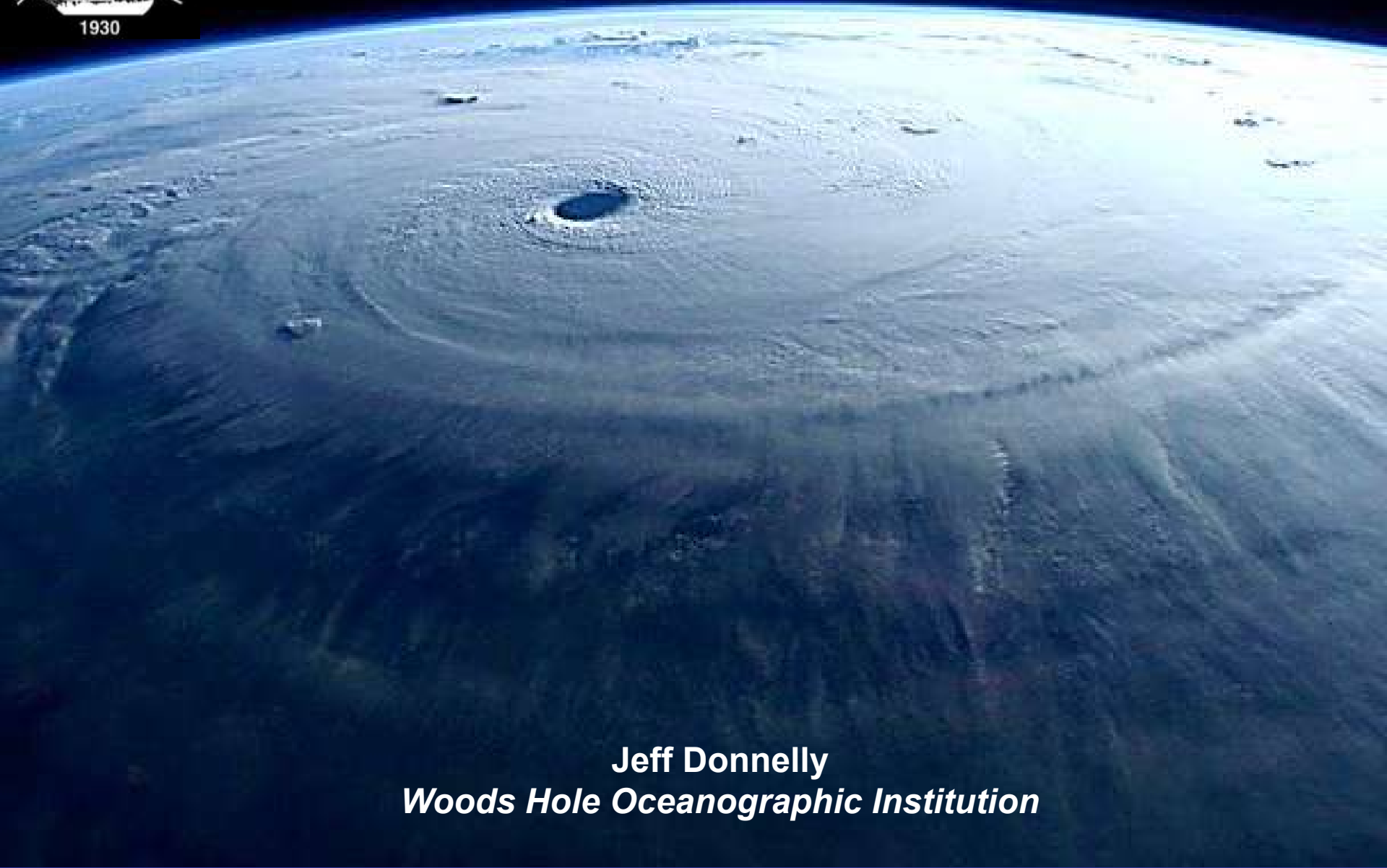


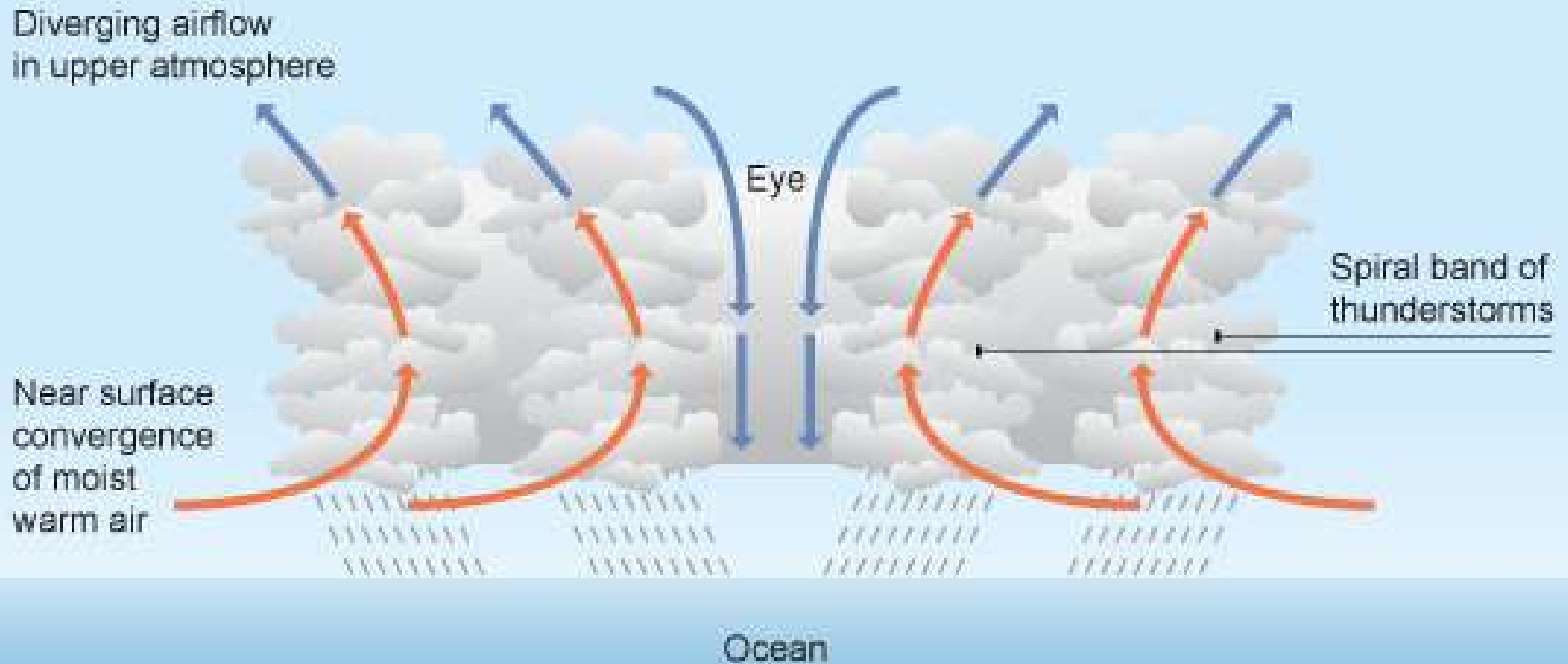


# Hurricane Risk in Southeastern MA



**Jeff Donnelly**  
*Woods Hole Oceanographic Institution*

# What is a tropical cyclone?



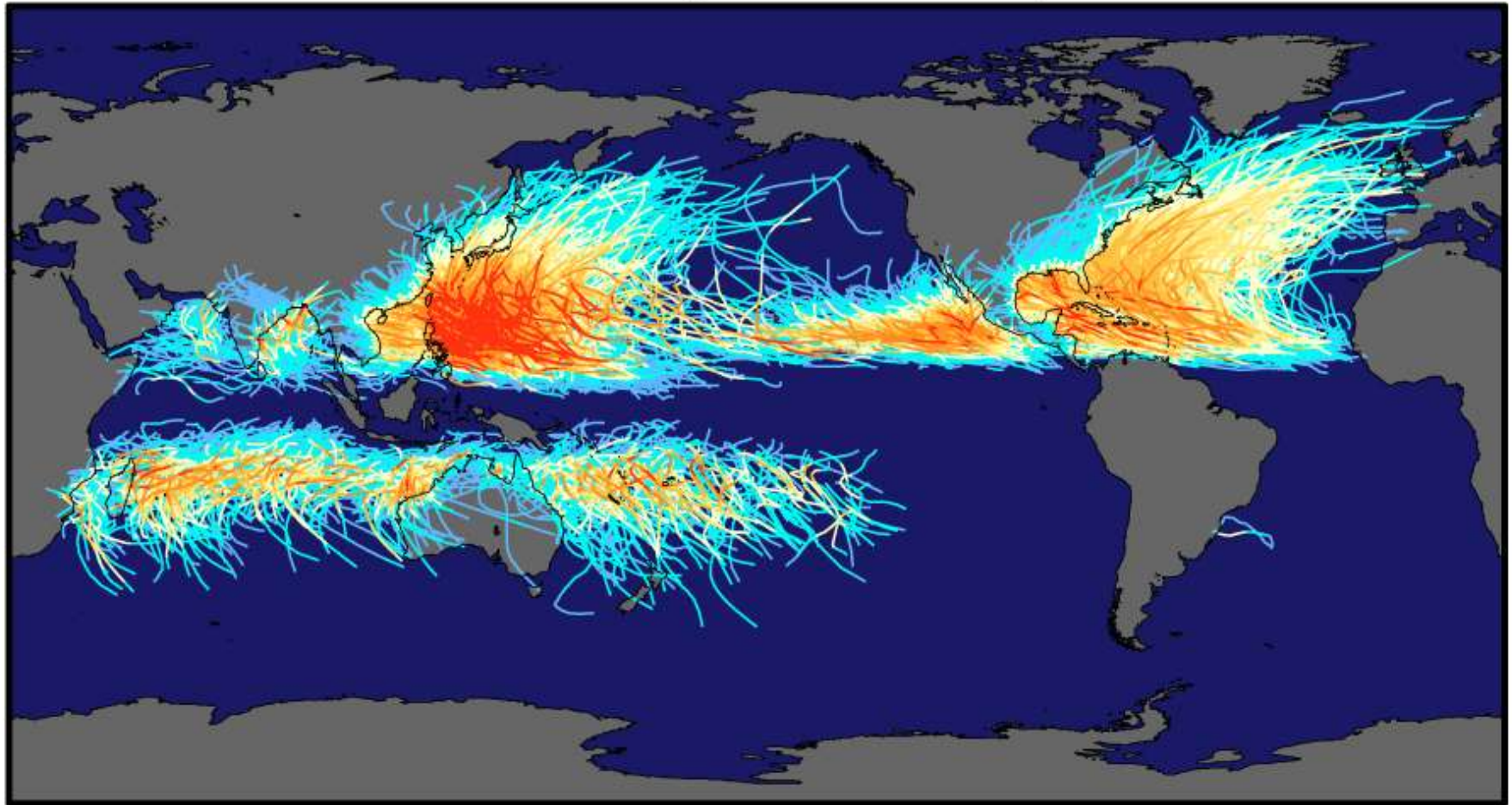
## Conditions for genesis

- Warm tropical waters  $> 26^{\circ}\text{C}$ ,  $80^{\circ}\text{F}$
- Minimal Wind Shear Aloft
- Prior disturbance
- Coriolis Deflection

# Where do they occur?



## Tracks and Intensity of All Tropical Storms



Saffir-Simpson Hurricane Intensity Scale

# Intensity



## Saffir-Simpson Scale for Hurricane Classification

Strength	Wind Speed (Kts)	Wind Speed (MPH)	Pressure (Millibars)	Pressure
Category 1	64- 82 kts	74- 95 mph	>980 mb	28.94 "Hg
Category 2	83- 95 kts	96-110 mph	965-979 mb	28.50-28.91 "Hg
Category 3	96-113 kts	111-130 mph	945-964 mb	27.91-28.47 "Hg
Category 4	114-135 kts	131-155 mph	920-944 mb	27.17-27.88 "Hg
Category 5	>135 kts	>155 mph	919 mb	27.16 "Hg

## Tropical Cyclone Classification

Tropical Depression	20-34kts
Tropical Storm	35-63kts
Hurricane	64+kts or 74+mph

# Tropical cyclones come in different sizes



## TROPICAL CYCLONE "RECORDS"

(ALL STATISTICS AS OF EARLY 2010)

TYPHOON "TIP"  
(1979 - PACIFIC)

1,200 MILES ACROSS

HURRICANE "IKE"  
(2008)

900 MILES ACROSS

TROPICAL STORM  
"MARCO" (2008)

10 MILES!

LARGEST EVER

LARGEST IN ATLANTIC

SMALLEST EVER

**YELLOW** = Tropical Storm Force Wind Envelope

**RED** = Hurricane Force Wind Envelope

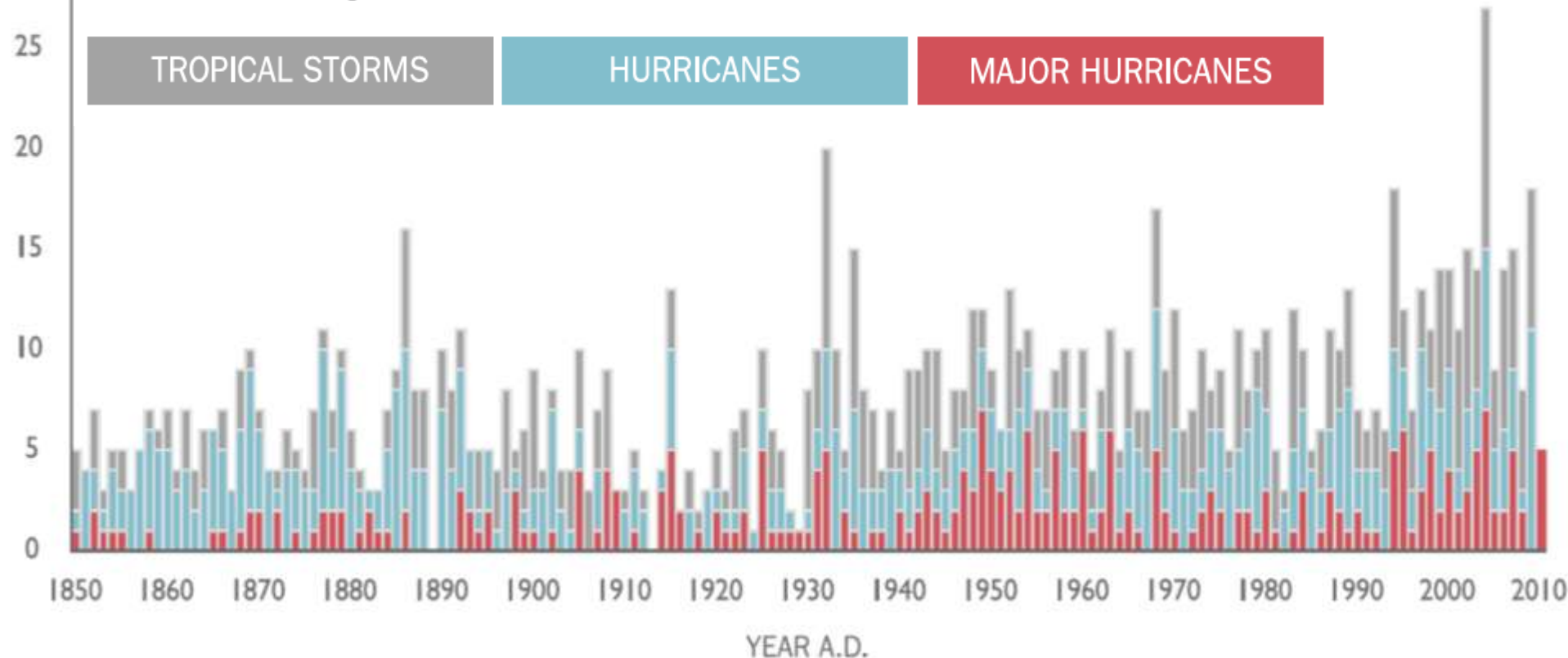
USGS / NOAA / JTWC / CDC 2010



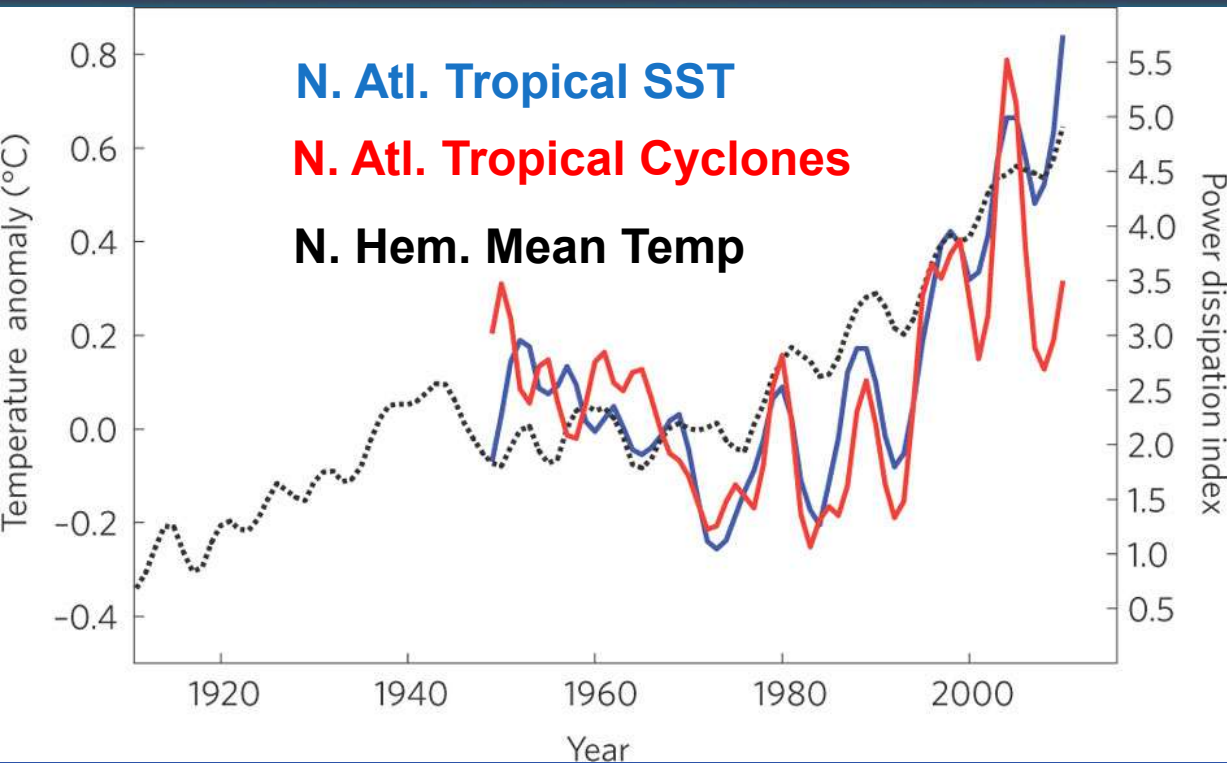
# Recent Hurricane Trends



## ANNUAL FREQUENCY OF NORTH ATLANTIC TROPICAL CYCLONES

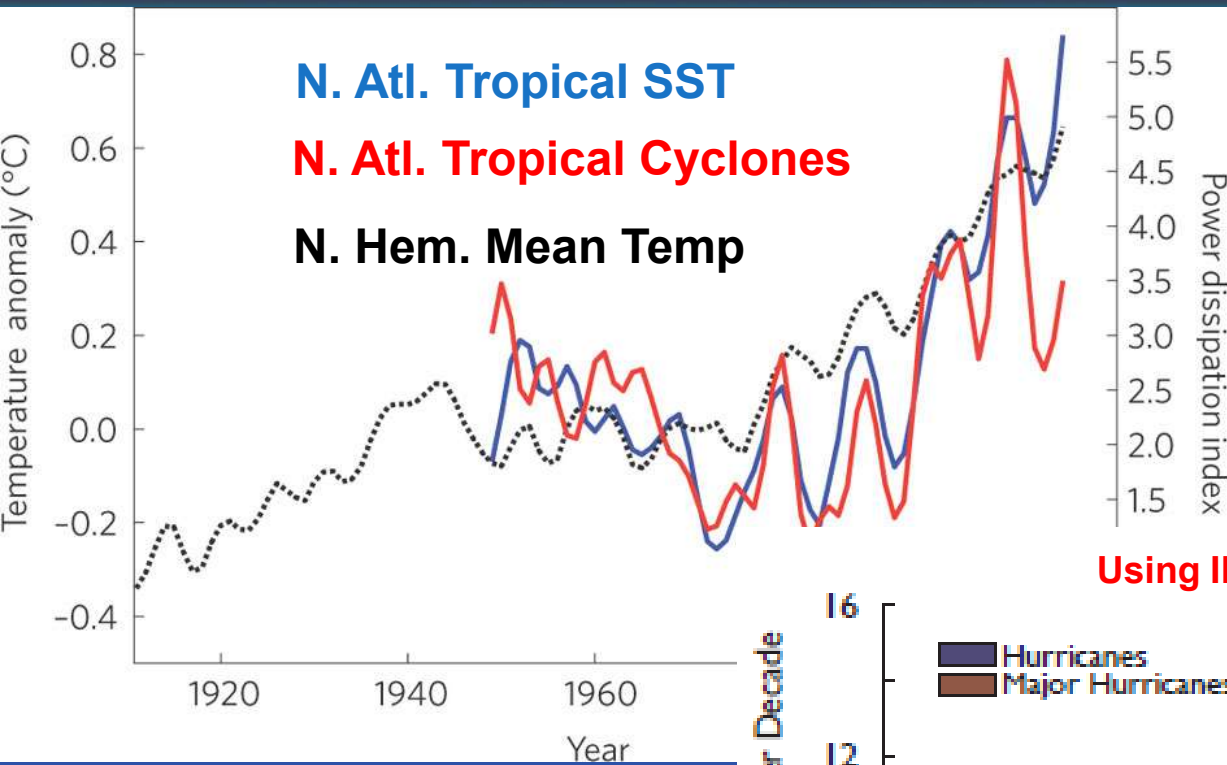


# What Might the Future Hold?



From  
Coumou and Rahmstorf, 2012  
*Nature Climate Change*

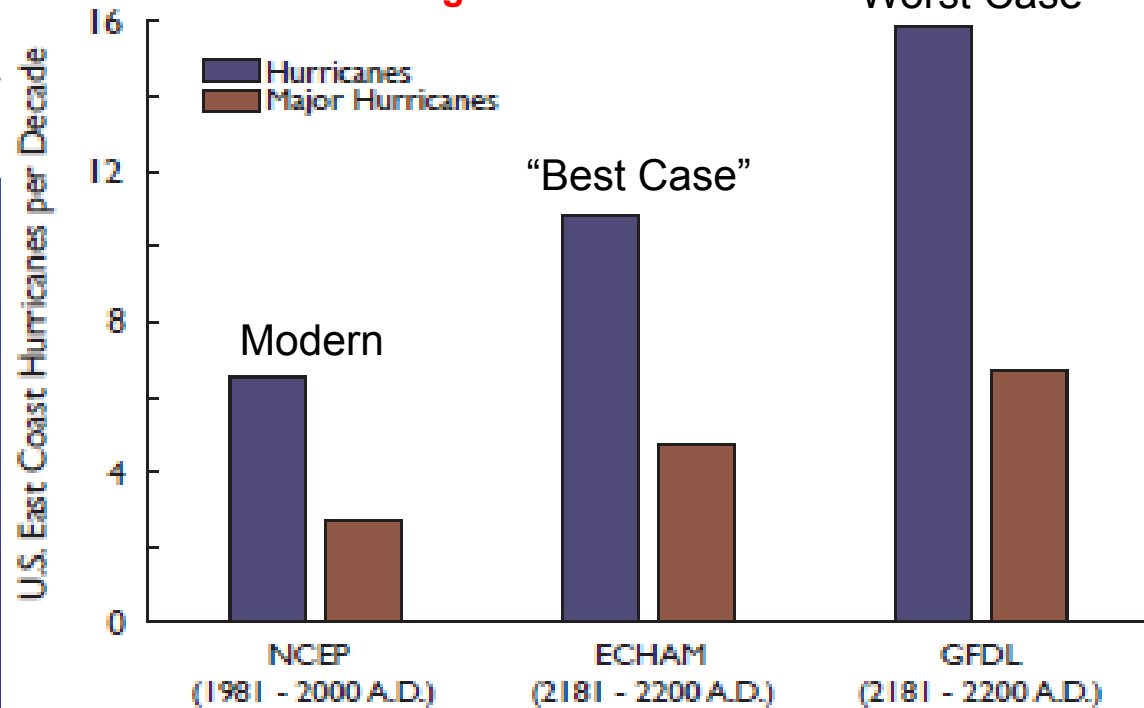
# What Might the Future Hold?



Frequency of hurricanes may increase (particularly intense storms)

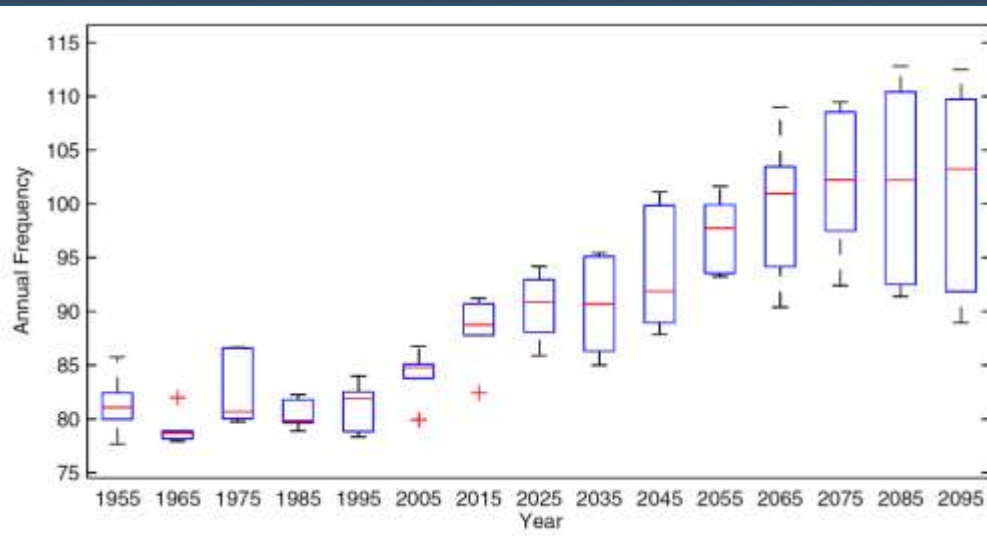
Using IPCC AR4 models

“Worst Case”



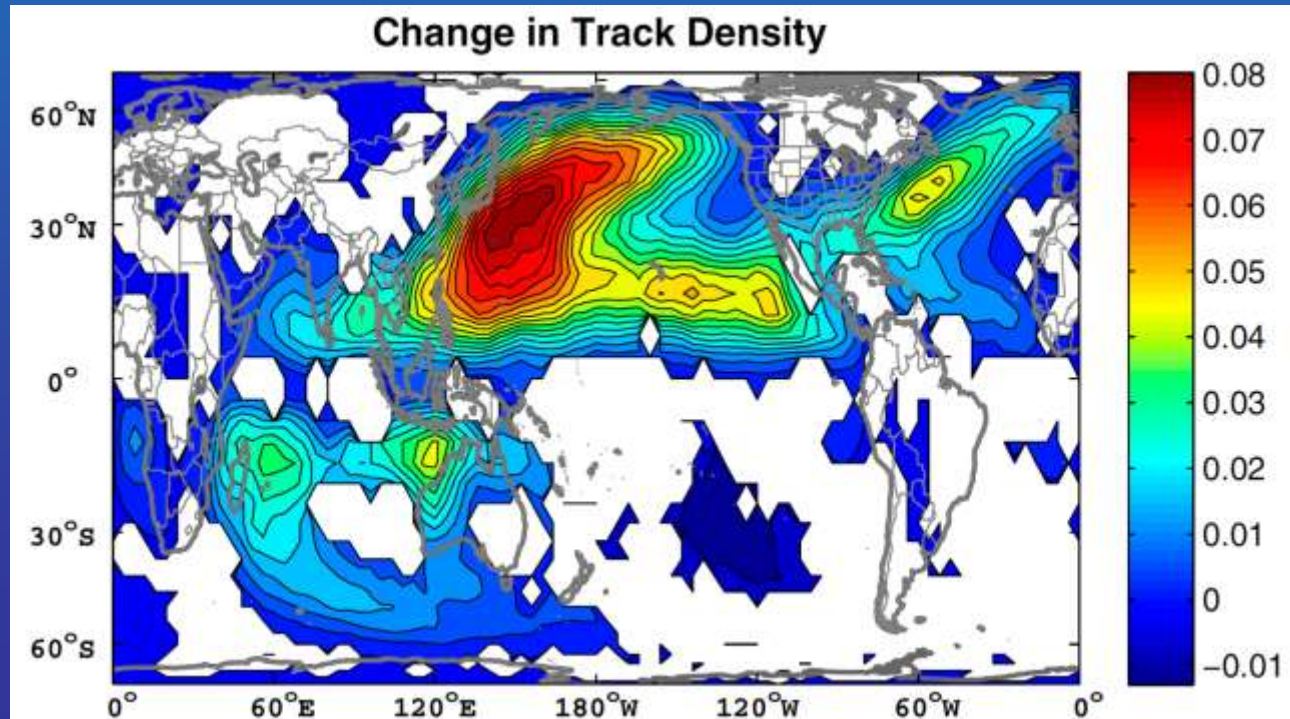


# What Might the Future Hold?



Frequency of hurricanes may increase (particularly intense storms)

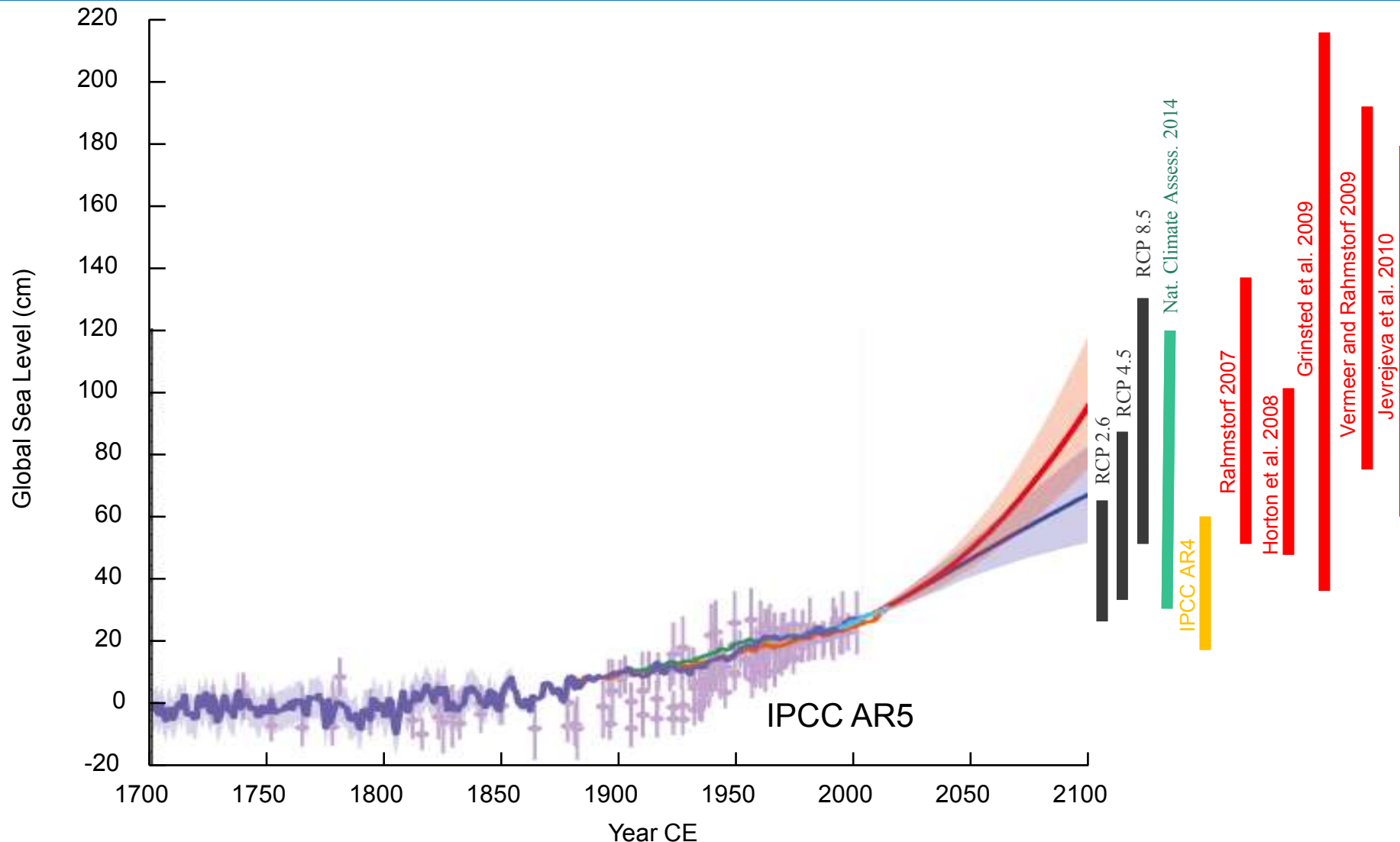
From Emanuel, 2013 PNAS  
Using IPCC AR5 models



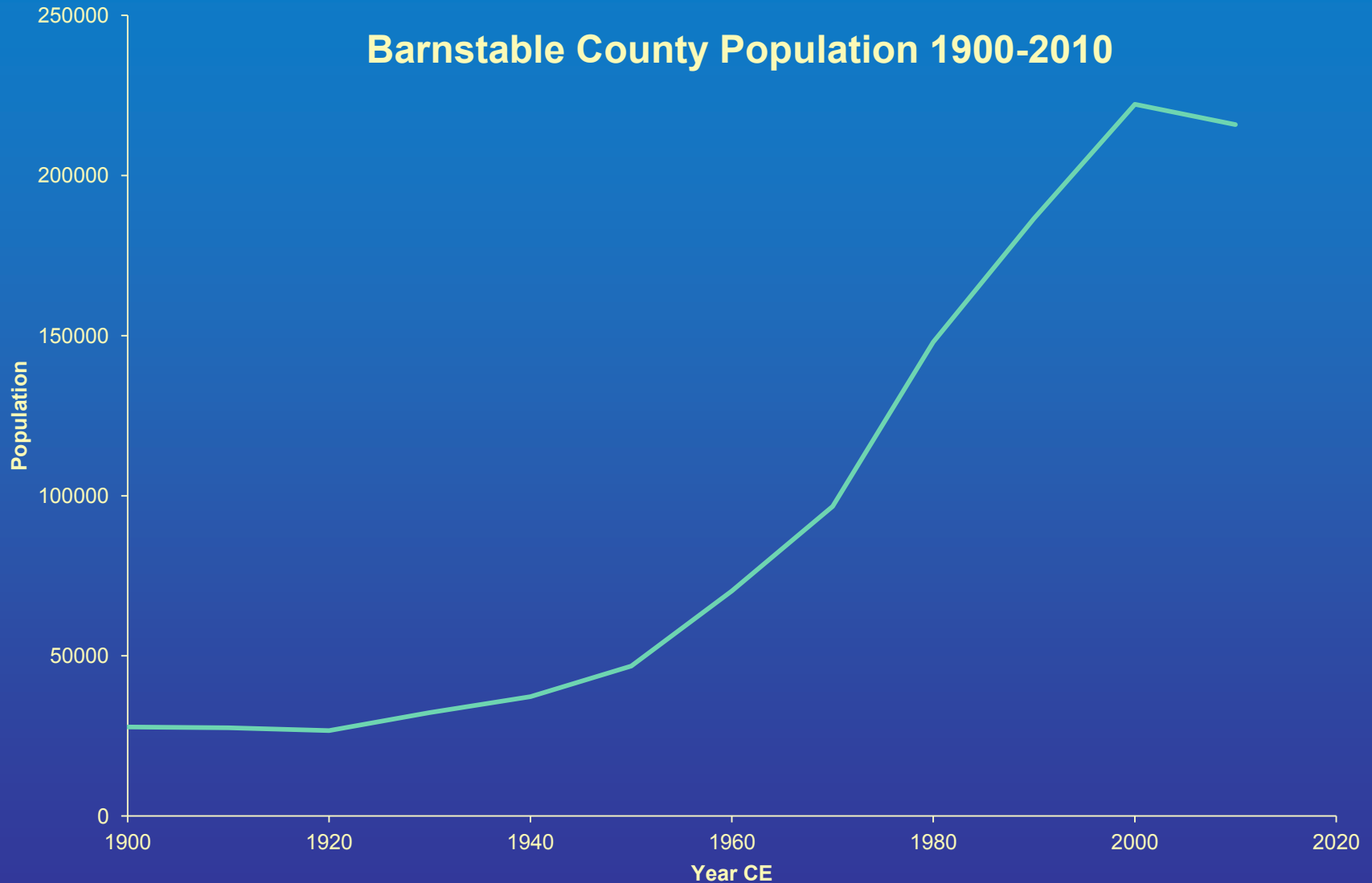
# Global Sea Level



Rate of sea-level rise will continue to accelerate



# Coastal Population Growth



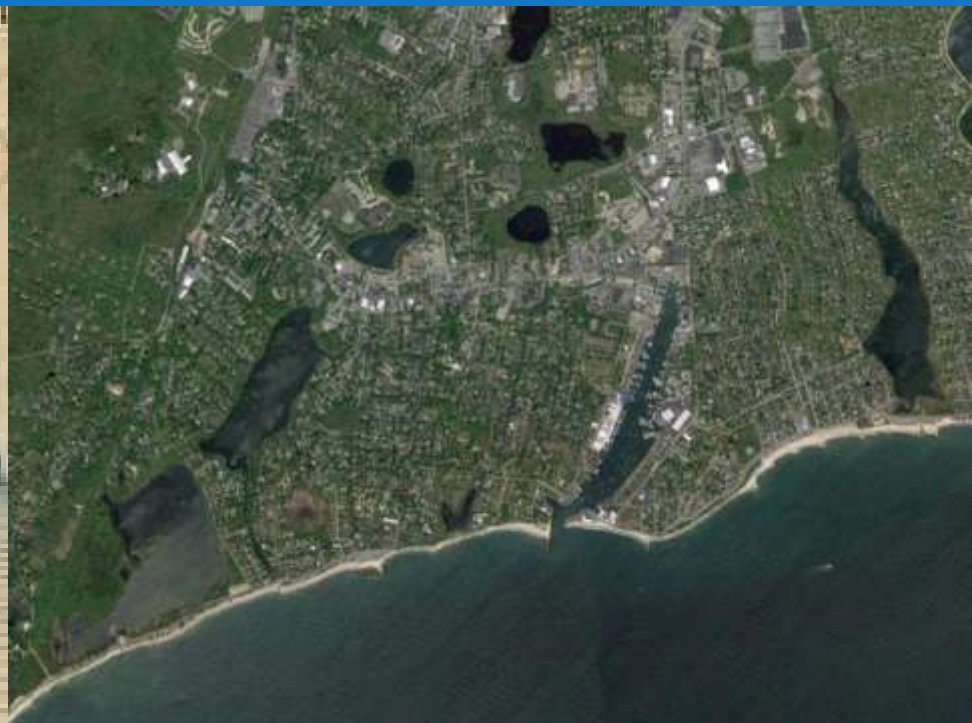
# Coastal Population Growth



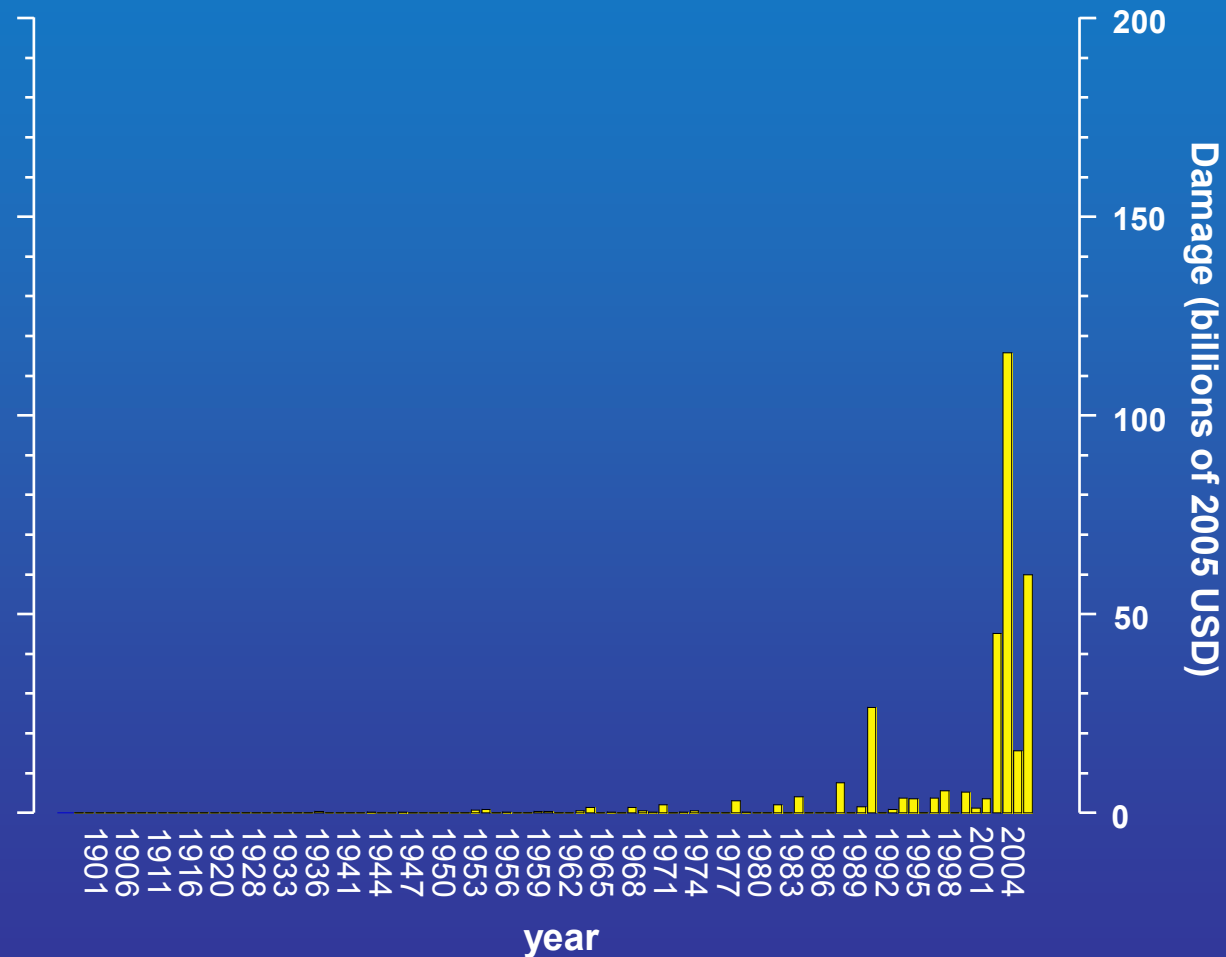
Falmouth 1886



Falmouth 2015



# 1900-2013 US Hurricane Damage in 2005 USD

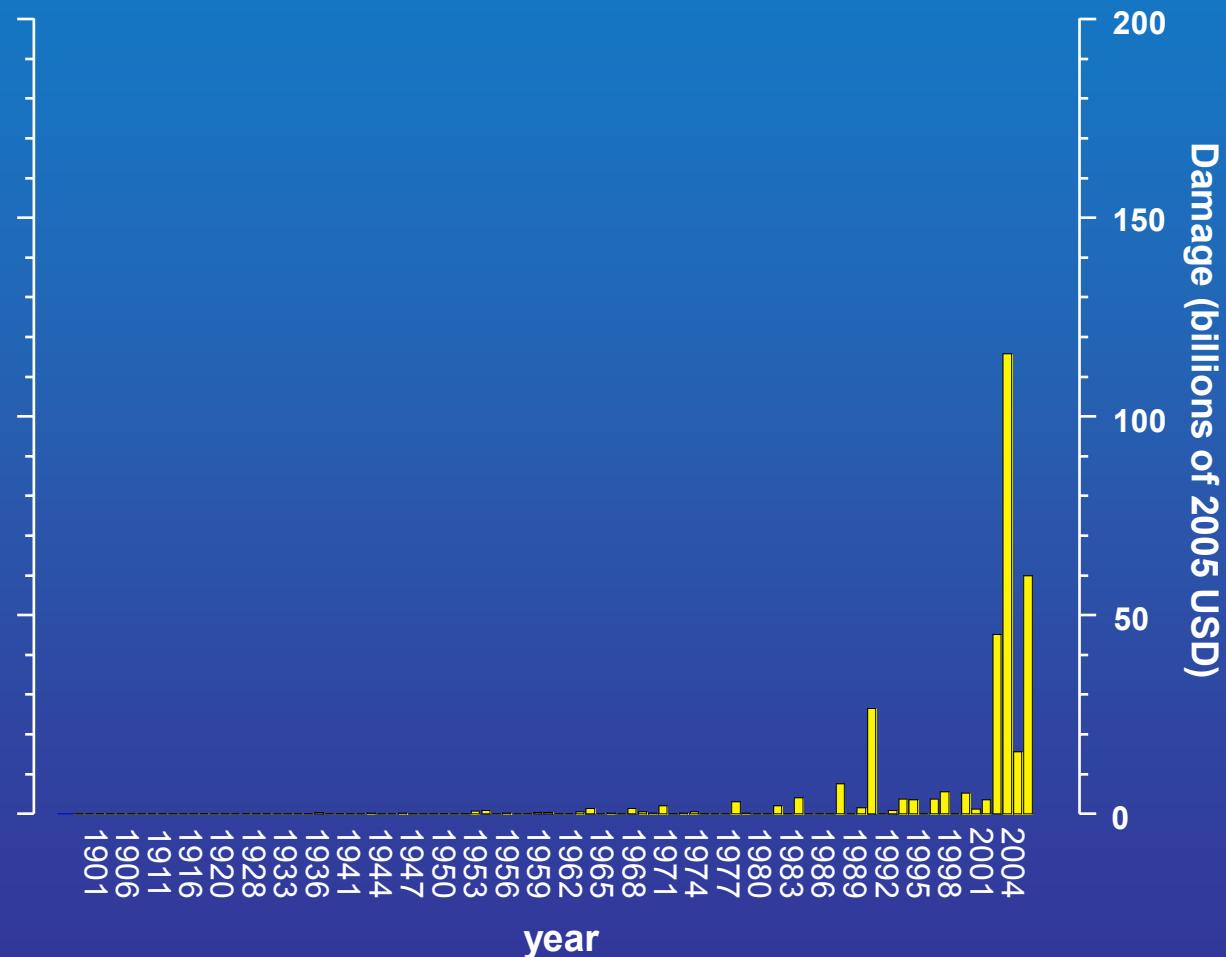


From Pielke et al., 2008

# 1900-2013 US Hurricane Damage in 2005 USD



But what if these storms were to strike today?

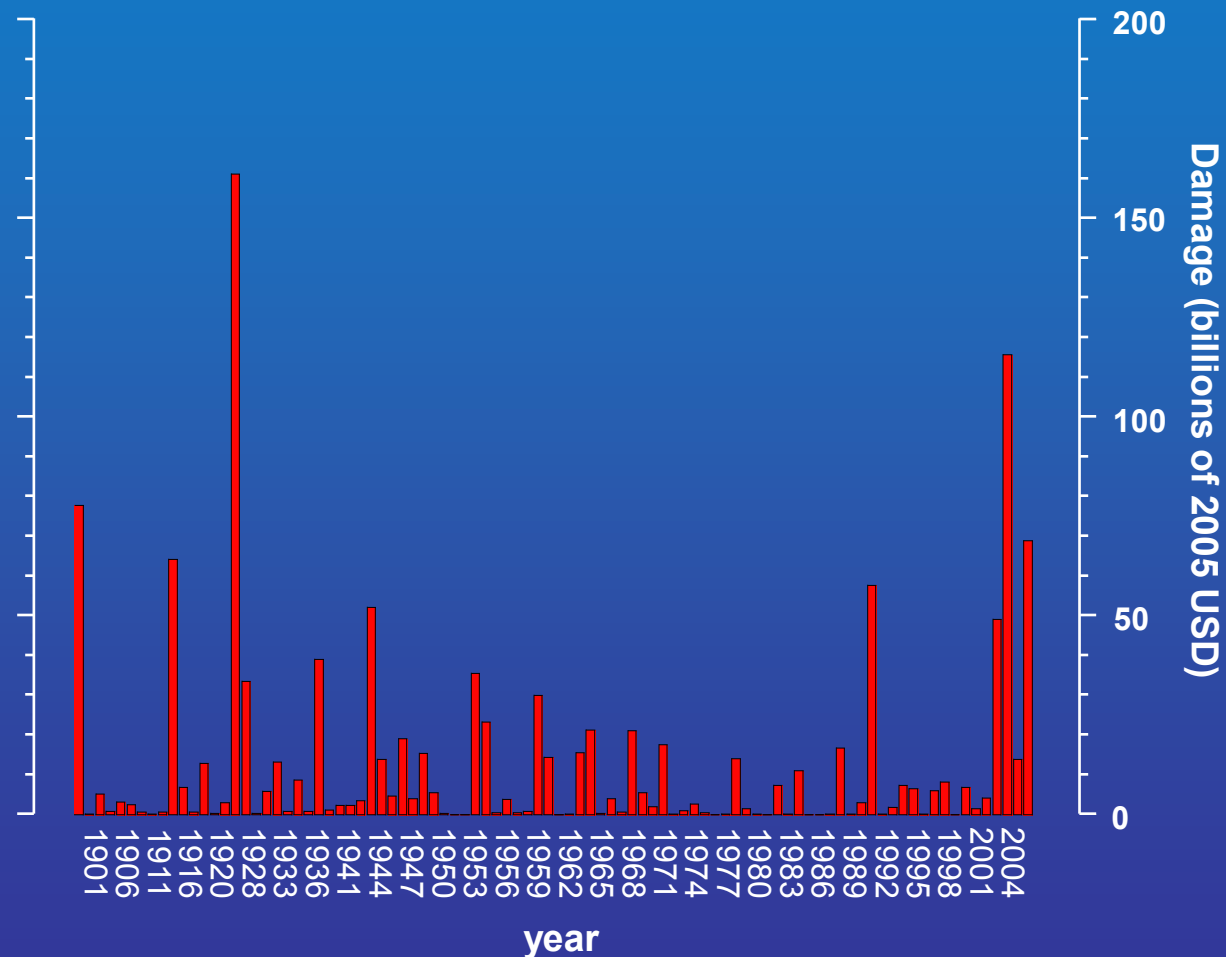




# 1900-2013 US Hurricane Damage in 2005 USD



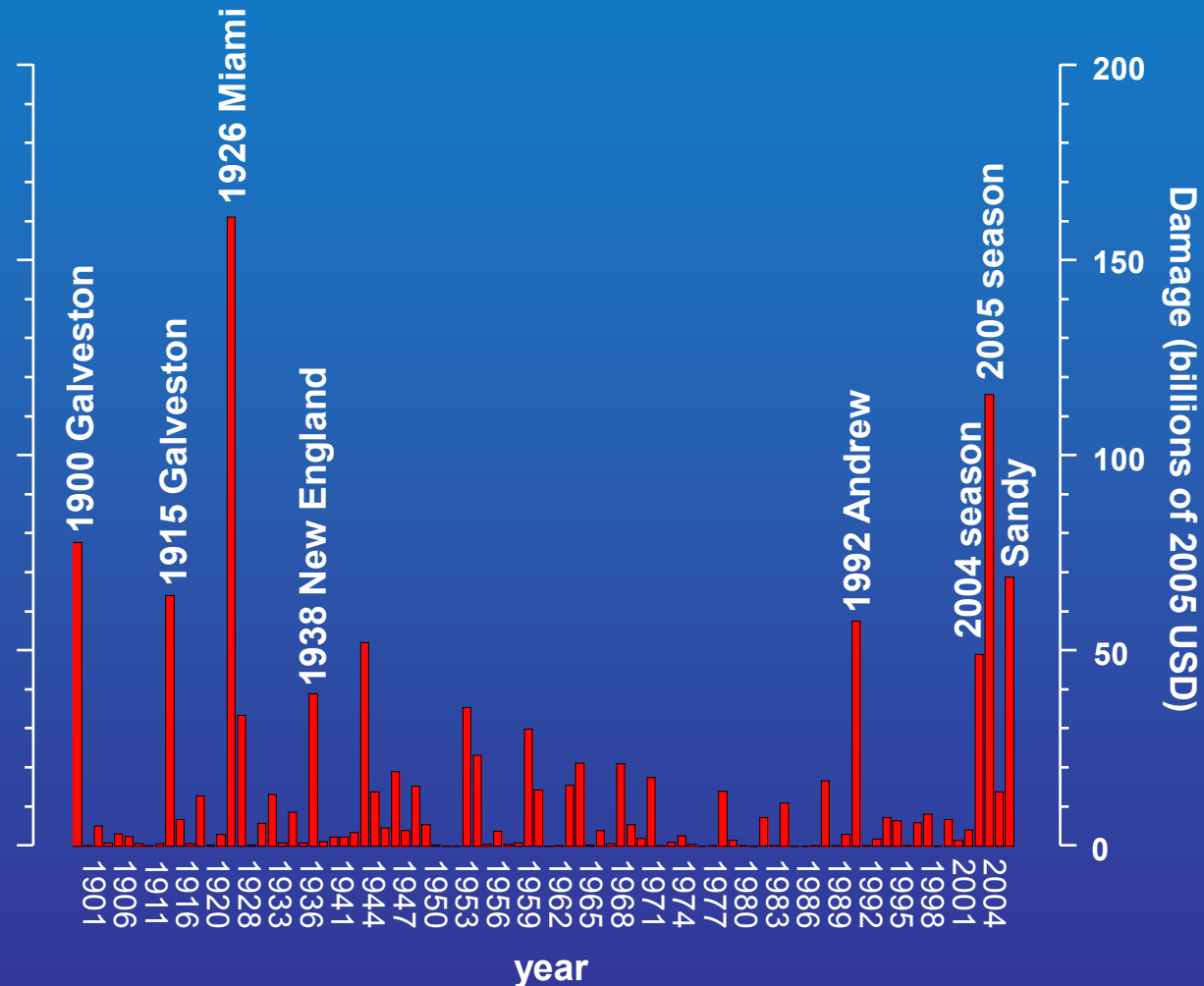
Damage accounting for increased wealth and population



# 1900-2013 US Hurricane Damage in 2005 USD



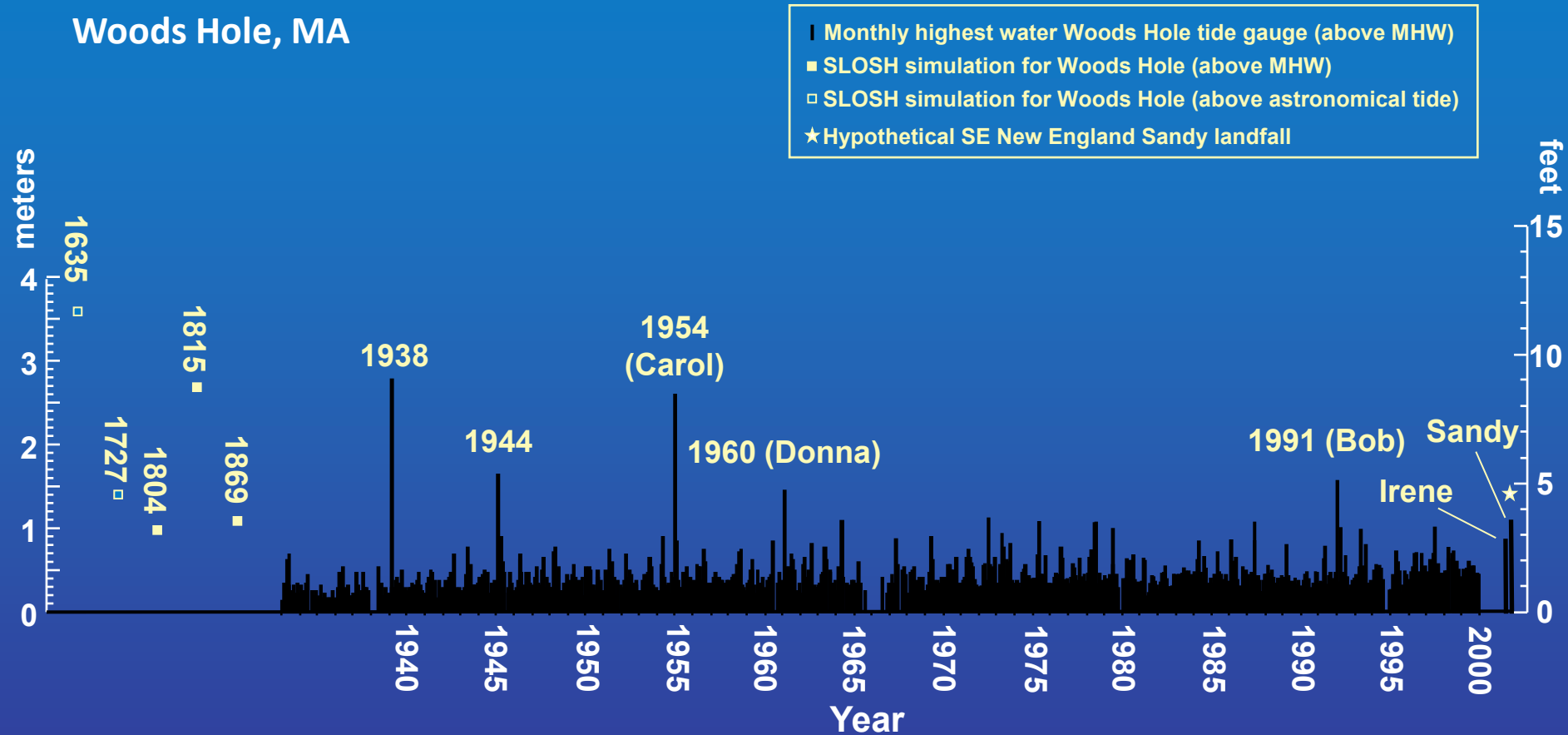
Damage accounting for increased wealth and population



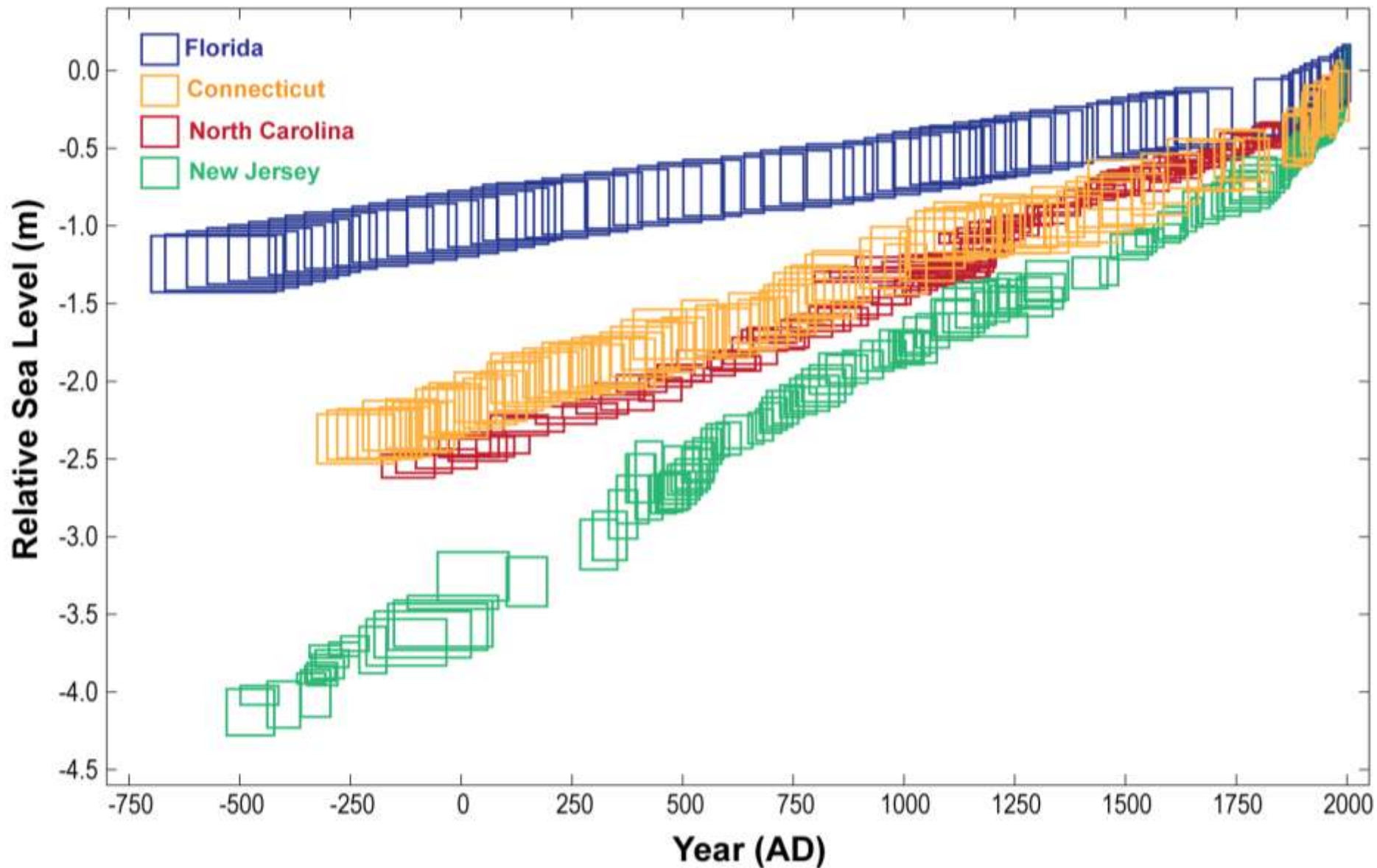
# Instrumental record of coastal Inundation



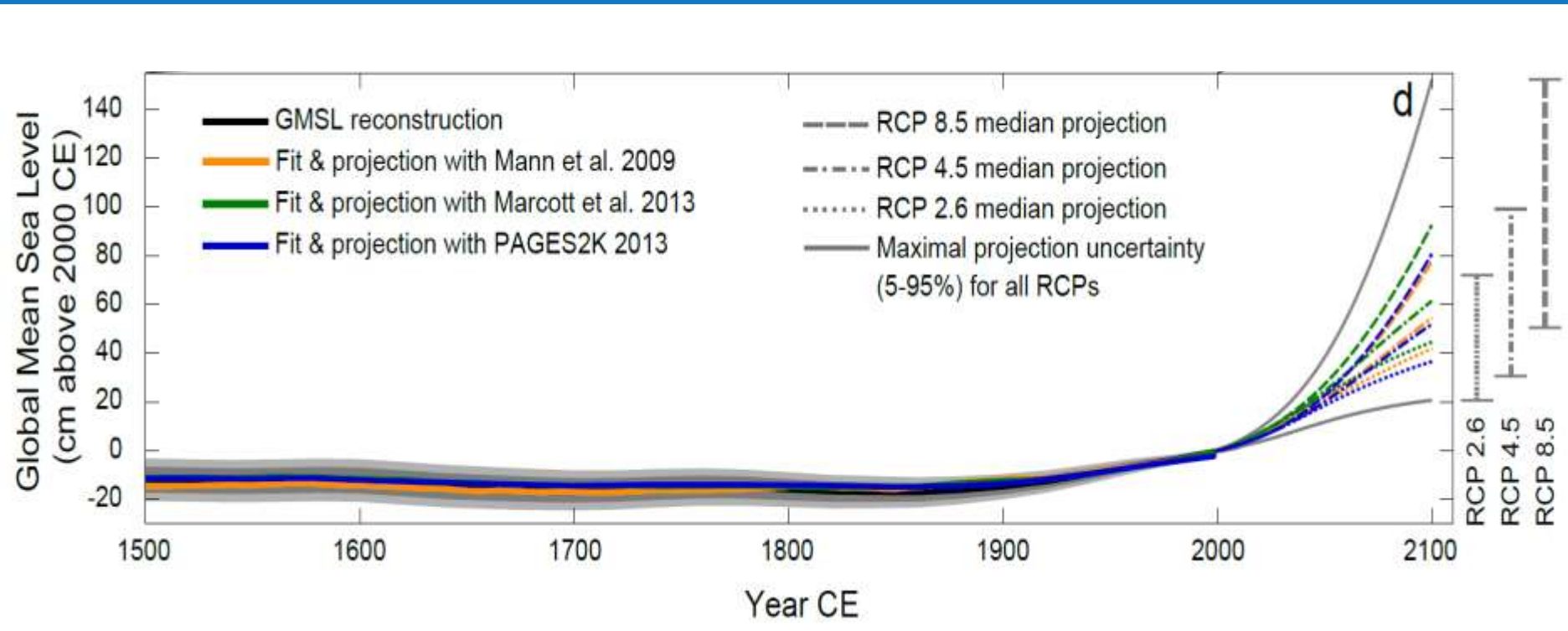
## Woods Hole, MA



# Sea Level Histories

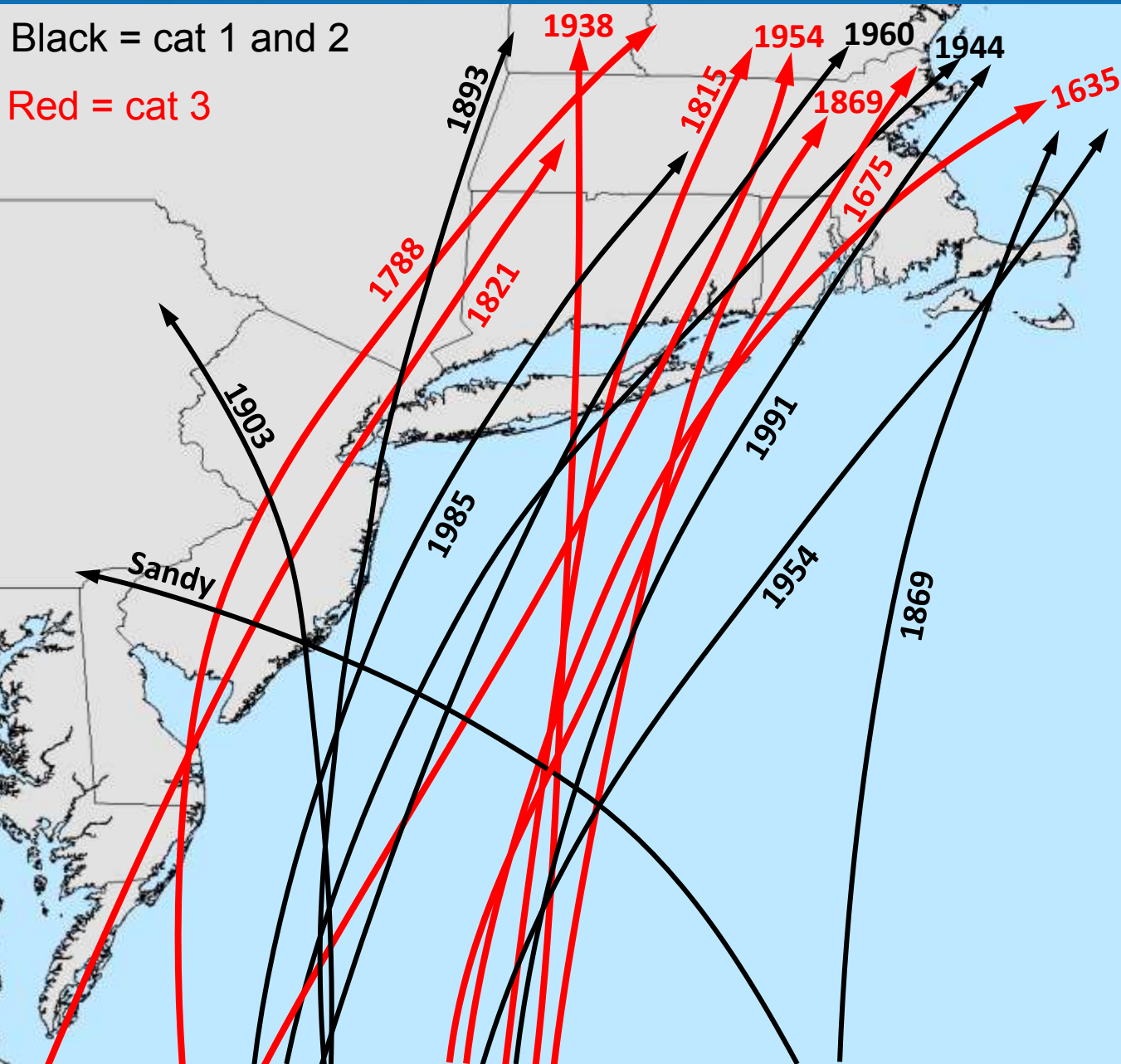


# Modeling future sea level changes



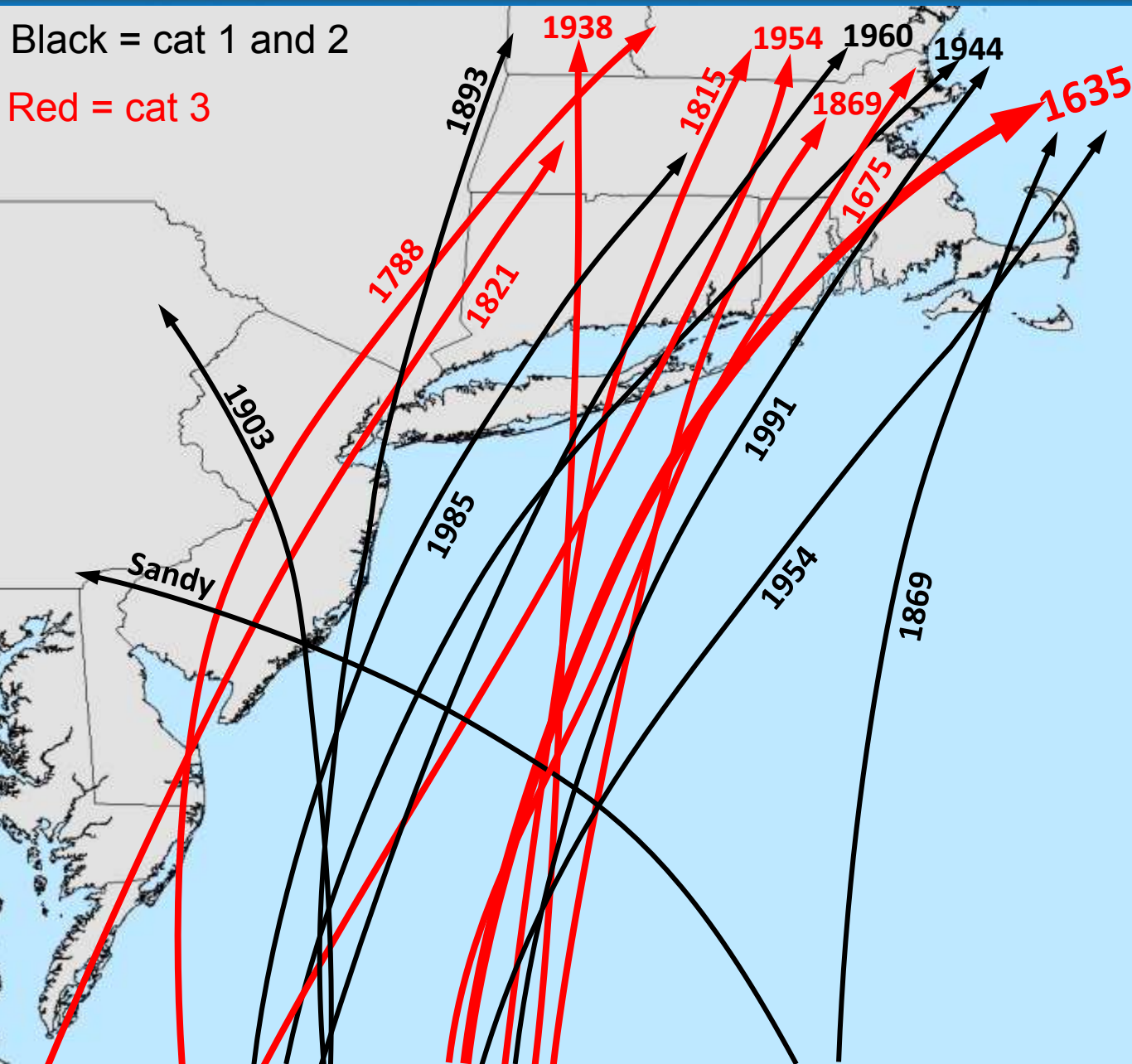
From Kopp et al. submitted

# Historical Northeast US Hurricanes





# Historical Northeast US Hurricanes



# Storm surge from the Great Colonial Hurricane of 1635



John Winthrop  
(Governor of Massachusetts Bay Colony)

*"The tide rose at Narragansett fourteen feet higher than ordinary, and drowned eight Indians flying from their wigwams"*

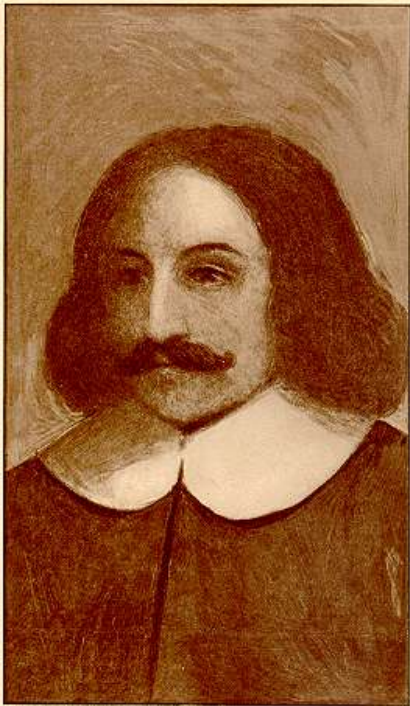


William Bradford (Governor of Plymouth Colony)

*"...a mighty storm of wind and rain as none living in these parts, either English or Indians ever saw"*

*"It caused the sea to swell to the south wind of this place above 20 foot right up and down, and made many of the Indians to climb into trees for their safety"*

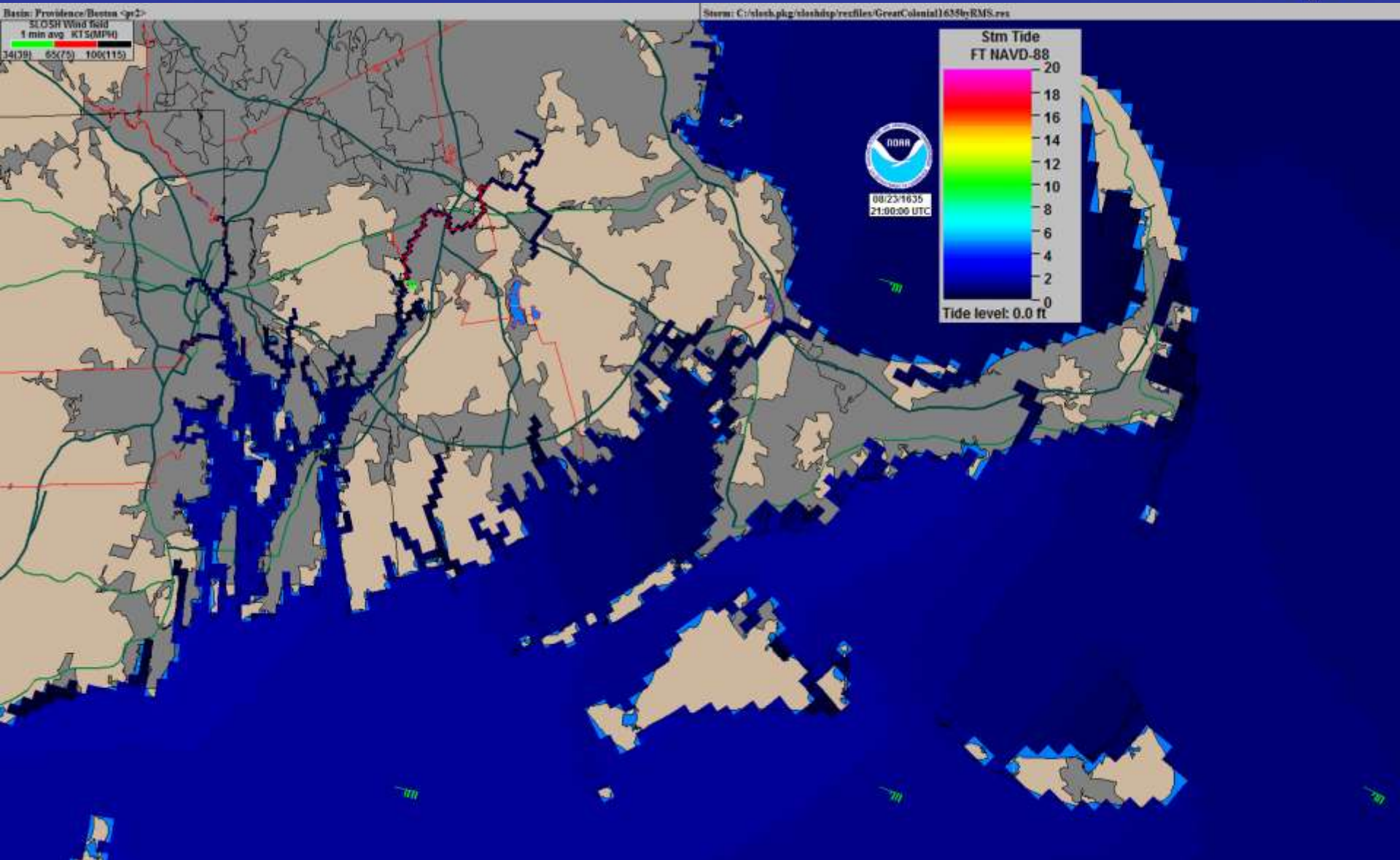
*"It blew down many hundred thousands of trees, turning up the stronger by the roots and breaking the higher pine trees off in the middle"*



Copyright, 1894, by A. S. Forester, Plymouth

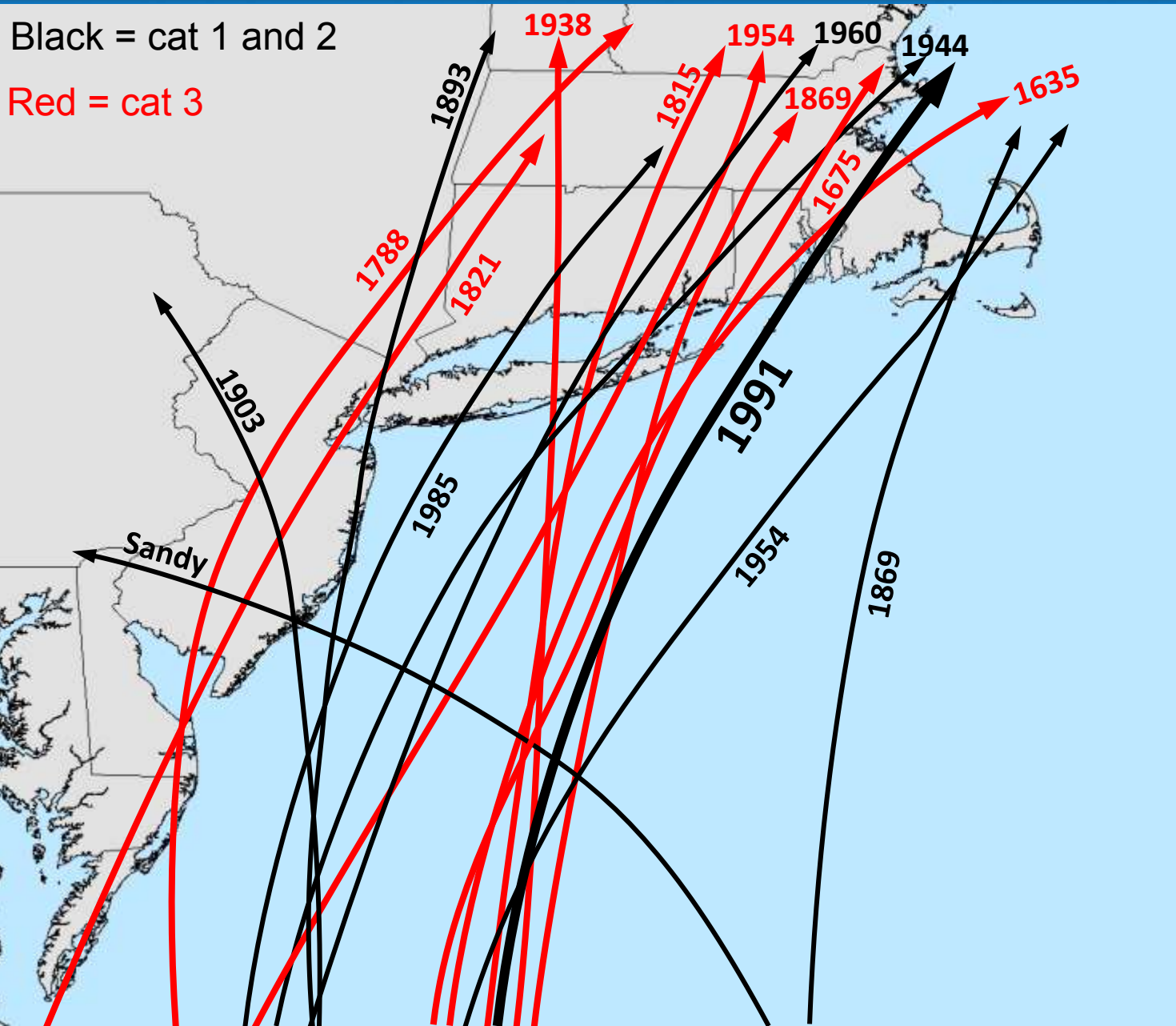
GOVERNOR WILLIAM BRADFORD

# Storm surge from the Great Colonial Hurricane of 1635

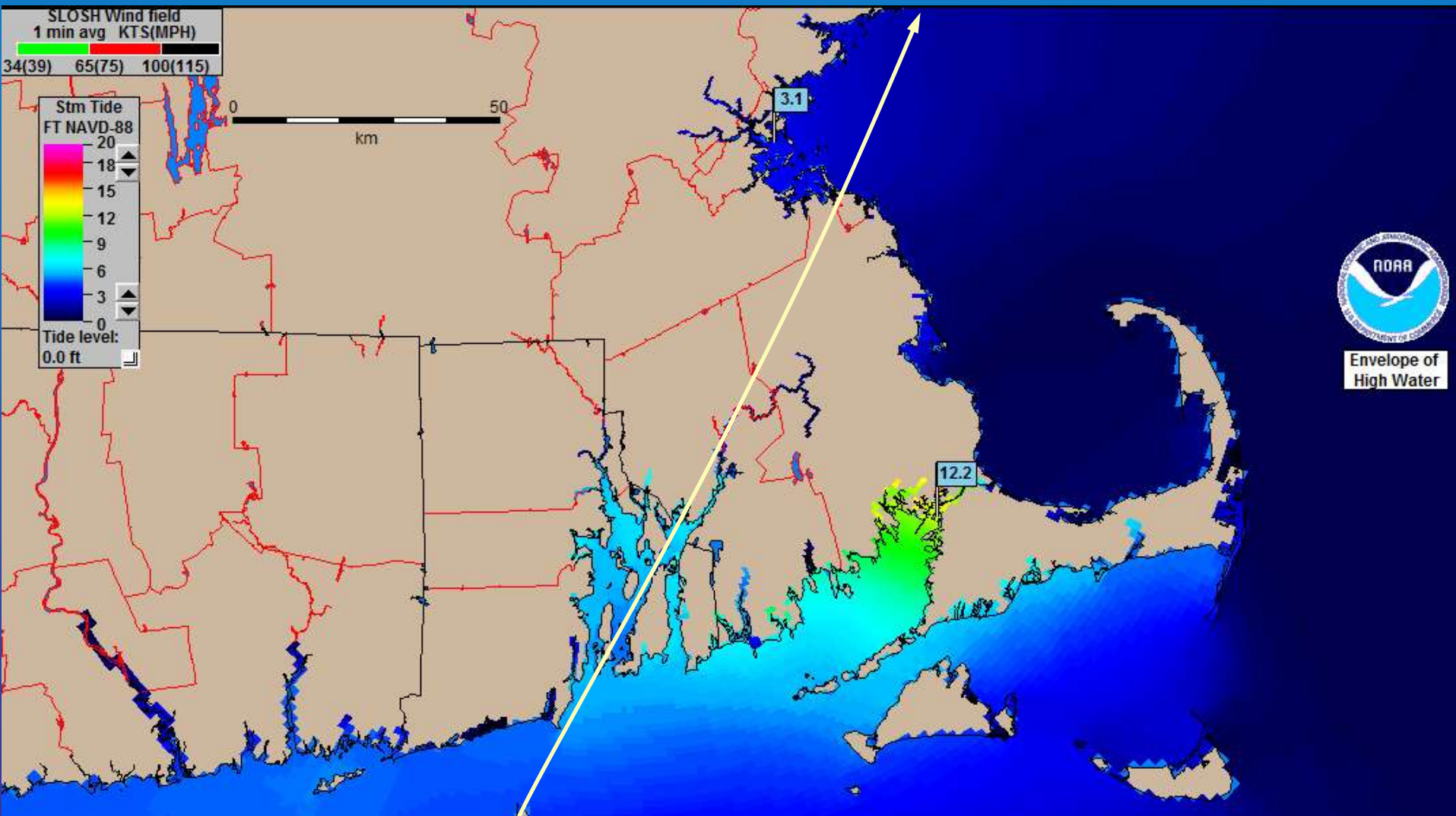




# Historical Northeast US Hurricanes



# Hurricane Bob (1991) Storm Surge



# What if the Hurricane of 1635 Struck Again?



## The Great Colonial Hurricane - 1635



0 0.5 1 1.5 Kilometers

Maximum Surge Heights Under Different Sea Levels

0.0m Sea Level Rise

0.5m Sea Level Rise

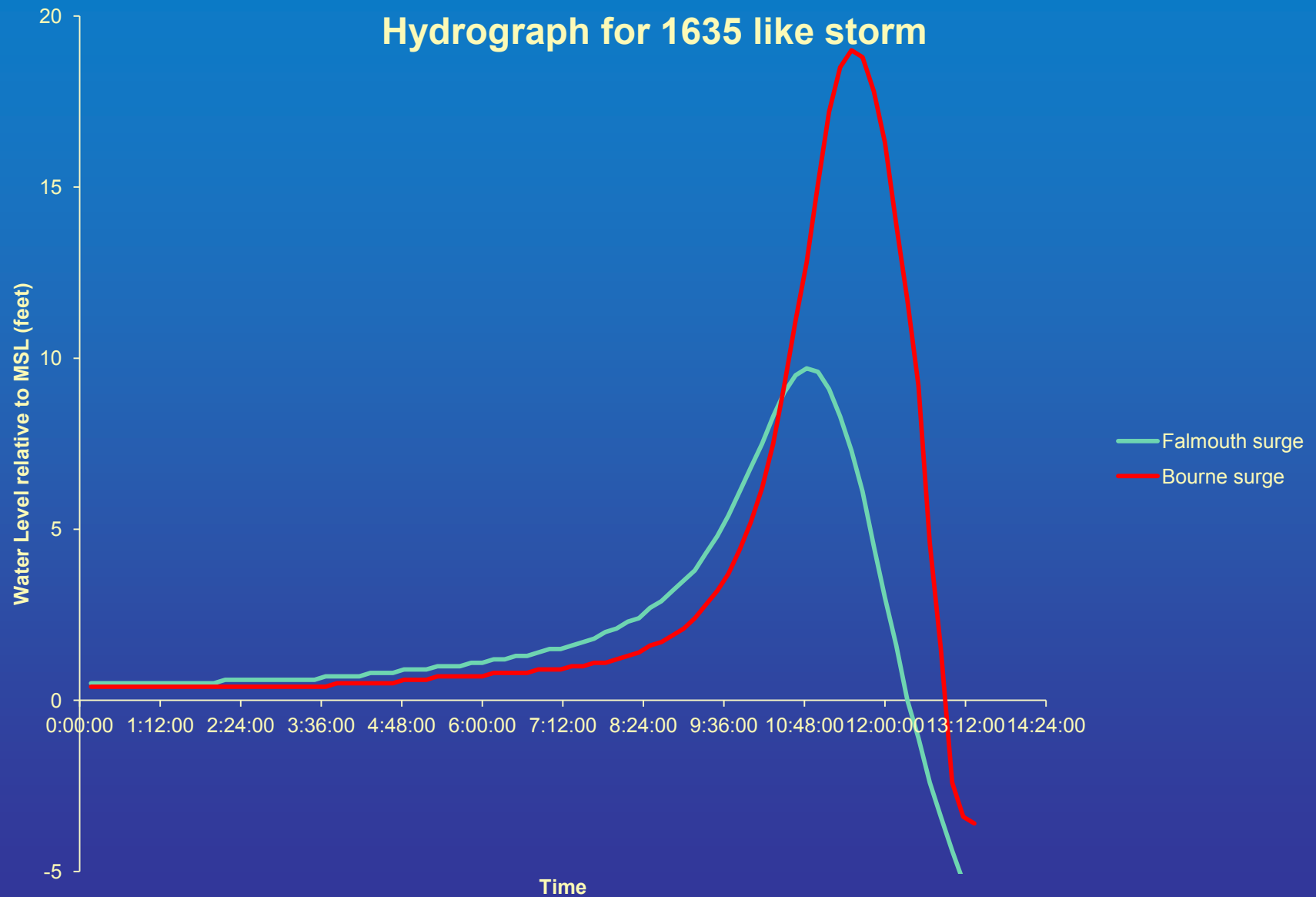
1.0m Sea Level Rise

1.5m Sea Level Rise

Falmouth



# What if the Hurricane of 1635 Struck Again?



# What if the Hurricane of 1815 Struck Again?



## The Great Gale - 1815



0 0.5 1 1.5 Kilometers

Maximum Surge Heights Under Different Sea Levels

0.0m Sea Level Rise

0.5m Sea Level Rise

1.0m Sea Level Rise

1.5m Sea Level Rise

Falmouth

# What if the Hurricane of 1815 Struck Again?



## The Great Gale - 1815

Providence in 1815



Surge Heights Under Different Sea Levels



Falmouth

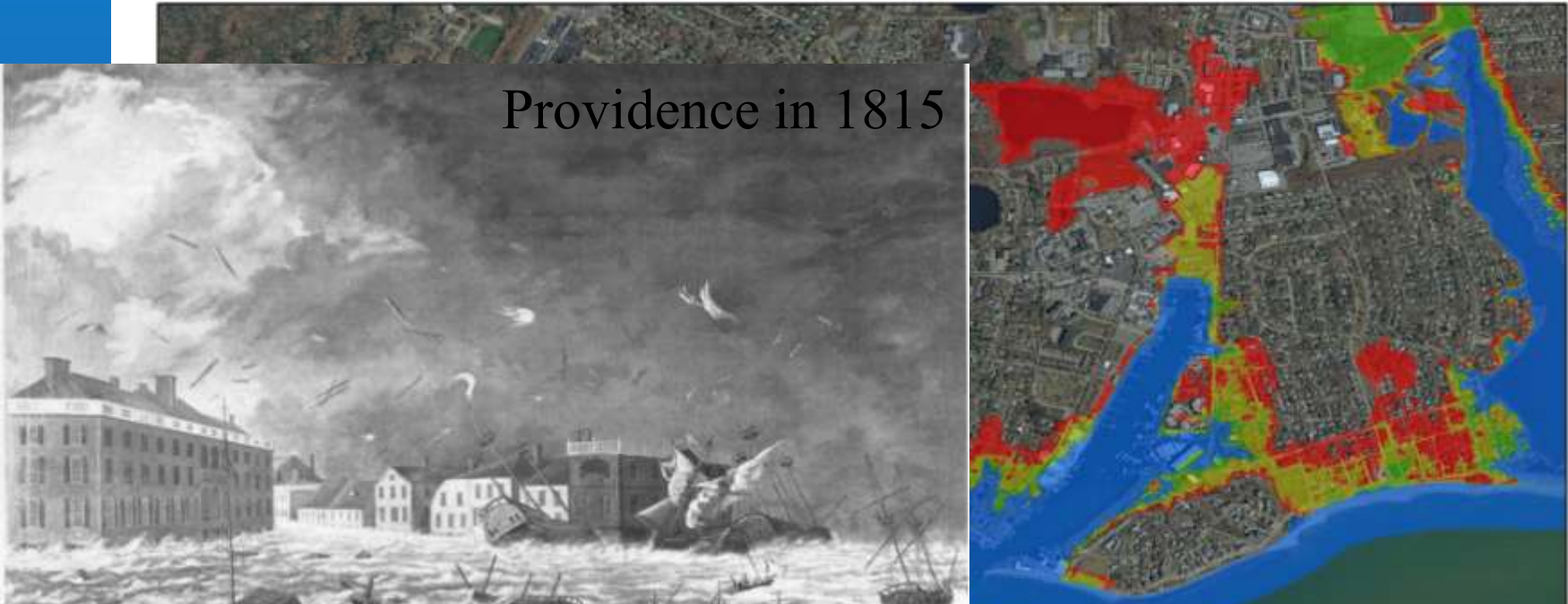


# What if the Hurricane of 1815 Struck Again?



## The Great Gale - 1815

Providence in 1815



Storm tide came within 15 inches of breaching isthmus where the canal is now (was over 20 feet above sea level)



Falmouth

# What if the Hurricane of 1938 Struck Again?



## The Great New England Hurricane - 1938



0 0.5 1 1.5 Kilometers

Maximum Surge Heights Under Different Sea Levels

0.0m Sea Level Rise

0.5m Sea Level Rise

1.0m Sea Level Rise

1.5m Sea Level Rise

Falmouth



# What if Hurricane Bob Struck Again?



## Hurricane Bob - 1991



0 0.5 1 1.5 Kilometers

Maximum Surge Heights Under Different Sea Levels

0.0m Sea Level Rise

0.5m Sea Level Rise

1.0m Sea Level Rise

1.5m Sea Level Rise

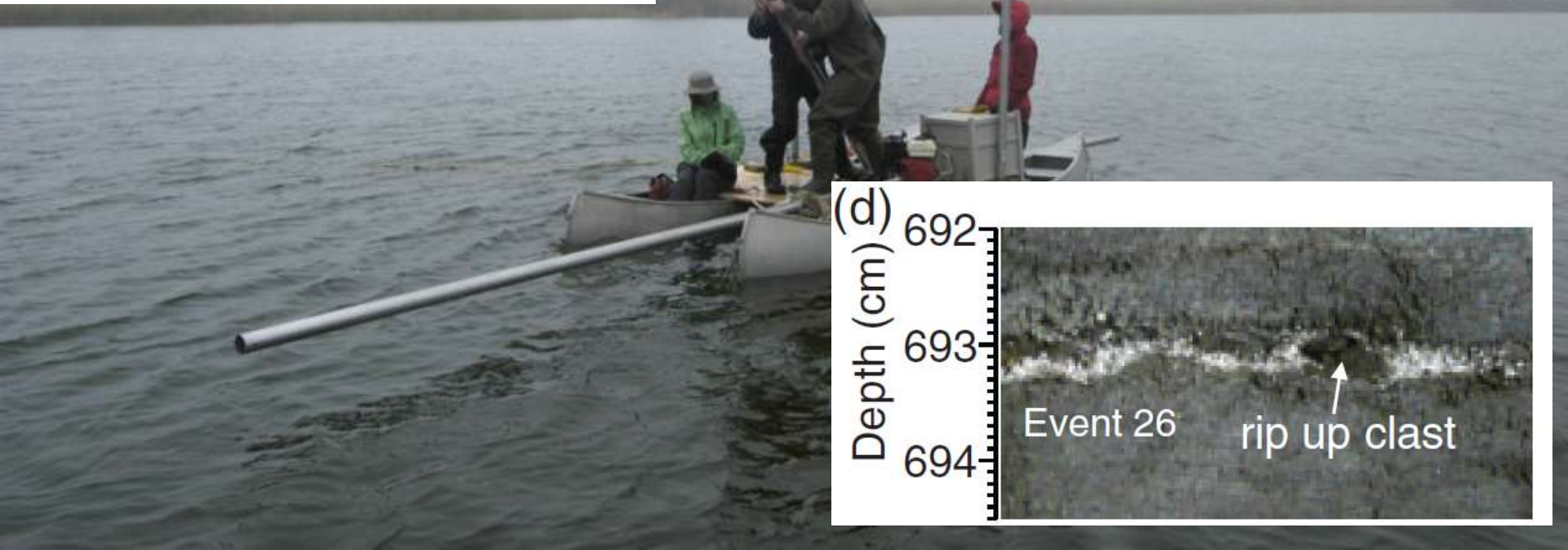
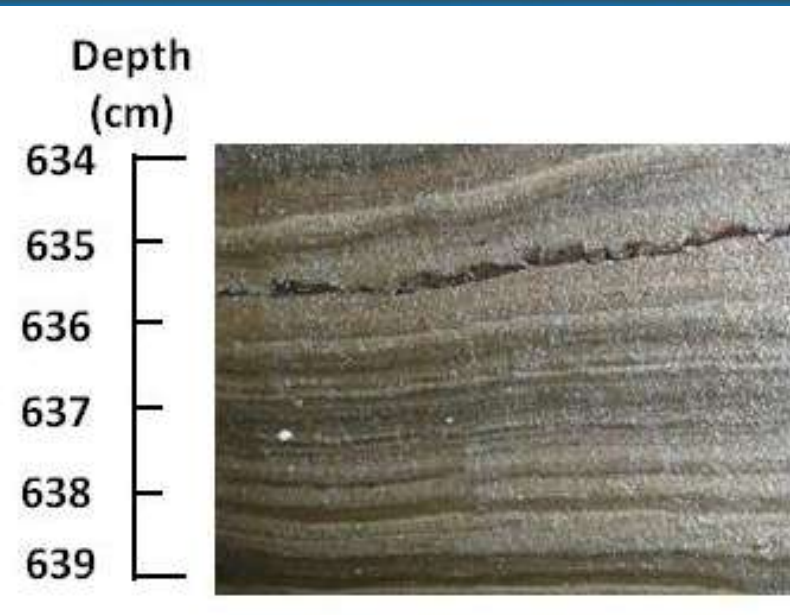
Falmouth



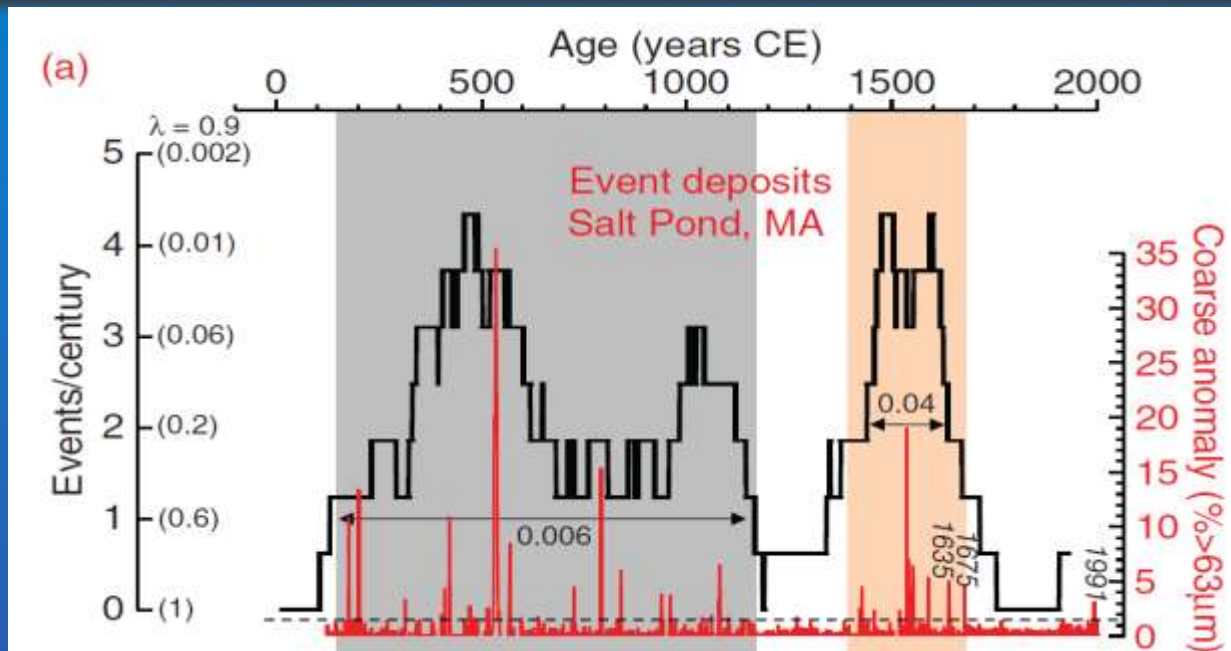
# High-Resolution Sediment Records



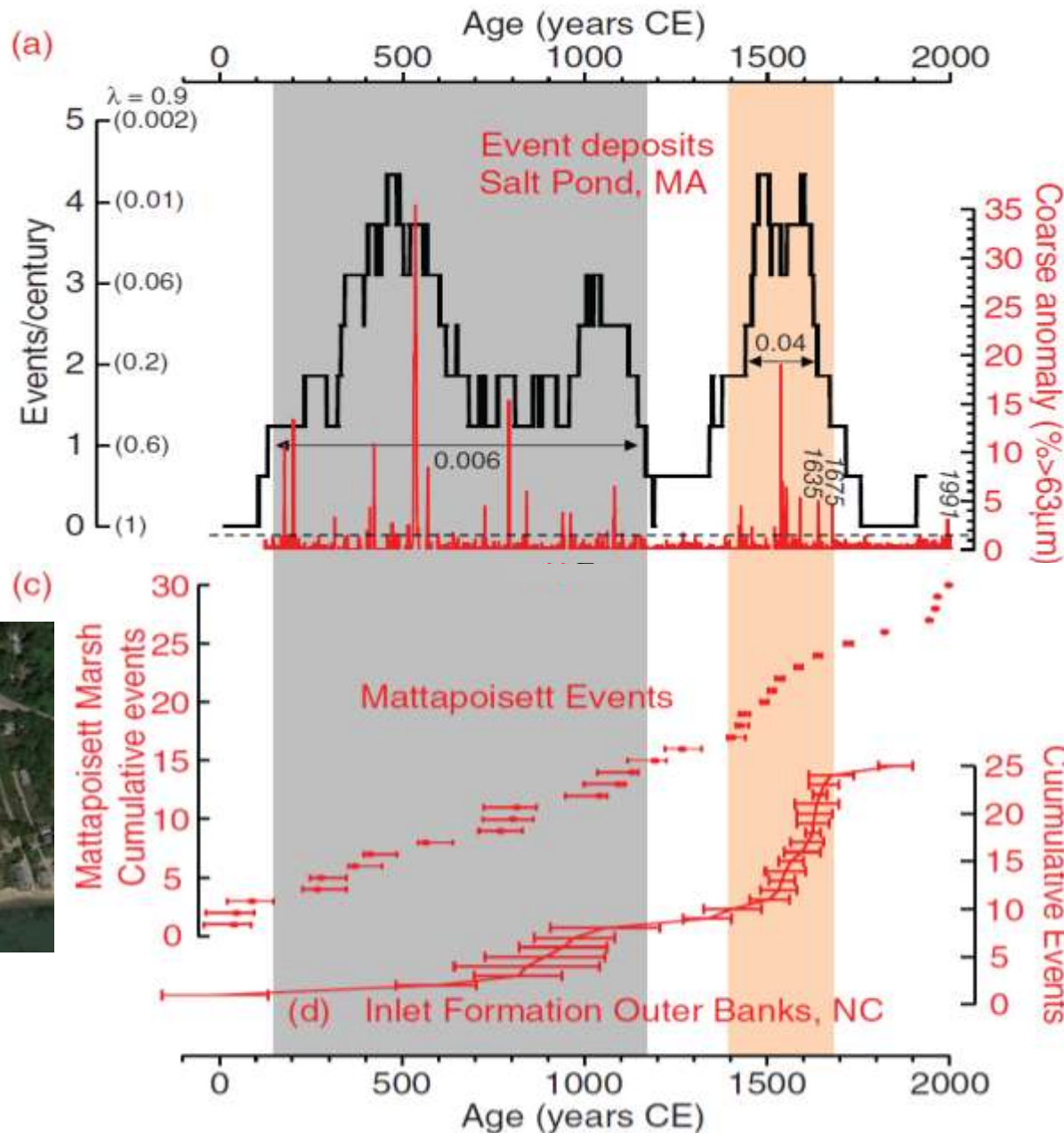
# High-Resolution Sediment Records



# Salt Pond Reconstruction



# Salt Pond Reconstruction

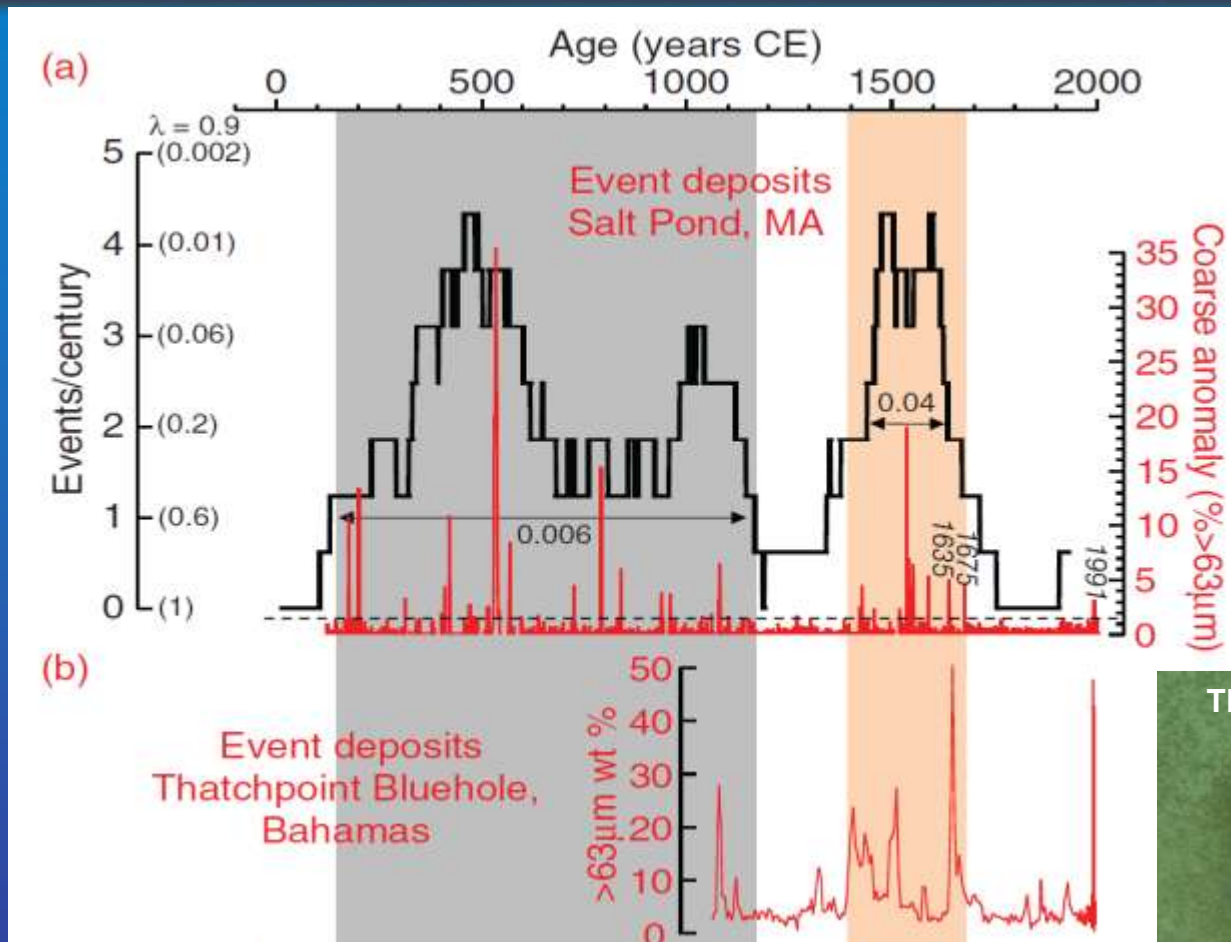


Mattapoissett Marsh

Outer Banks

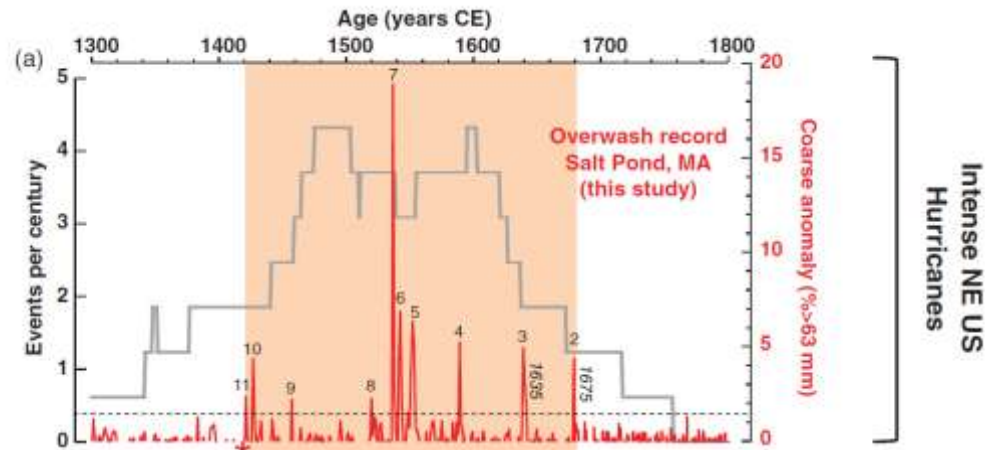


# Salt Pond Reconstruction



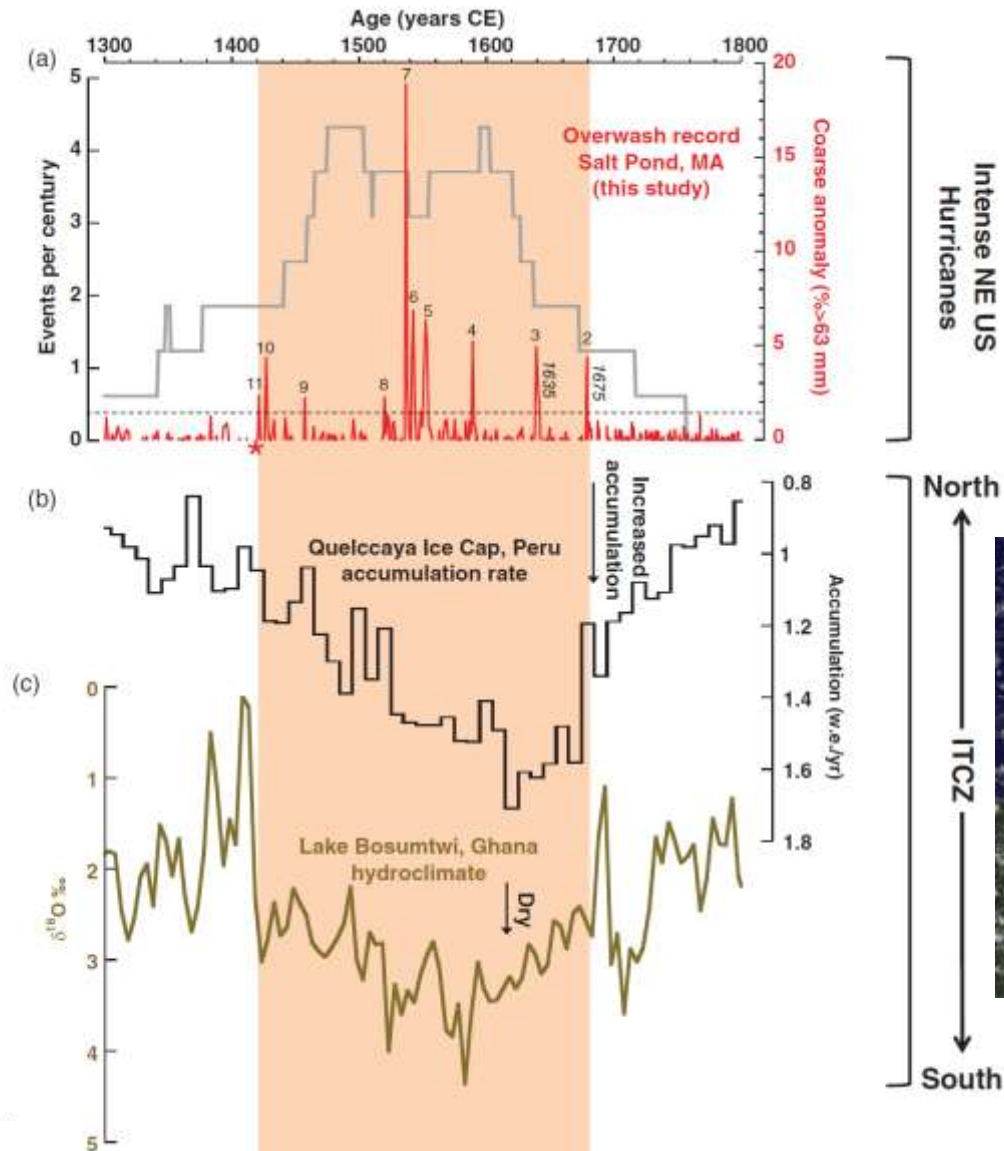
Thatchpoint Bluehole

# Climate Forcing

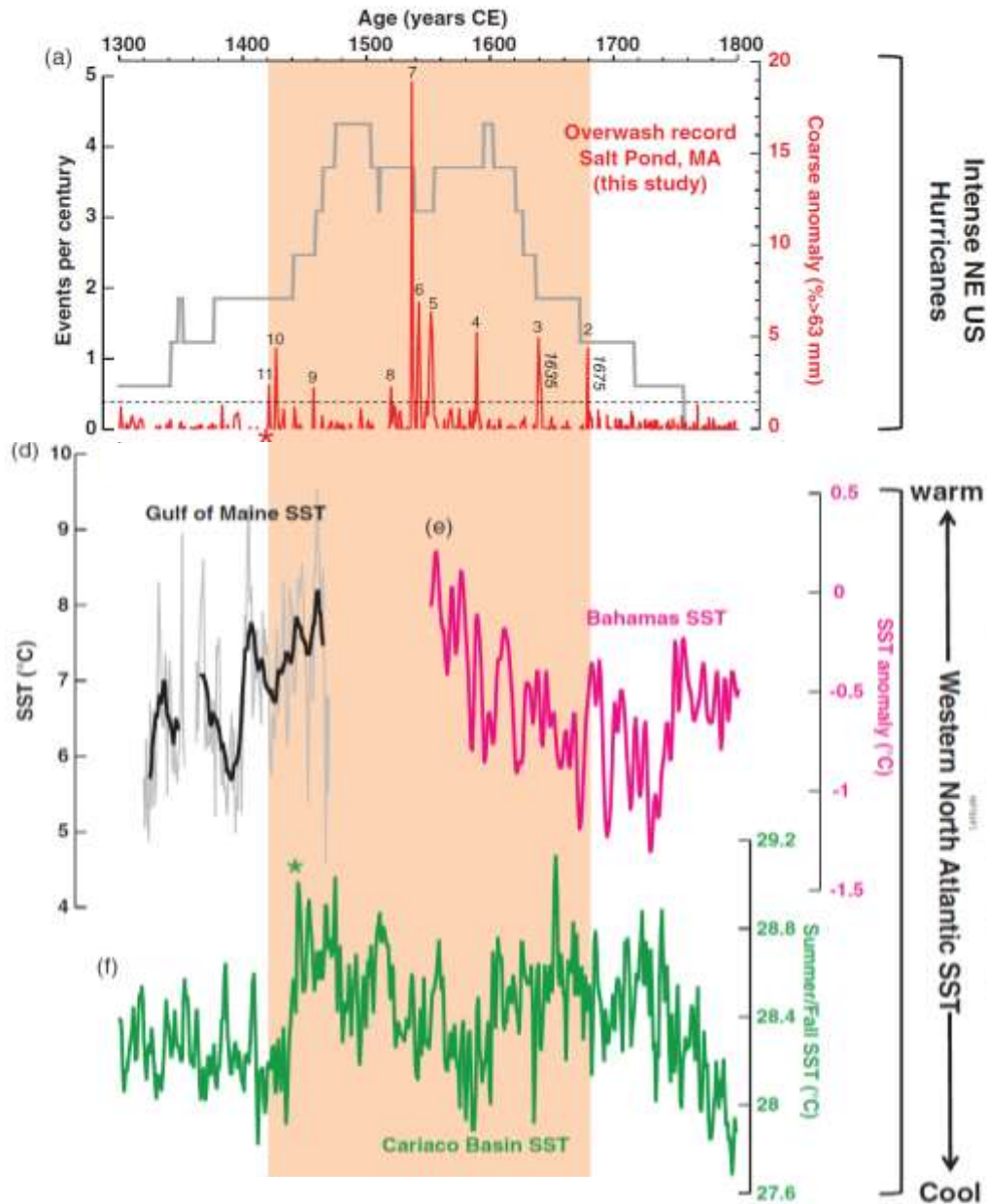




# Climate Forcing



# Climate Forcing



# Summary

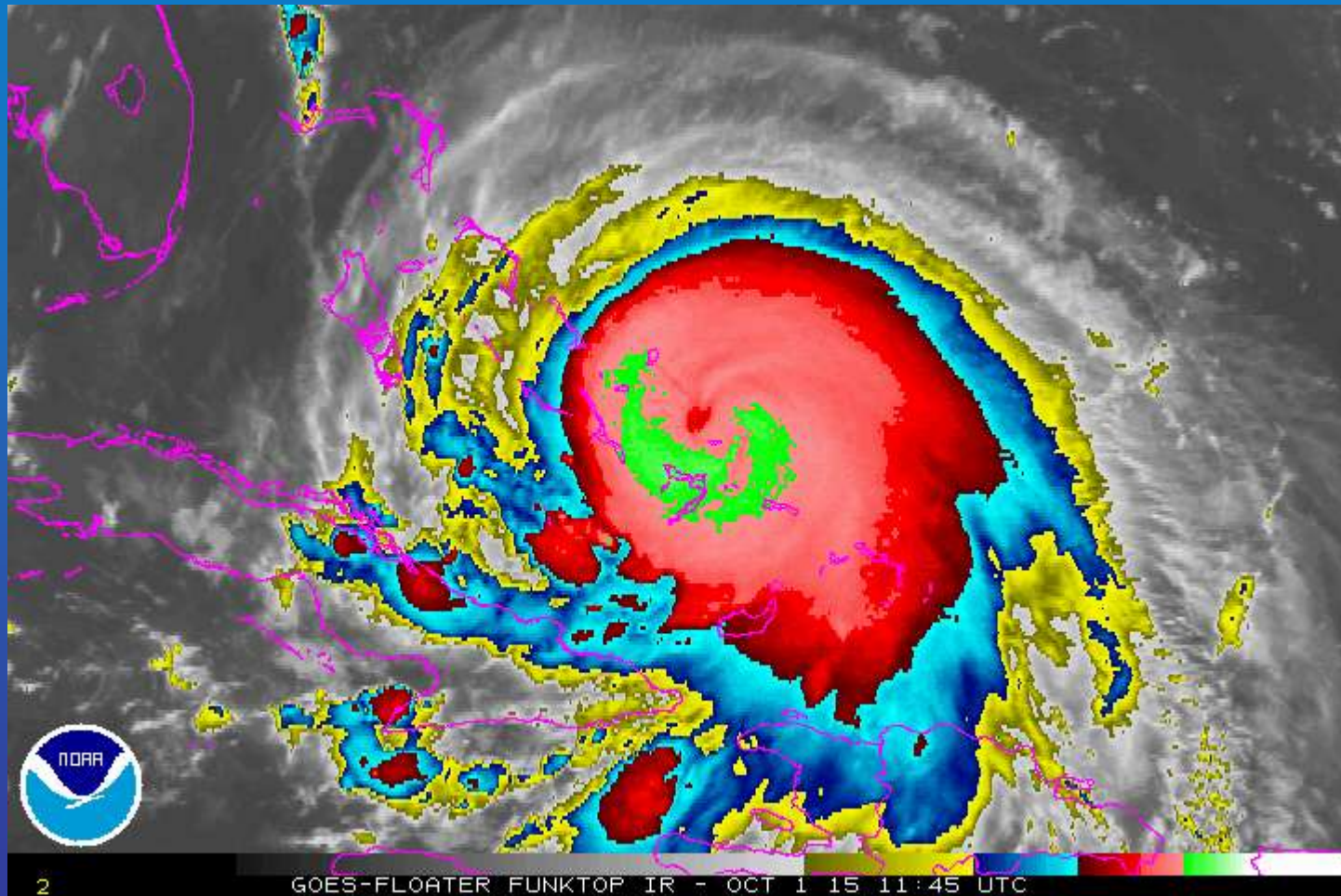


Past intervals of heightened hurricane activity appear to be associated with warm sea surface temperatures

Increased hurricane activity along the eastern US seaboard is possible (perhaps even likely) in the coming decades

The impacts of future hurricane activity will be greatly exacerbated by continuing sea-level rise and coastal population growth, regardless of whether or not we experience significant increases in hurricane landfalls

# Thank you!



For more info see:  
[www.whoi.edu/science/GG/coastal/](http://www.whoi.edu/science/GG/coastal/)