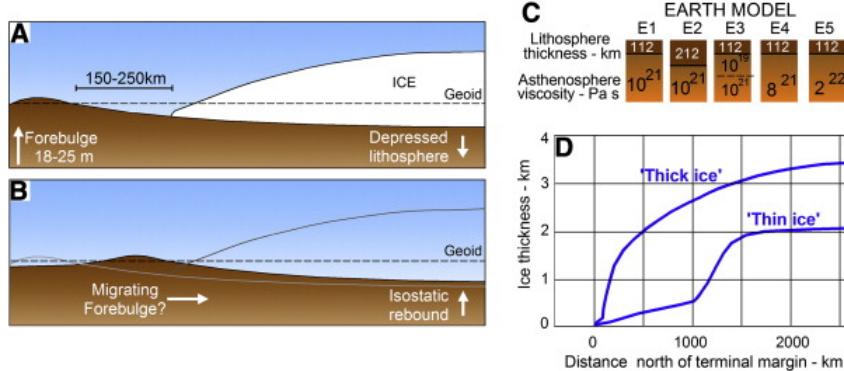
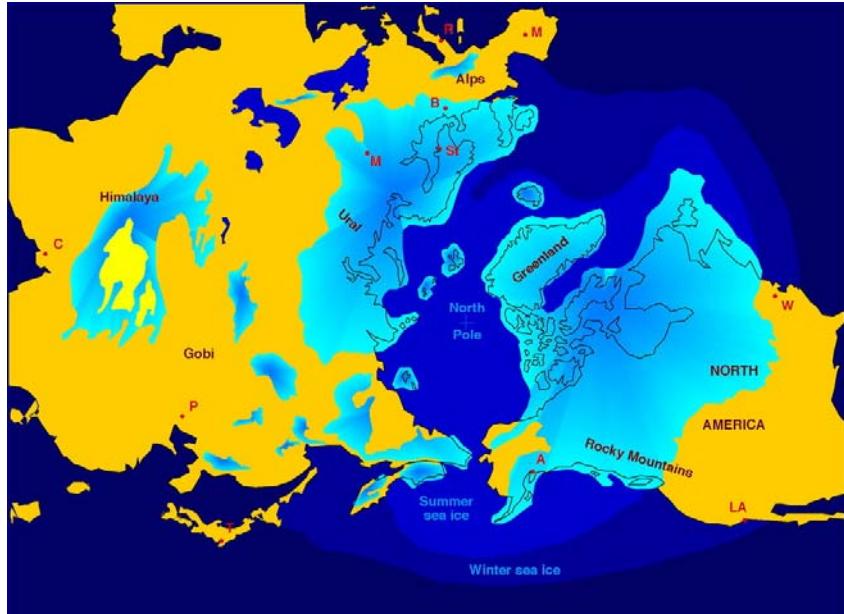
# Arctic Land and Sea Ice Melt



# Contributions Due to Ice Melt and Thermal Expansion



# Glacial Isostatic Adjustment – Relative Sea Level Change



# Scenario Projections of Relative Sea Level Change

## NOAA NOS CO-OPS Technical Report 083

Global and Regional Sea Level Rise Scenarios for the United States, January 2017.

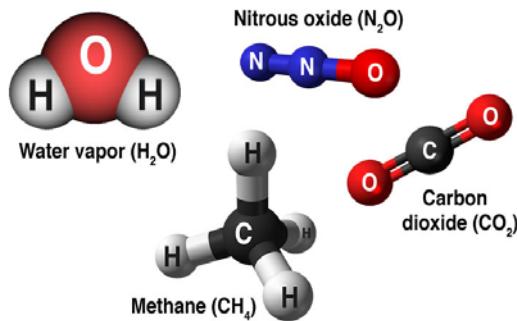
- ✓ Scenario-based
- ✓ Probabilistic projections

National Oceanic and  
Atmospheric  
Administration  
Government agency

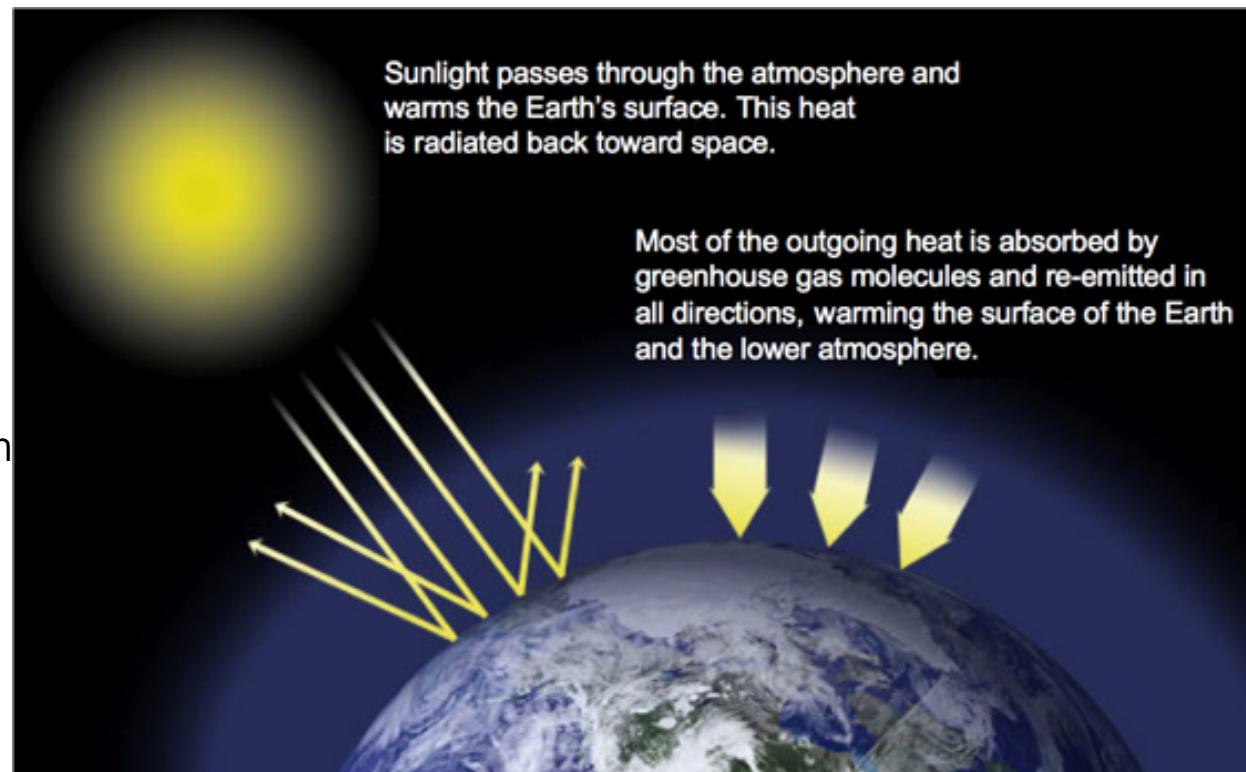


RUTGERS  
UNIVERSITY | NEW BRUNSWICK

# Greenhouse Gas Emissions

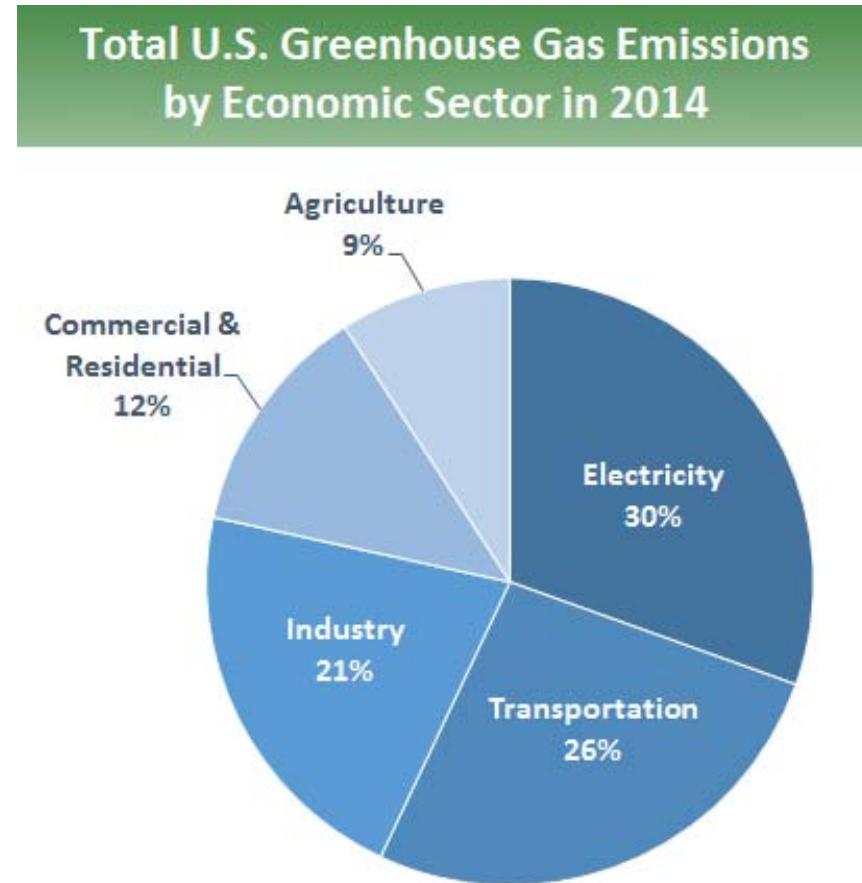


- ✓ **Carbon Dioxide:** Respiration, volcanoes, deforestation, land use change, fossil
- ✓ **Methane:** landfills, agriculture, digestion and manure
- ✓ **Nitrous Oxide:** fertilizers, fossil fuels, biomass, nitric acid
- ✓ **Chlorofluorocarbons:** largely regulated (ozone)
- ✓ **Water vapor:** Feedback



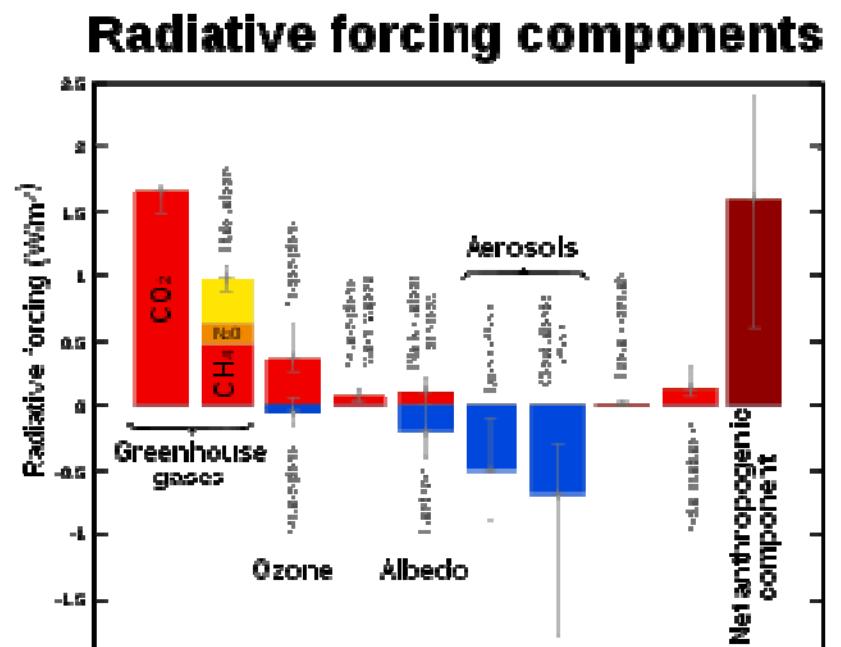
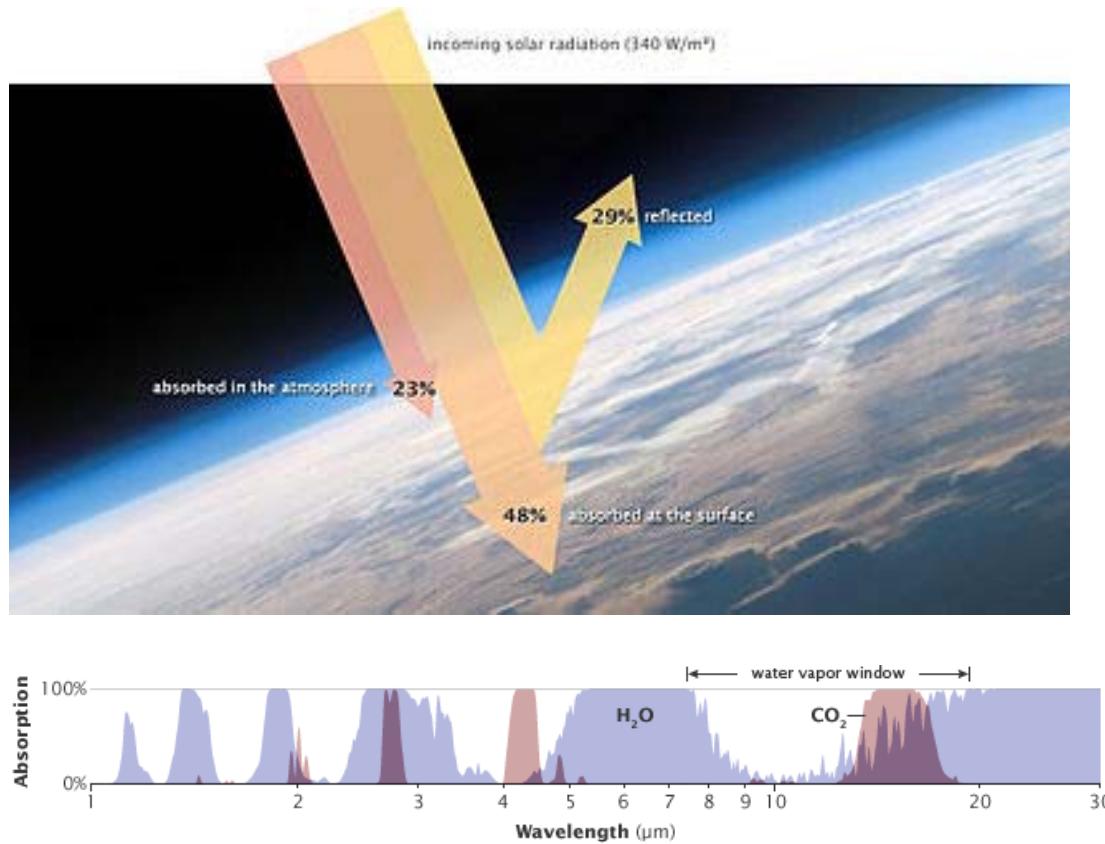
# Anthropogenic Greenhouse Gas Sources

- ✓ **Electricity Production:** +/-67% burning fossil fuels (mostly coal and natural gas)
- ✓ **Transportation:** fossil fuels for cars, trucks, ships, trains and planes (90% of fuel: gas)
- ✓ **Industry:** fossil fuels for energy, production of goods
- ✓ **Commercial and Residential:** fossil fuels for heat, waste
- ✓ **Agriculture:** livestock, soils and rice production
- ✓ **Land Use and Forestry:** sink (absorbing CO<sub>2</sub>)



# Radiative Forcing

Difference between sunlight absorbed by the Earth and energy radiated back to space



# Representative Concentration Pathways: Emission-Dependent Sea Level Rise Projections (IPCC AR5)

RCP8.5: High range emission scenario (increasing GHG emissions:possible development for high population numbers, high fossil/coal use)

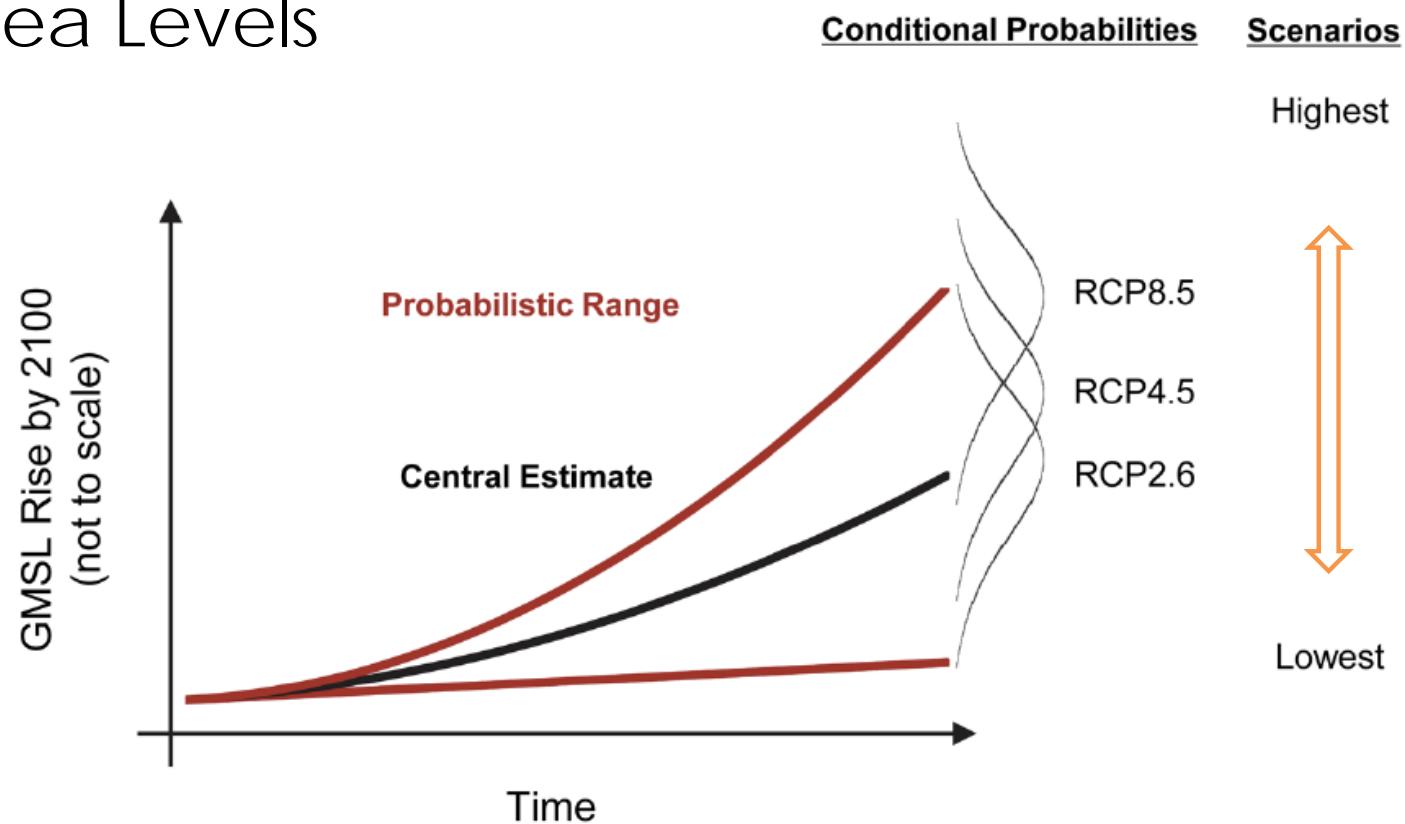
RCP6.0 : Medium range emission scenario (low-medium baseline scenario or stabilization after 2100)

RCP4.5: Medium range emission scenario (stabilization scenario after 2100; ambitious GHG emission reduction)

RCP2.6: Low range mitigation scenario: “peak and decline” scenario

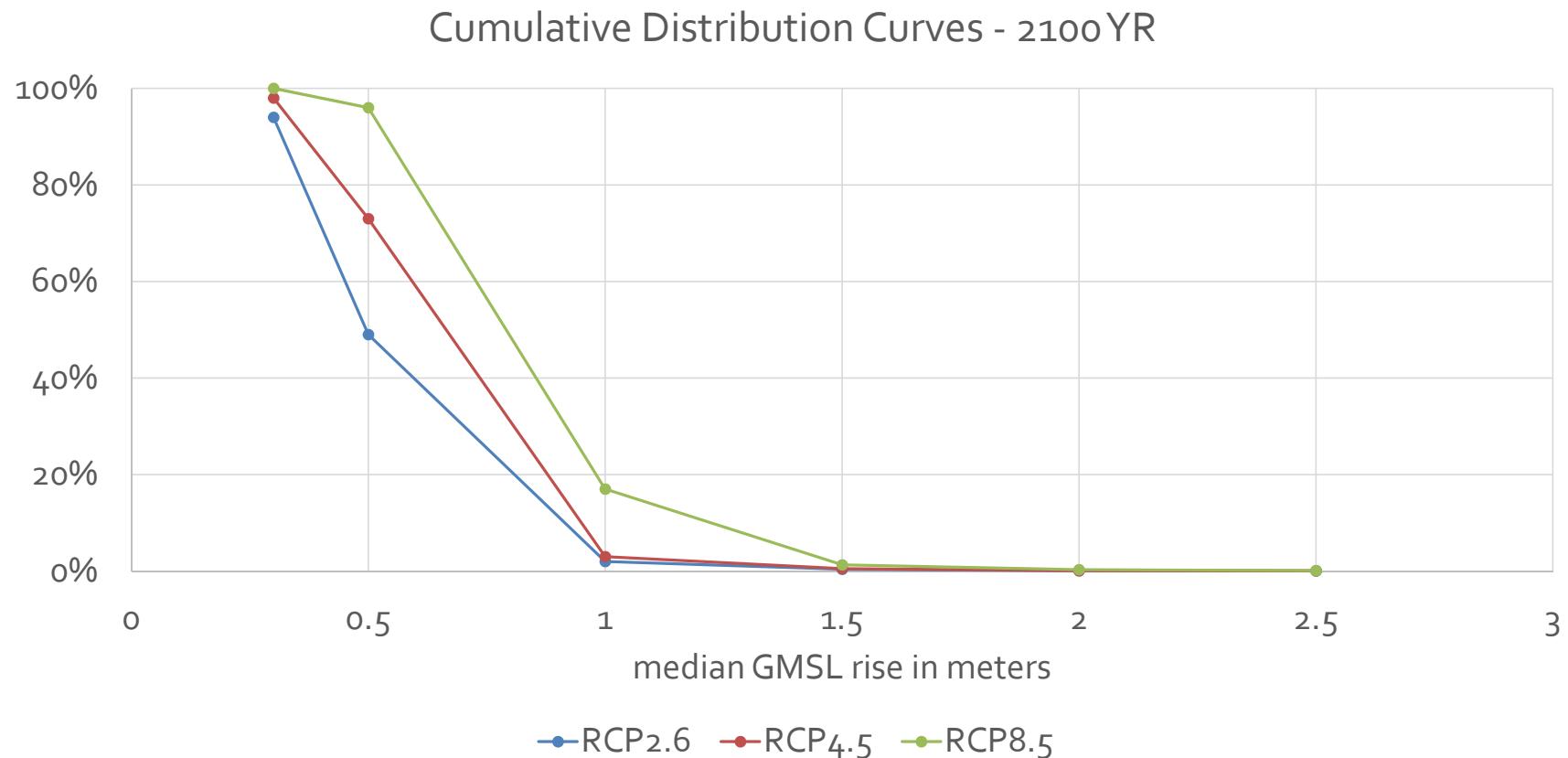
- Four possible Climate Futures
- Named after range of radiative forcing values in the year 2100 (W/m<sup>2</sup>)
- Relative to pre-industrial values
- Represent predicted GHG concentrations

# Representative Concentration Pathways: Emission-Dependent Sea Level Rise Projections (IPCC AR5) – Global Sea Levels



**Figure 2.** Schematic showing the intersection of scenario approaches with emission-dependent (conditional) probabilistic projections of sea level rise under the climate modeling community's Representative Concentration Pathways (RCP) (van Vuuren et al., 2011).

# Representative Concentration Pathways: Emission-Dependent Sea Level Rise Projections (IPCC AR5)



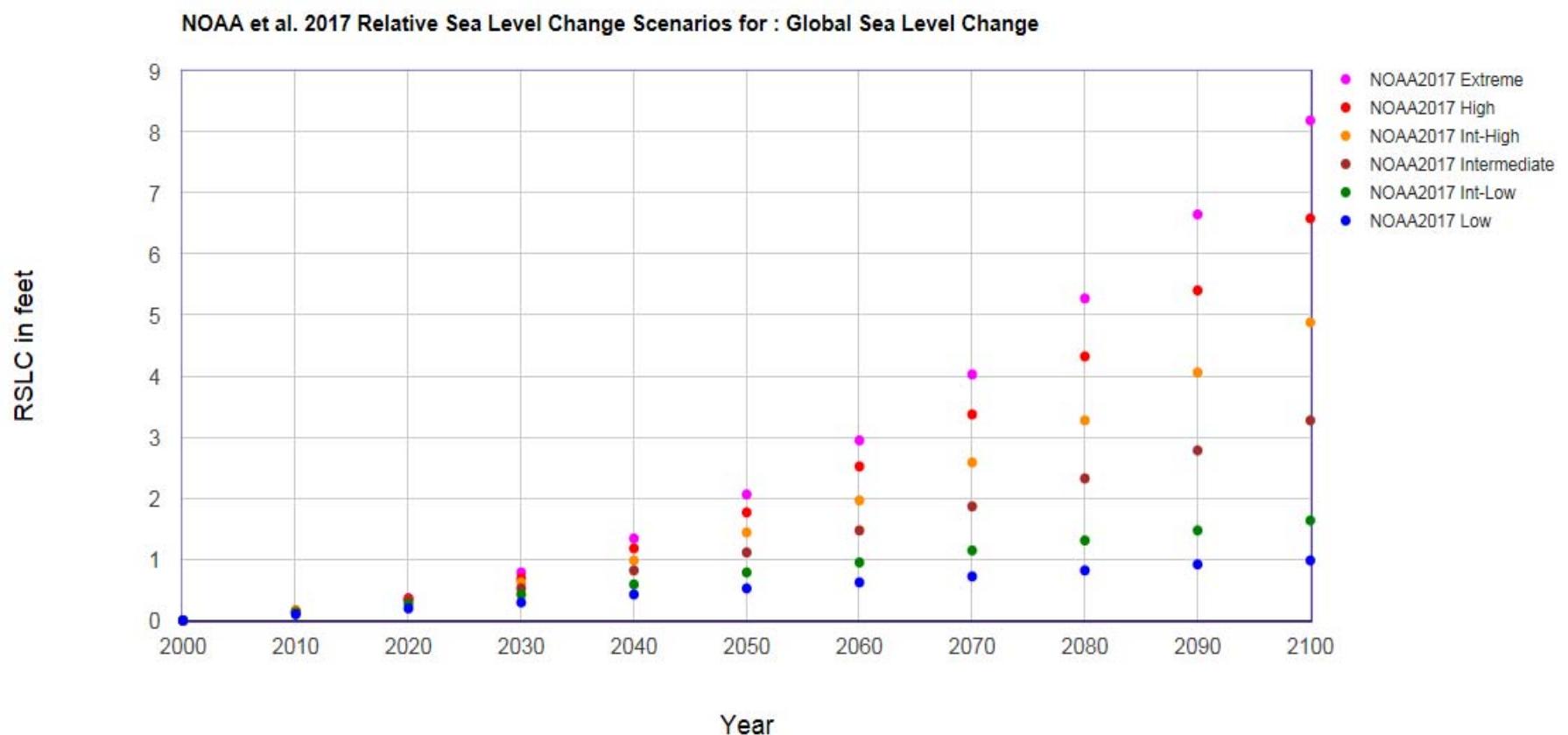
# Representative Concentration Pathways: Emission-Dependent Sea Level Rise Projections (IPCC AR5)

**Table 4.** Probability of exceeding GMSL (median value) scenarios in 2100 based upon Kopp et al. (2014).

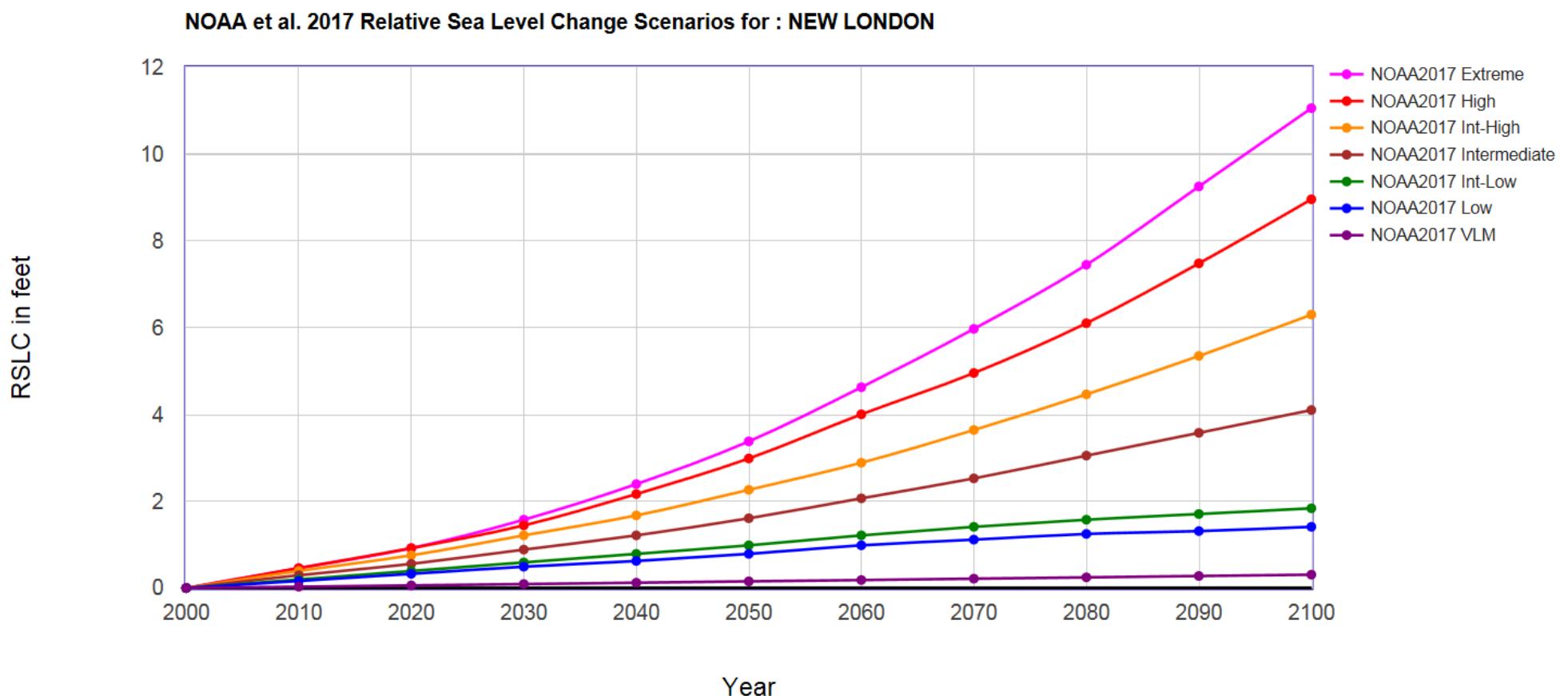
GMSL rise Scenario	RCP2.6	RCP4.5	RCP8.5
Low (0.3 m)	94%	98%	100%
Intermediate-Low (0.5 m)	49%	73%	96%
Intermediate (1.0 m)	2%	3%	17%
Intermediate-High (1.5 m)	0.4%	0.5%	1.3%
High (2.0 m)	0.1%	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.05%	0.1%

Increase degrees Celsius                    1.9-2.3°                    2.0-3.6°                    3.2-5.4°  
2081-2100 relative to 1850-1900

# Emission-Dependent Sea Level Rise Projections (IPCC AR5) – Global Sea Levels



# Emission-Dependent Sea Level Rise Projections (IPCC AR5) – Local Sea Levels



# Relative Sea Level Change Implications

## Chronic Flooding

Chronic Flooding:

- 26 times per year (every other week)

Chronic Inundation:

- 10% or more developed land area



# Relative Sea Level Change Implications

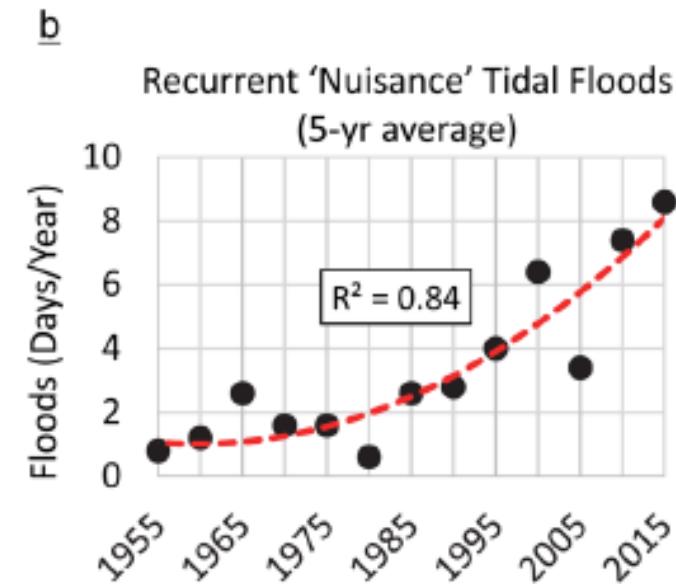
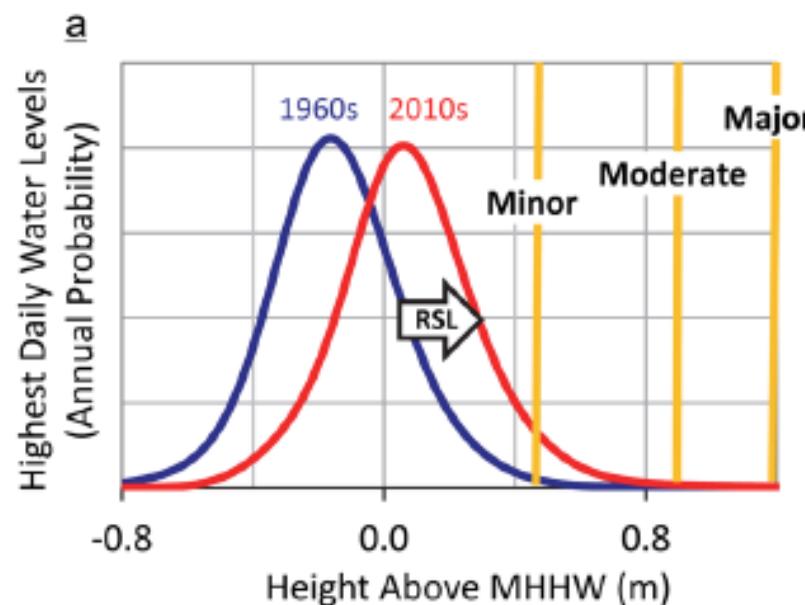
## National Weather Service Impact Criteria

MHHW +0.5m: Nuisance Flooding

MHHW + 0.9m: Moderate

MHHW+ 1.2m Major

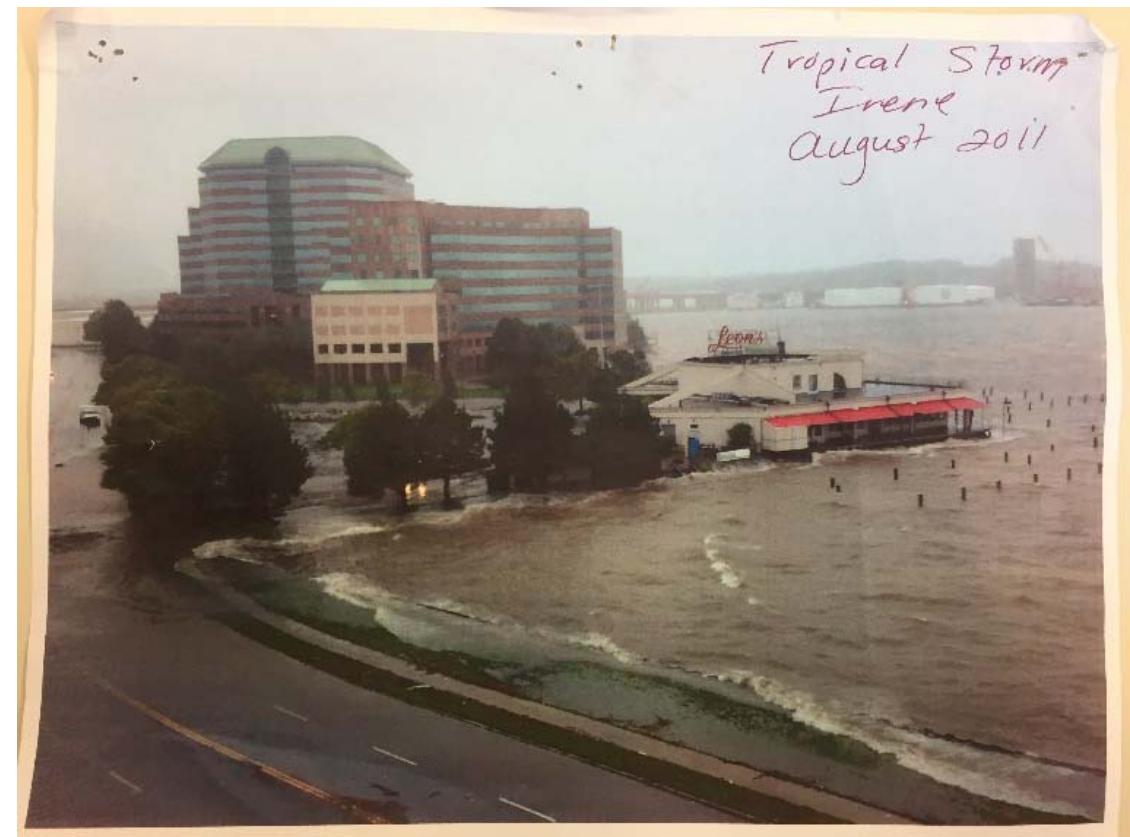
Norfolk, Virginia



# Relative Sea Level Change Implications

## Extreme Flood Events

Increased frequency and flood levels due to storm surge

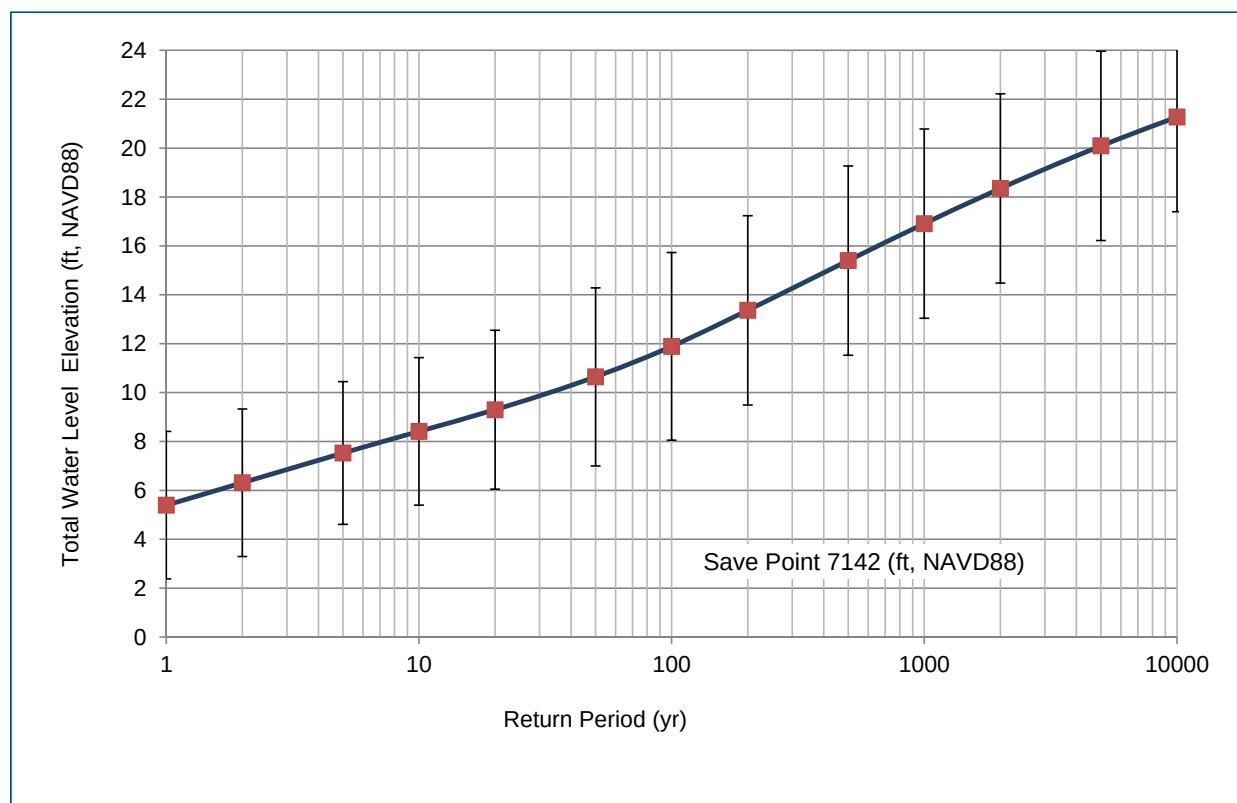


# Relative Sea Level Change Implications

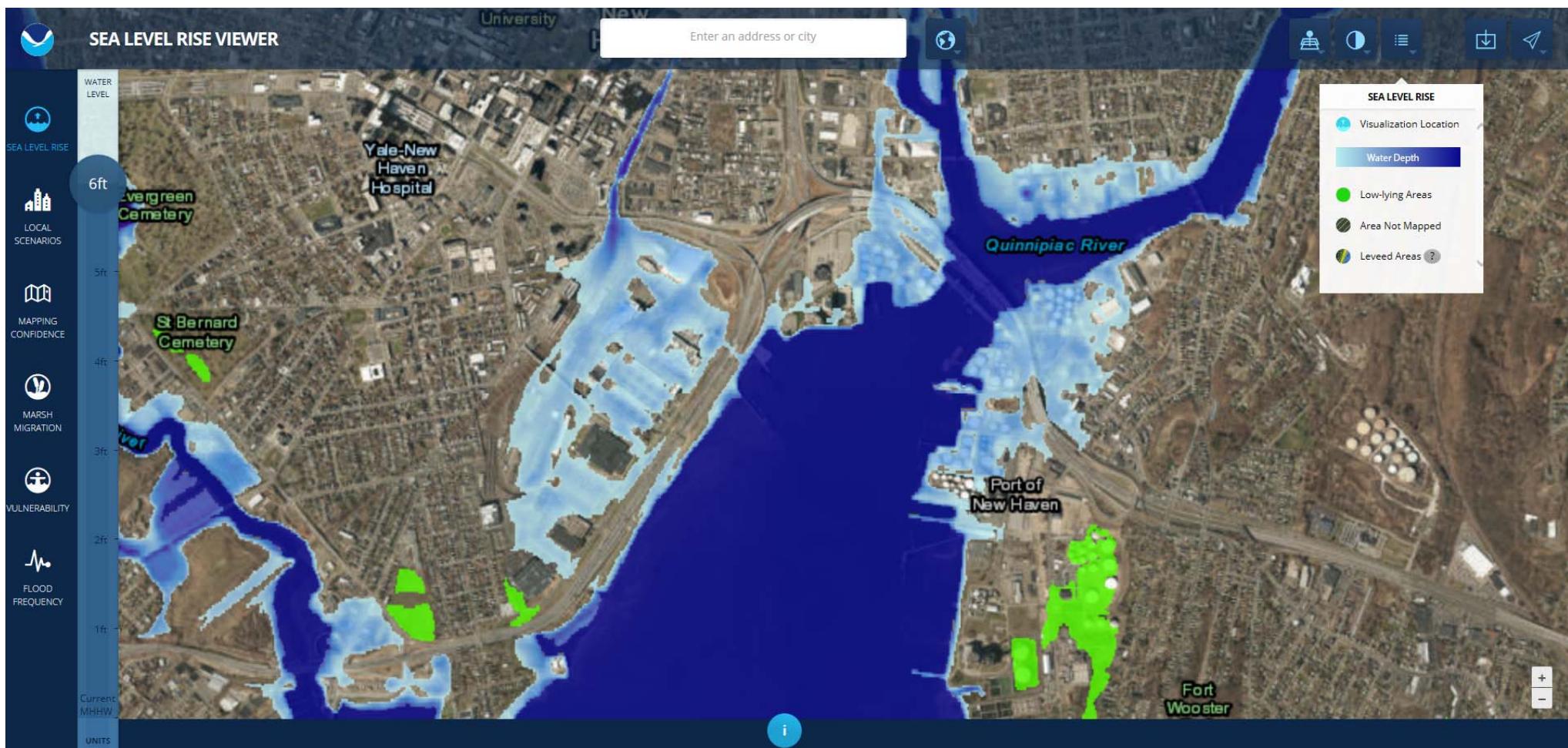
## New Haven Flood-Frequency

100-year return period flood:

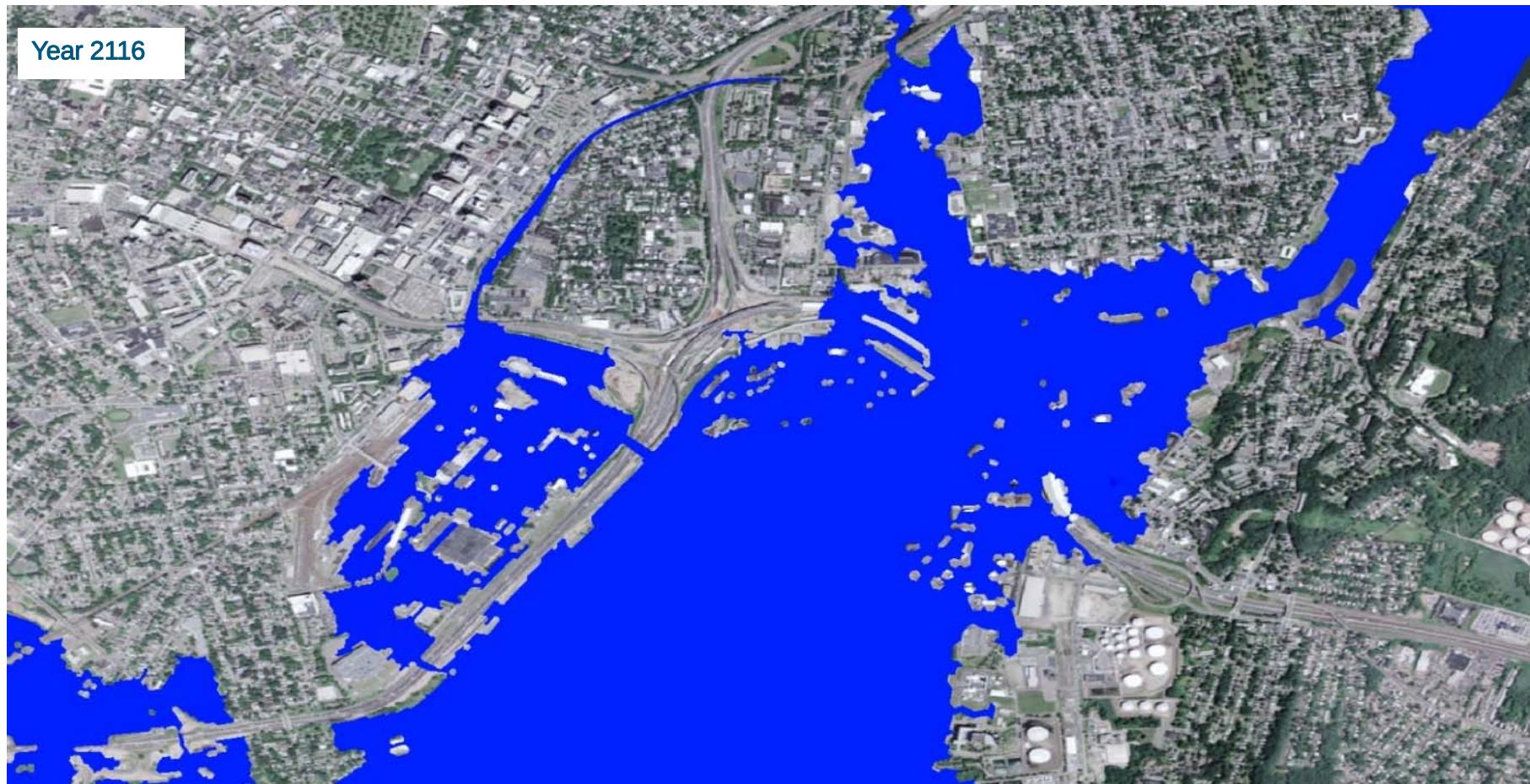
- 2016: Elevation 11.7 NAVD88
- 2041: Elevation 12.6 NAVD88
- 2066: Elevation 13.9 NAVD88
- 2116: Elevation 18.0 NAVD88



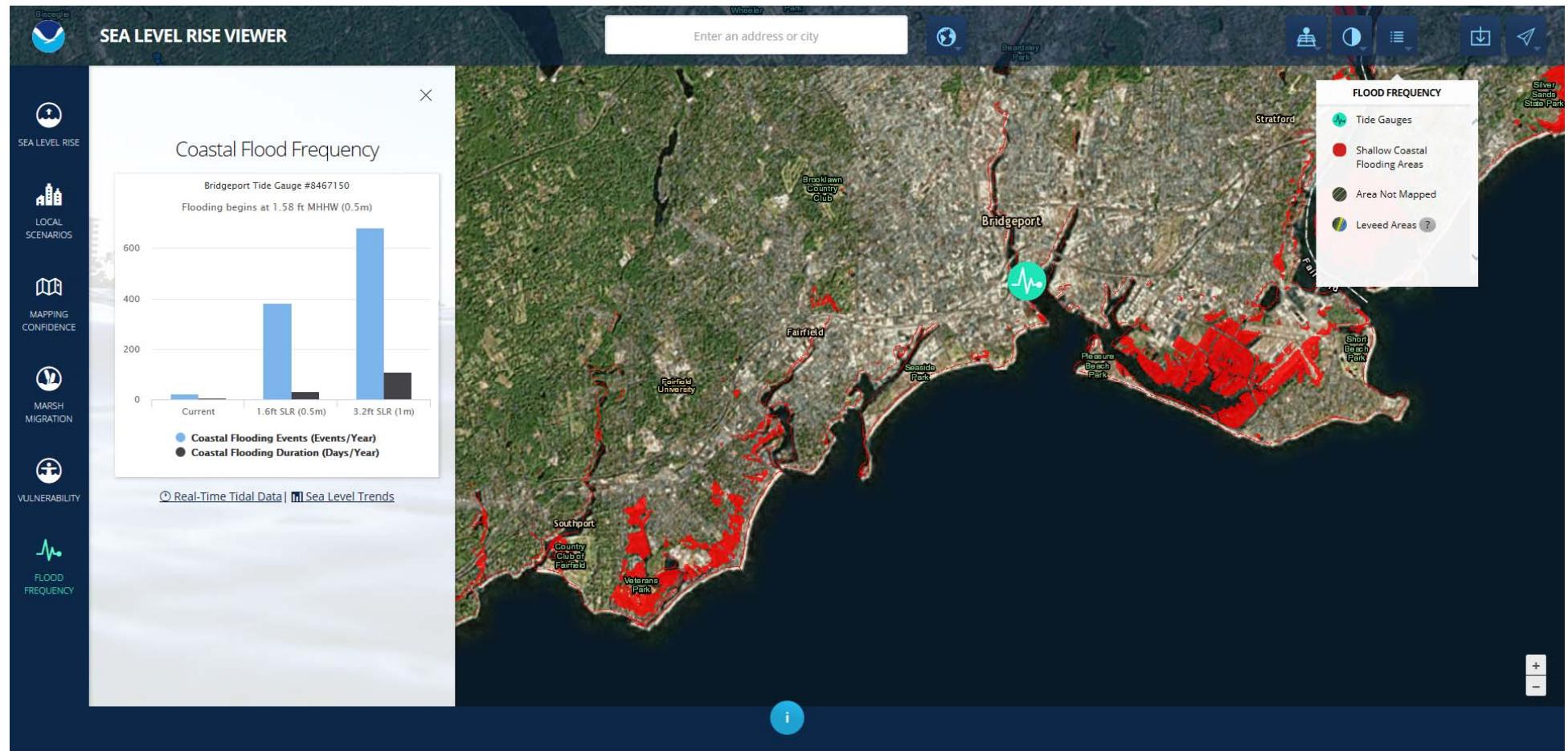
# NOAA Sea Level Rise Viewer



# Example of Relative Sea Level Change on Tidal Flooding: New Haven High Resolution Numerical Modeling

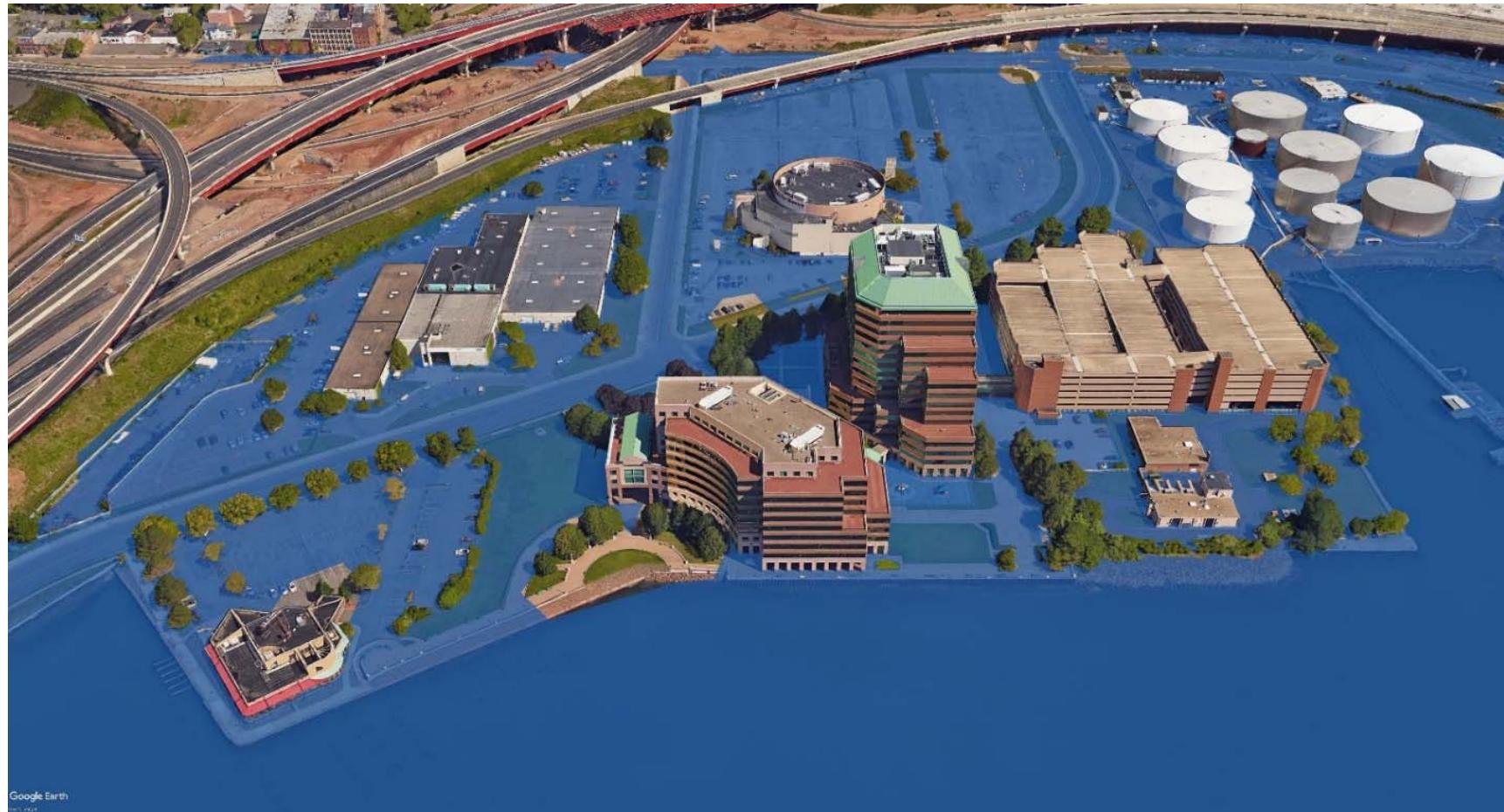


# NOAA Sea Level Rise Viewer



# Relative Sea Level Change Implications

100-year return period flood



Google Earth  
2010

# Planning Implications of Sea Level Rise

**Risk = probability of an event x consequences**

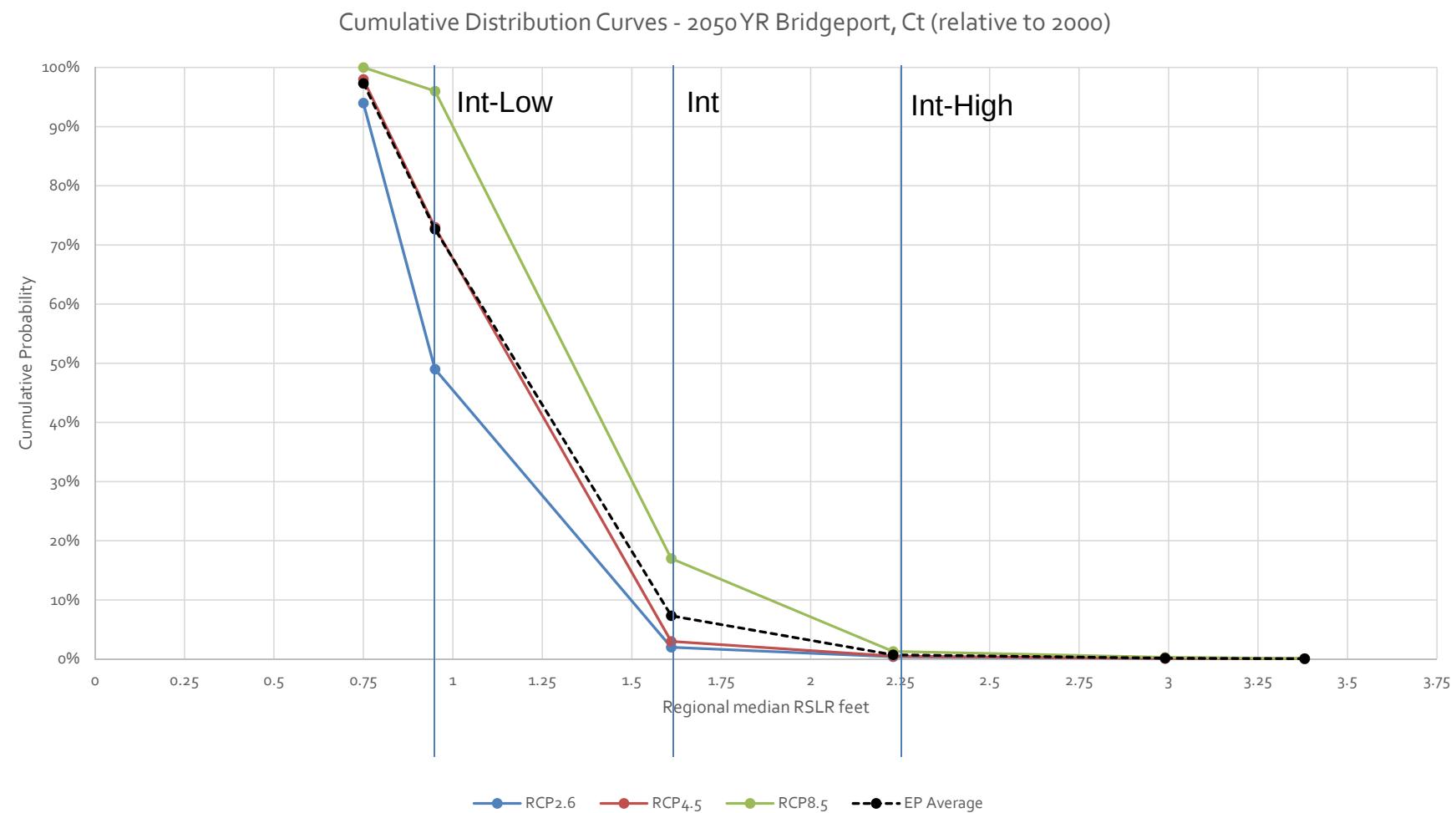
✓ Risk-Informed (Based on Probability):

- Expected Loss
- Criticality
- Planning Horizon
- Tipping Points
- Risk Tolerance

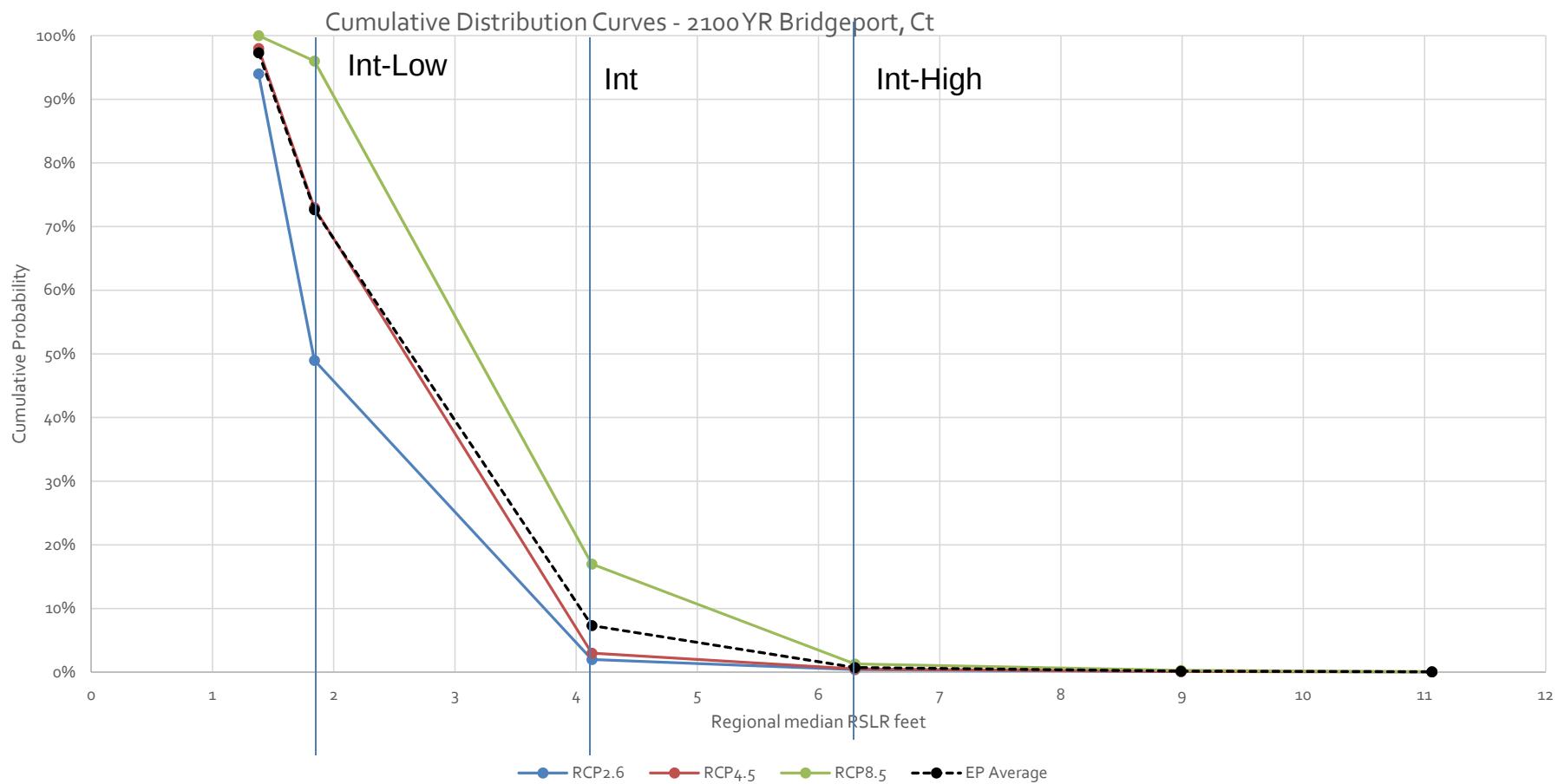
✓ Envelope Risk (mid-range and upper bound):

- NOAA, 2017 Intermediate-Low    49% to 96% - very likely
- NOAA, 2017 Intermediate        2% to 17% - likely
- NOAA, 2017 Intermediate-High 0.4% to 1.3% - low but possible

# Planning Implications of Sea Level Rise



# Planning Implications of Sea Level Rise



# Planning Implications of Sea Level Rise

## Bridgeport, Connecticut Projections

Year 2040:

NOAA, 2017 Intermediate-Low:	0.79 foot
NOAA, 2017 Intermediate:	1.25 feet
NOAA, 2017 Intermediate-High:	1.74 feet

Year 2070:

NOAA, 2017 Intermediate-Low:	1.35 feet
NOAA, 2017 Intermediate:	2.53 feet
NOAA, 2017 Intermediate-High:	3.64 feet

Year 2050:

NOAA, 2017 Intermediate-Low:	0.95 foot
NOAA, 2017 Intermediate:	1.61 feet
NOAA, 2017 Intermediate-High:	2.23 feet

Year 2100:

NOAA, 2017 Intermediate-Low:	1.84 feet
NOAA, 2017 Intermediate:	4.13 feet
NOAA, 2017 Intermediate-High:	6.30 feet

# Planning Implications of Sea Level Rise

## State of Connecticut Guidance and Regulation:

- PA 12-101
- PA 13-179

## Must Consider RSLC:

- Plans of Conservation and Development
- Hazard Mitigation Plans
- Coastal Management
- Inconsistencies in definition of sea level rise
- Does not consider structure criticality

## Forthcoming Guidance: UCONN/CIRCA

- Mid-range Planning **1.7 feet by 2050**
- Long Term – be aware **3.25 feet by 2100**
- Updated every decade

The screenshot shows the UConn CIRCA website. At the top, there's a dark header with the university logo and navigation links for Home, About, What We Do, Funding Opportunities, Projects & Products, Resources, Announcements, and Contact Us. Below the header, the main content area has a light gray background. A green header bar contains the title "Sea Level Rise". Underneath, a green sidebar box is titled "CIRCA Sea Level Rise Projects & Products". It describes the projects and provides links to the "Sea Level Rise Projects & Products" site and two PDF files: "O'Donnell 2017 Technical Report Executive Summary" and "Presentation (with audio) cr and slides only". Below the sidebar, a paragraph explains CIRCA's mission to enhance coastal resilience. To the right of the sidebar, there's a small image of a flooded residential area.