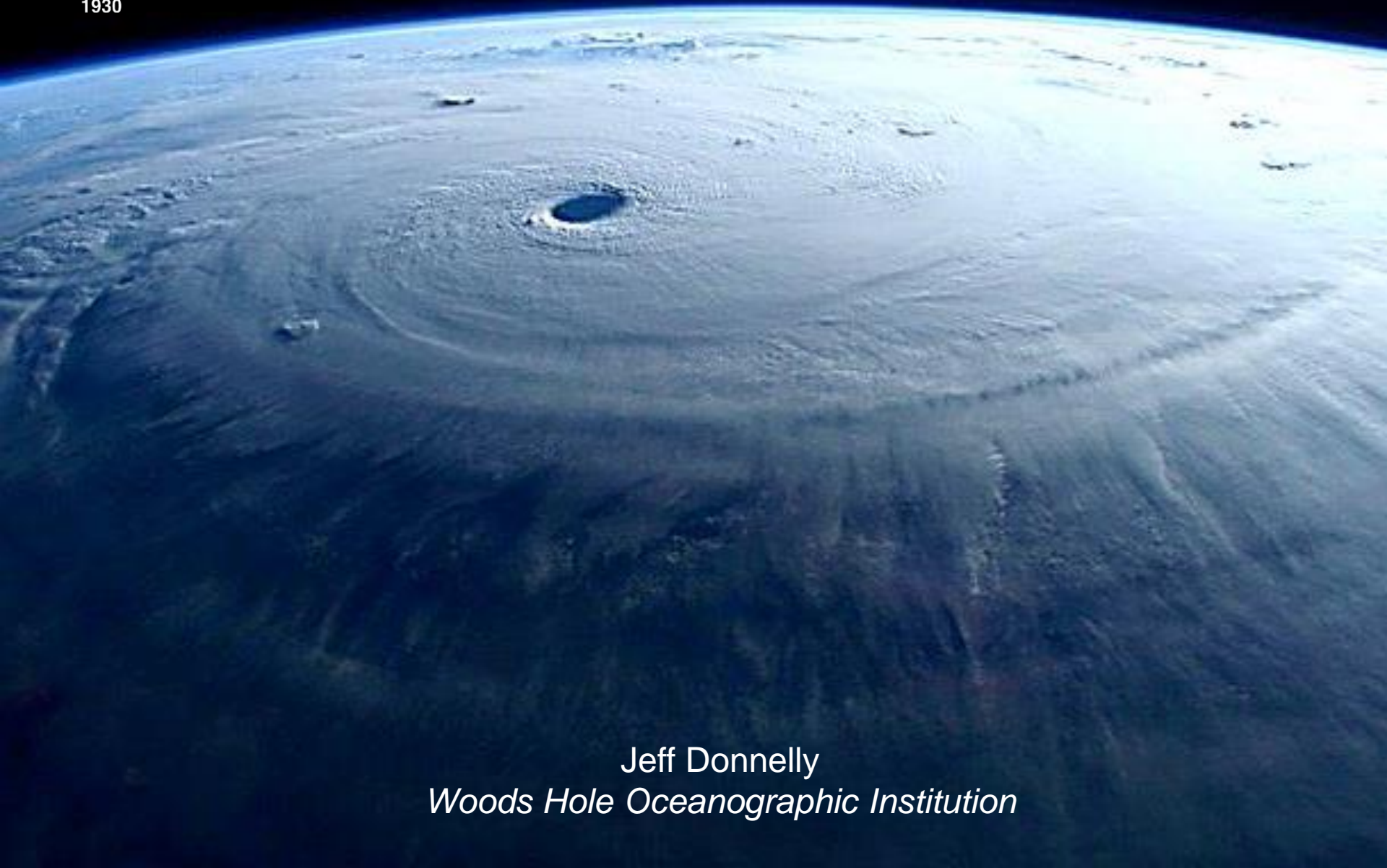




Chasing Ancient Hurricanes in Oyster Pond and Beyond

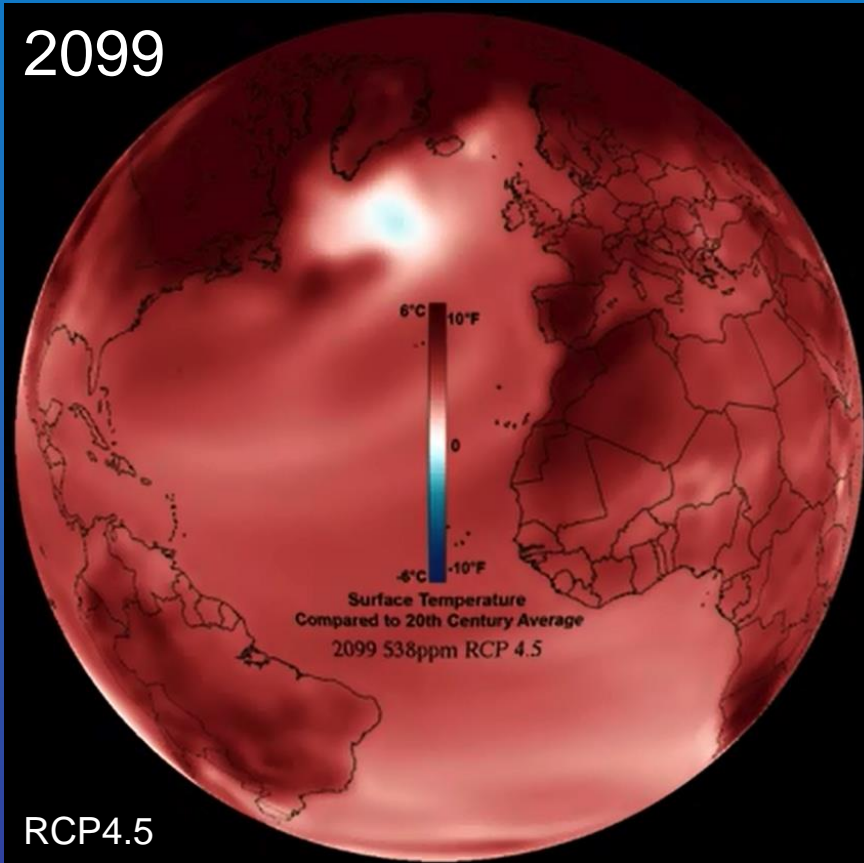


Jeff Donnelly
Woods Hole Oceanographic Institution

Temperatures will continue to warm



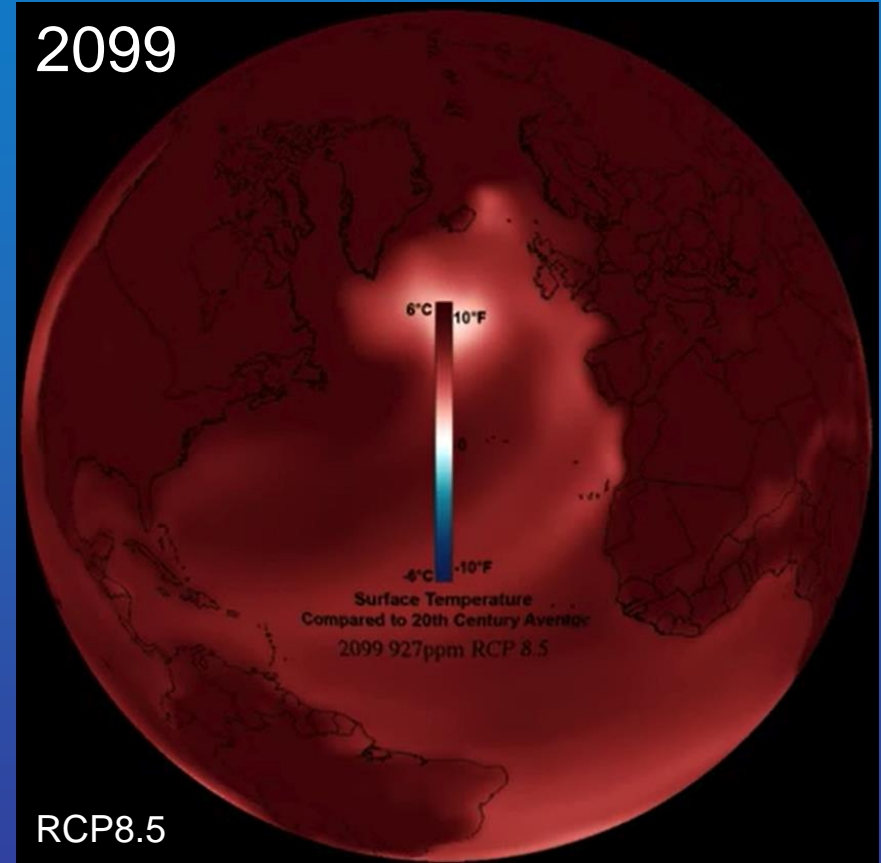
2099



RCP4.5

Similar to COP 21

2099

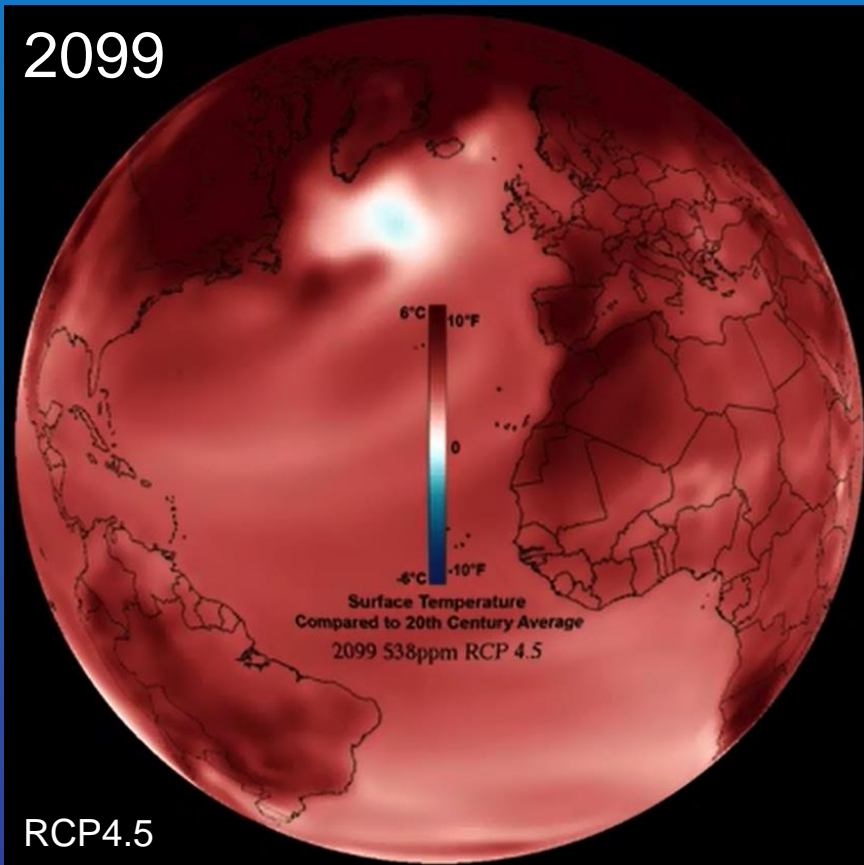


RCP8.5

Temperatures will continue to warm



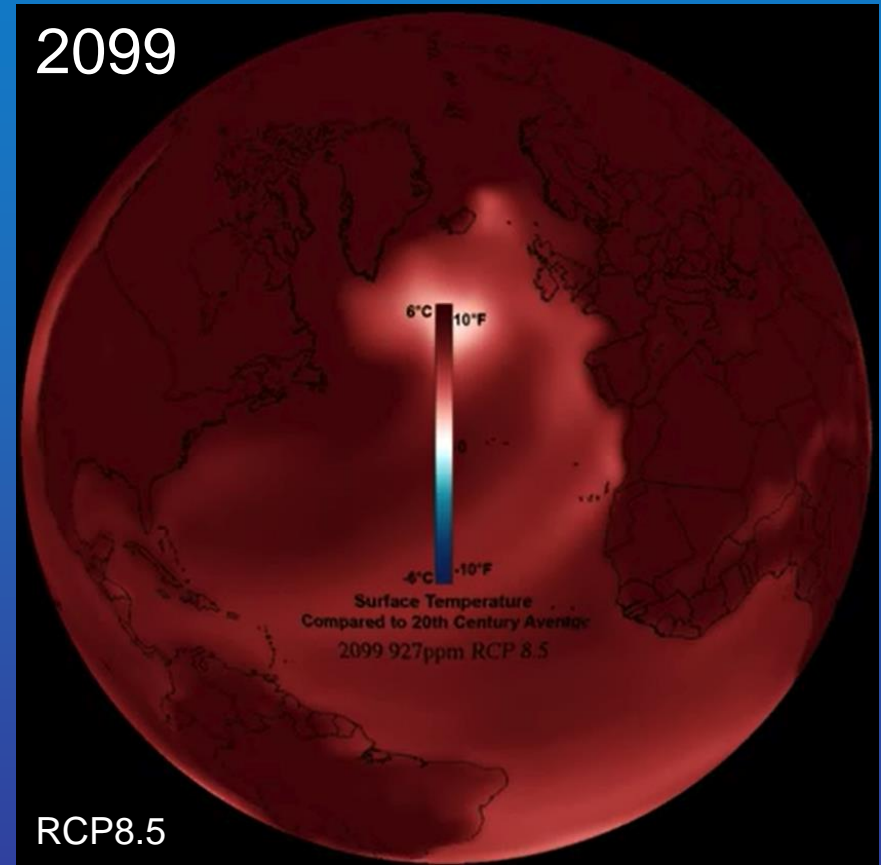
2099



RCP4.5

Similar to COP 21

2099



RCP8.5

How will warming impact tropical cyclone activity?

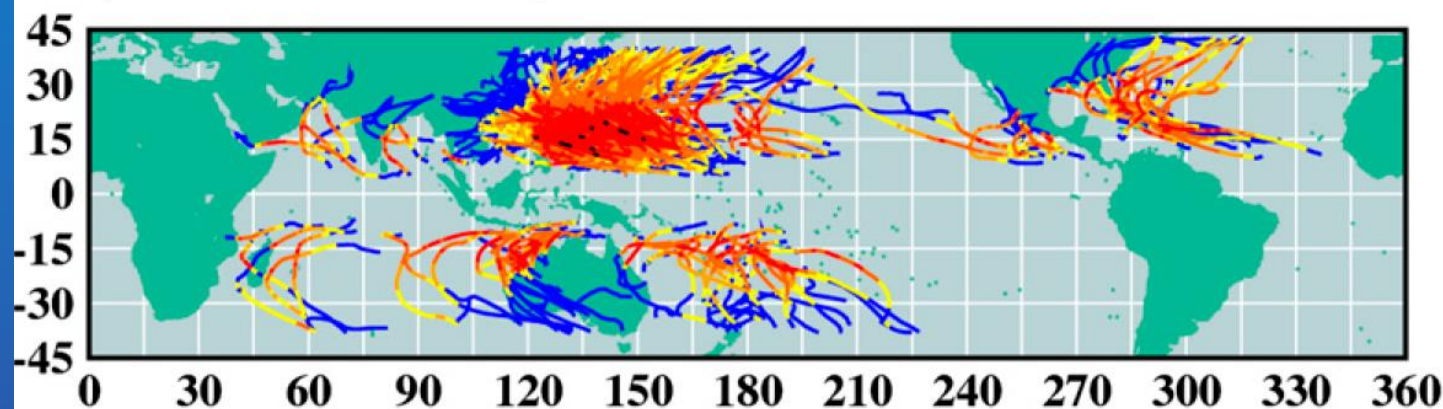
Models Indicate Increases in the Most Intense Storms



KNUTSON ET AL.

28% increase globally
42% increase in Atlantic

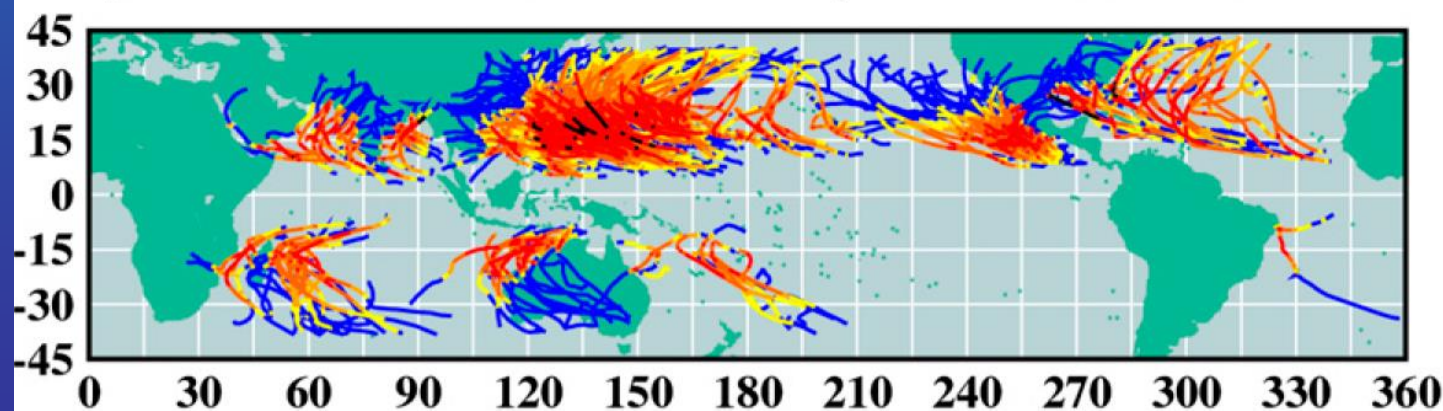
a) Present Day Simulation: 244 Cat 4-5 storms



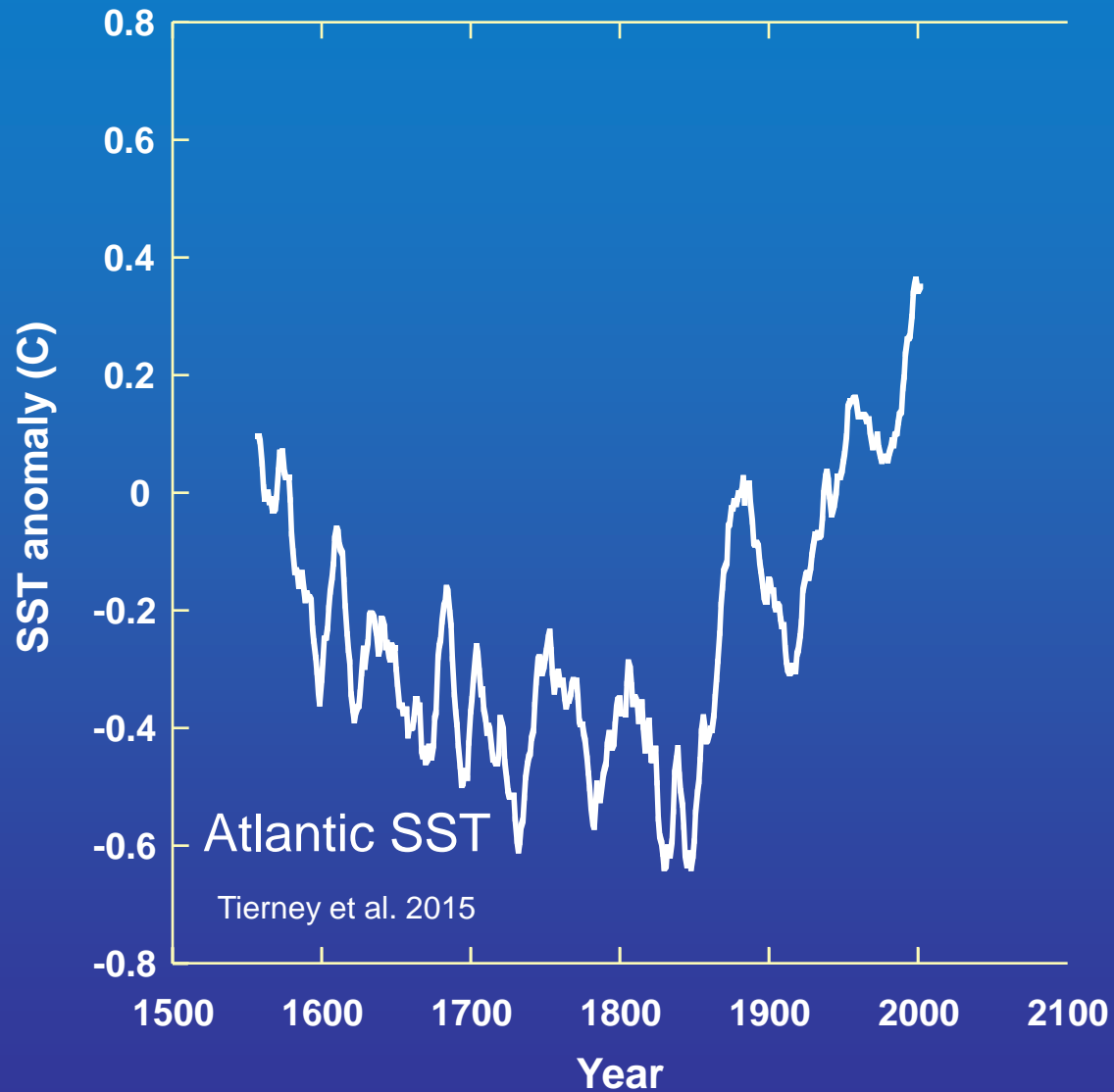
Storm
Category



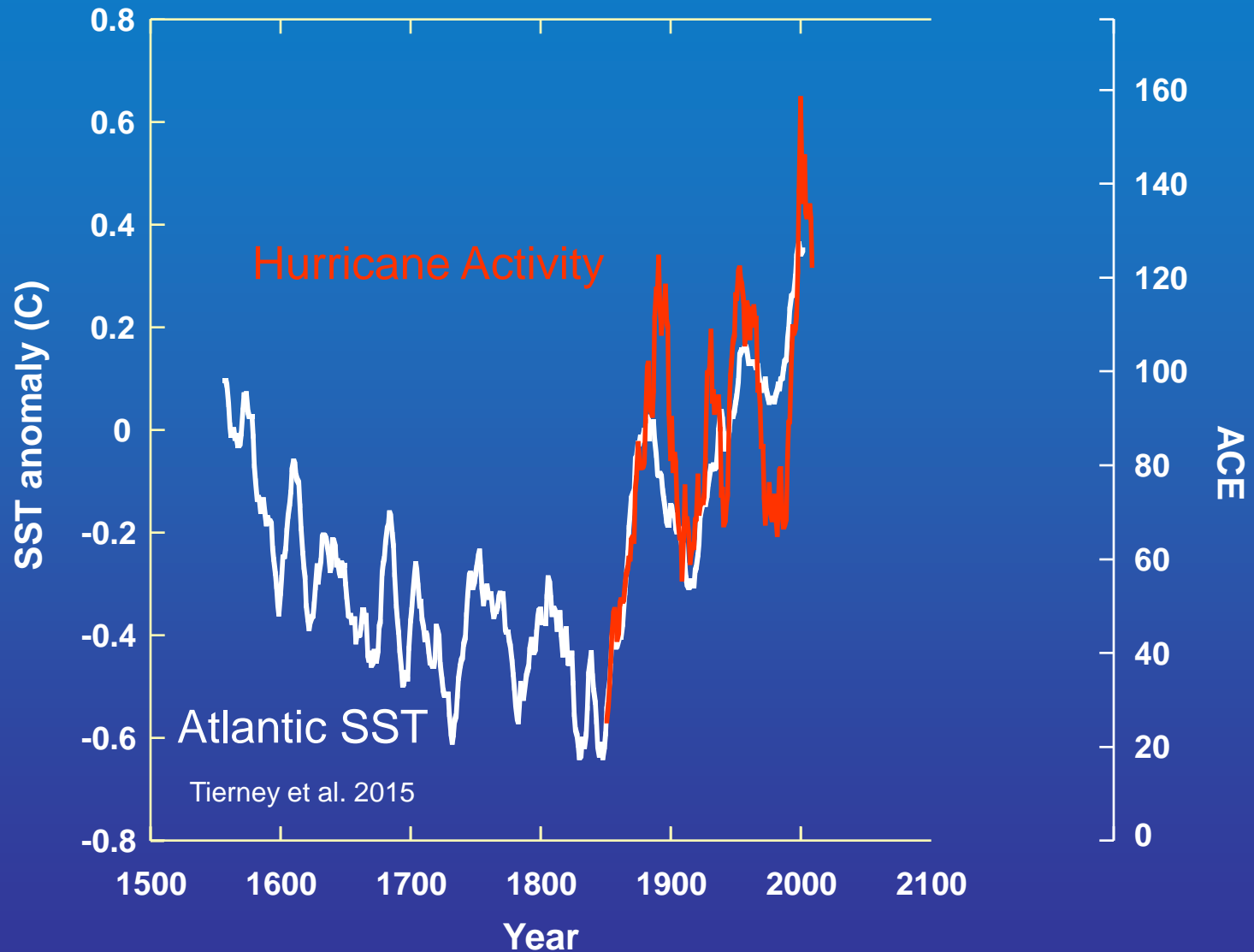
b) RCP4.5 Late 21st Century: 313 Cat 4-5 storms



Hurricanes and Sea Surface Temperature



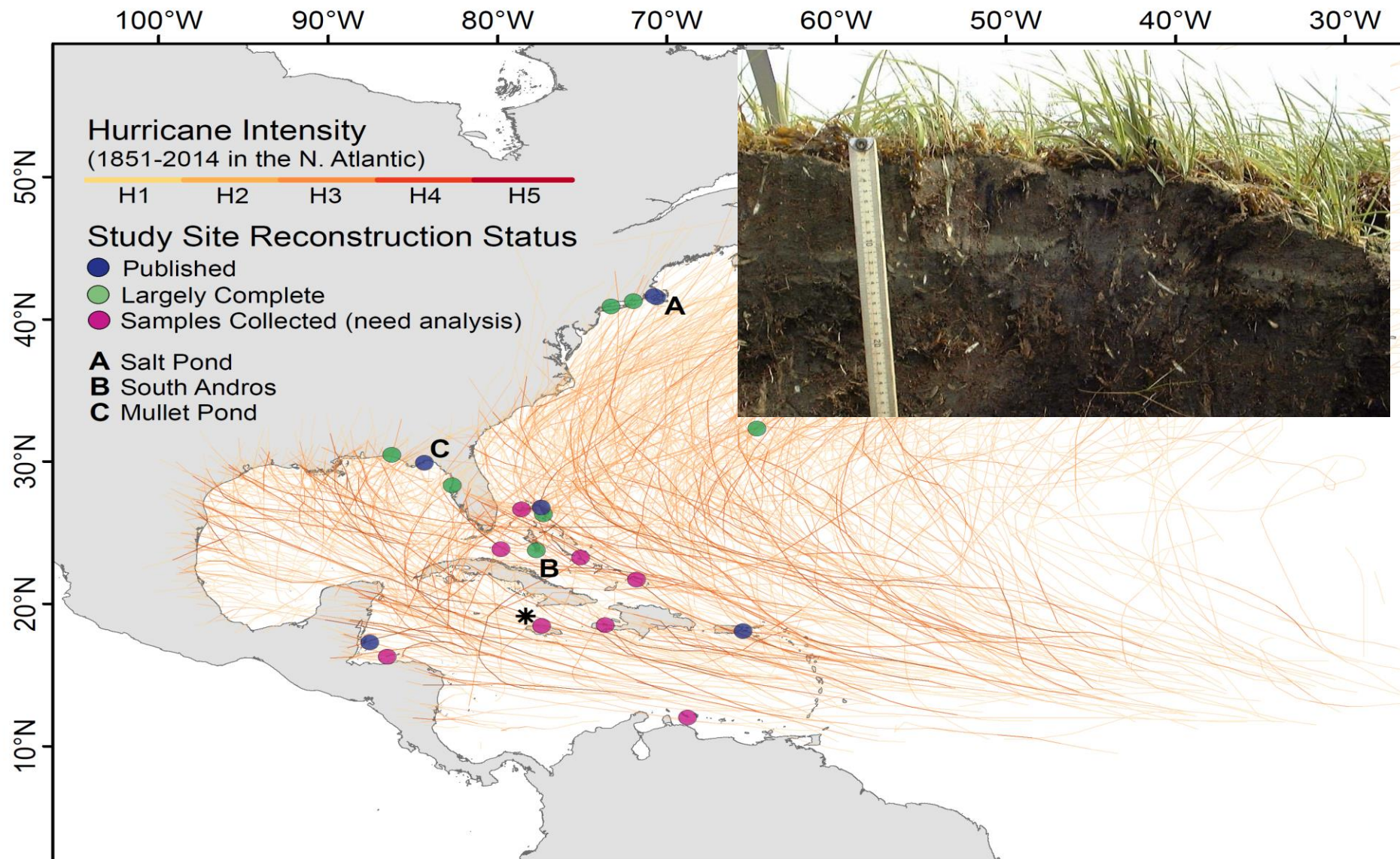
Hurricanes and Sea Surface Temperature



Sedimentary Records of Hurricane Strikes



How has hurricane activity varied prehistorically?



Where paleotemperature got its start – Oyster Pond

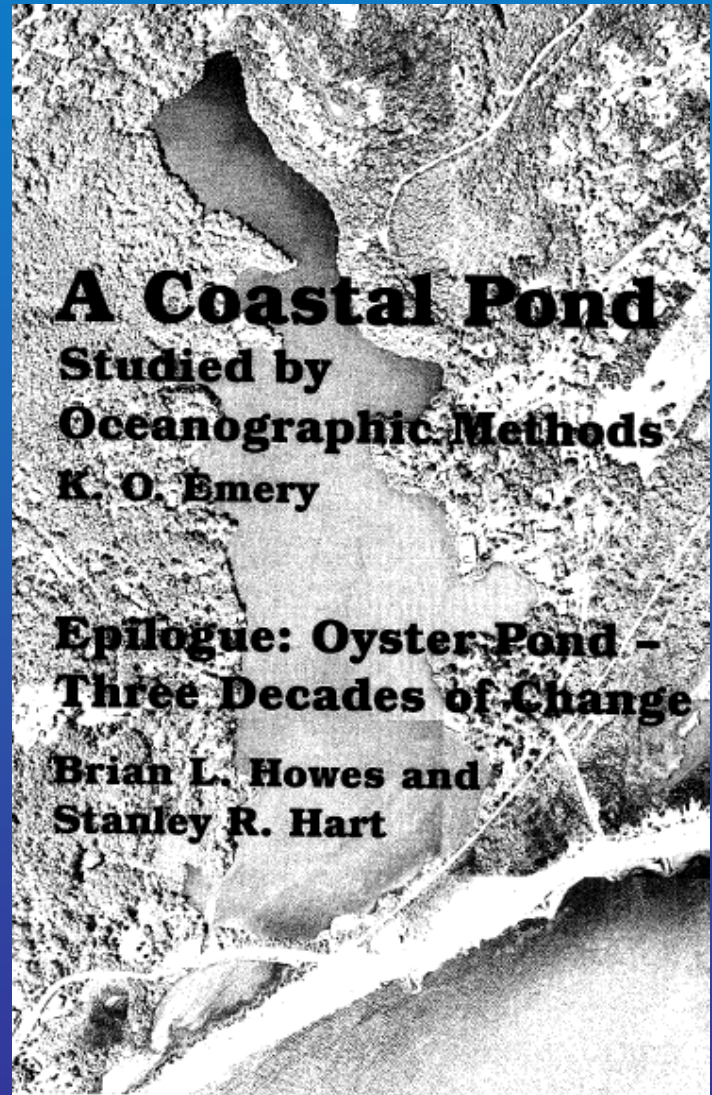


A Coastal Pond Studied by Oceanographic Methods

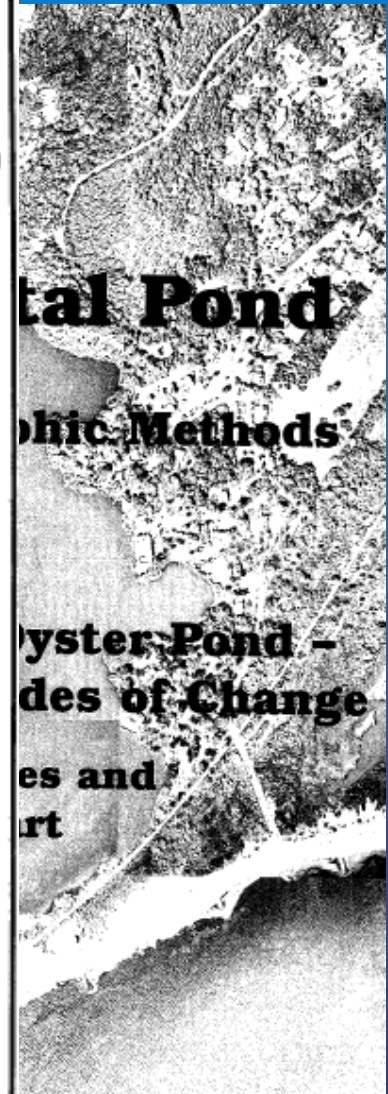
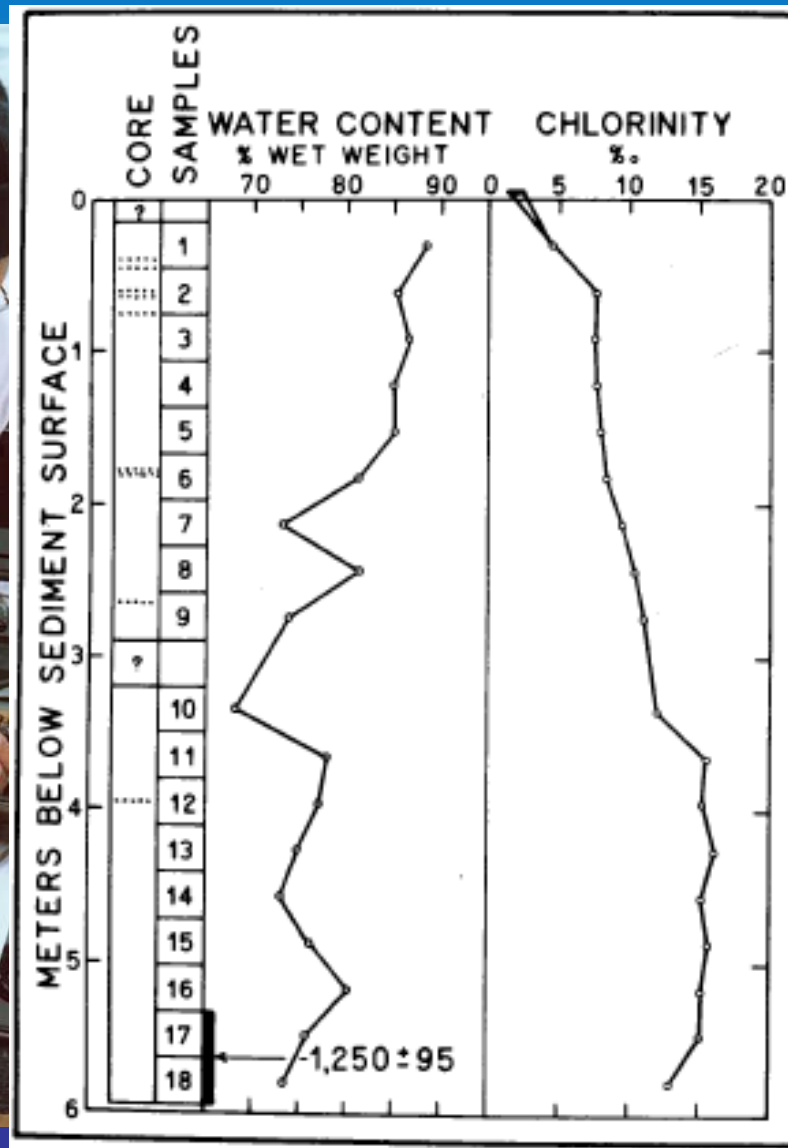
K. O. Emery

Epilogue: Oyster Pond – Three Decades of Change

**Brian L. Howes and
Stanley R. Hart**



Where paleotemperature got its start – Oyster Pond



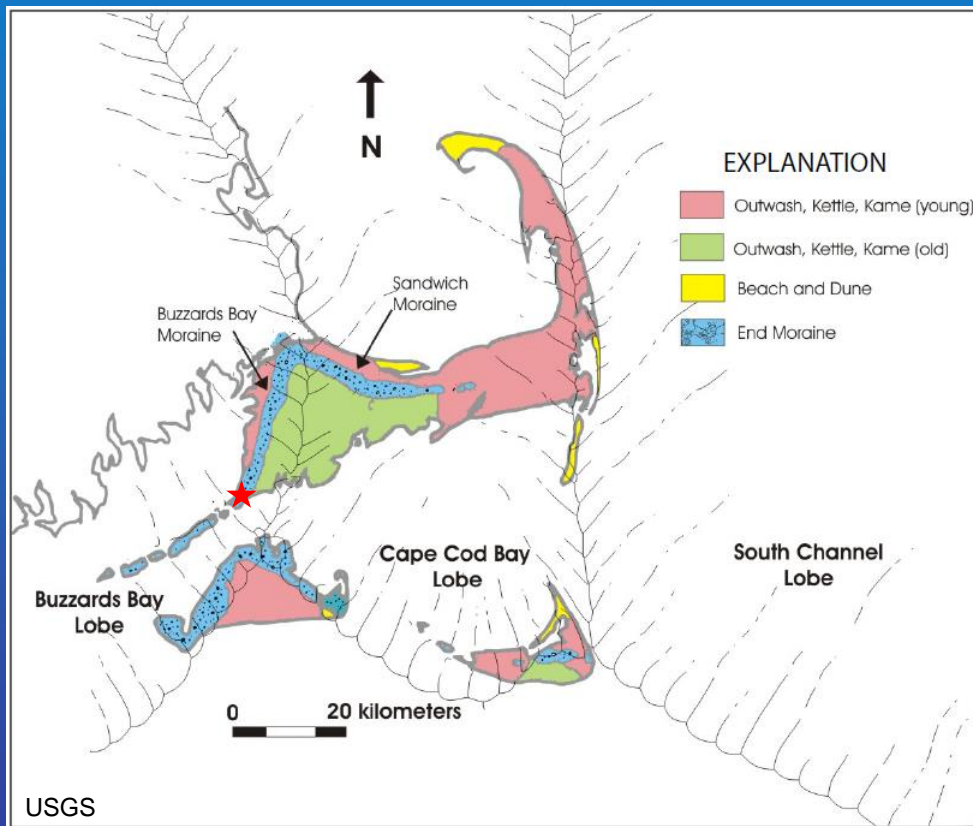
Oyster Pond

Geologic Methods

**Oyster Pond -
Records of Change**

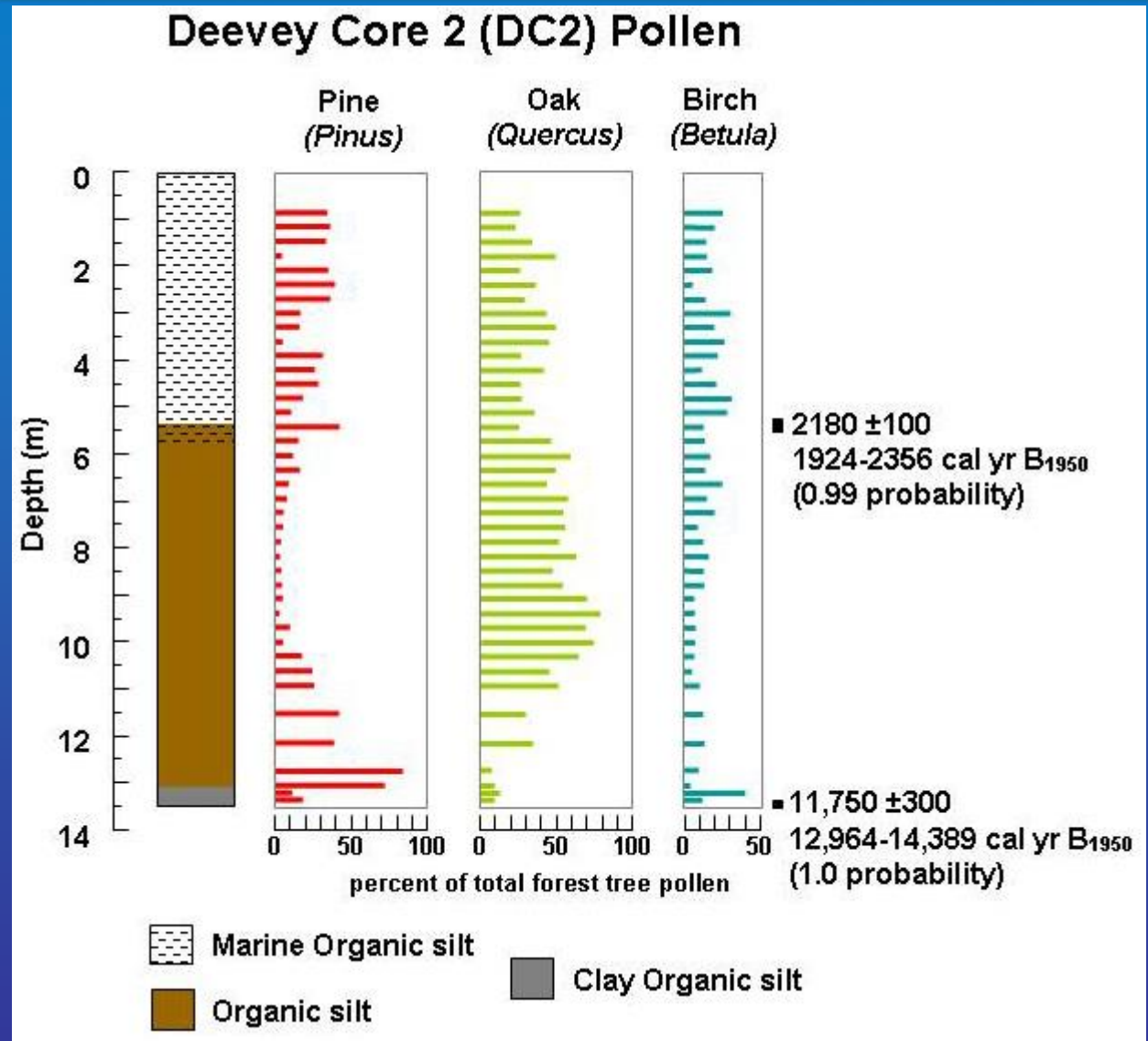
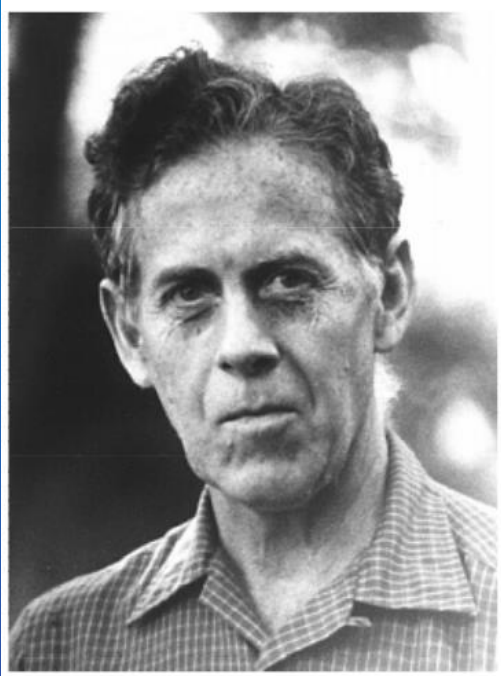
**Isotopes and
Sediment**

Oyster Pond, Falmouth MA



My lab →

Oyster Pond, Falmouth MA



"[T]he high tides and storm waves of the 1944 hurricane washed completely over the basin, and marine debris (*Fucus* and other seaweeds) still hangs in the bushes to a high-water mark about four feet above present lake level." Deevey, 1948 (American Journal of Science)

Oyster Pond, Falmouth MA

Sidescan sonar survey



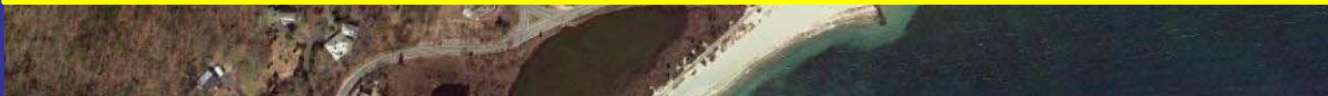
Oyster Pond, Falmouth MA

Sidescan sonar survey



Oyster Pond, Falmouth MA

Sidescan sonar survey



Oyster Pond, Falmouth MA

Sidescan sonar survey



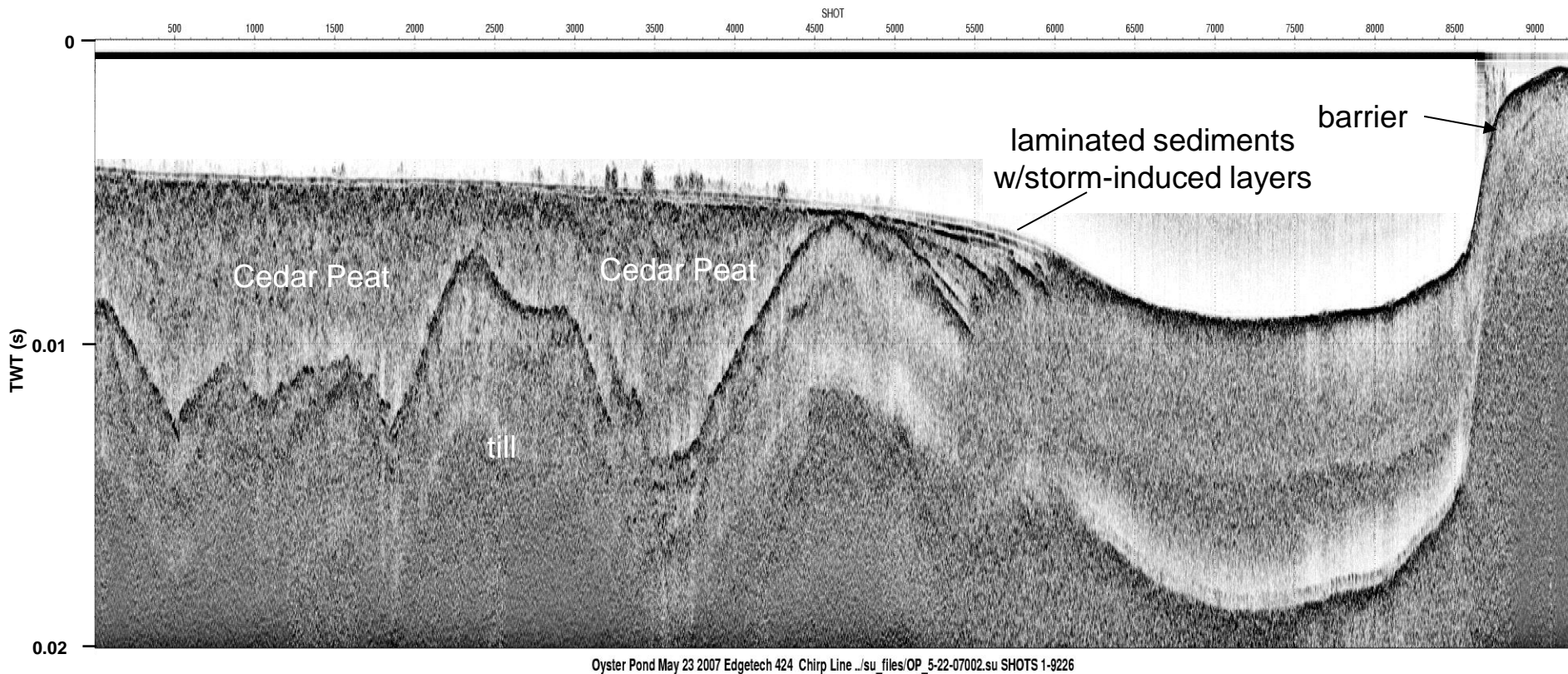
Oyster Pond, Falmouth MA

Sidescan sonar survey



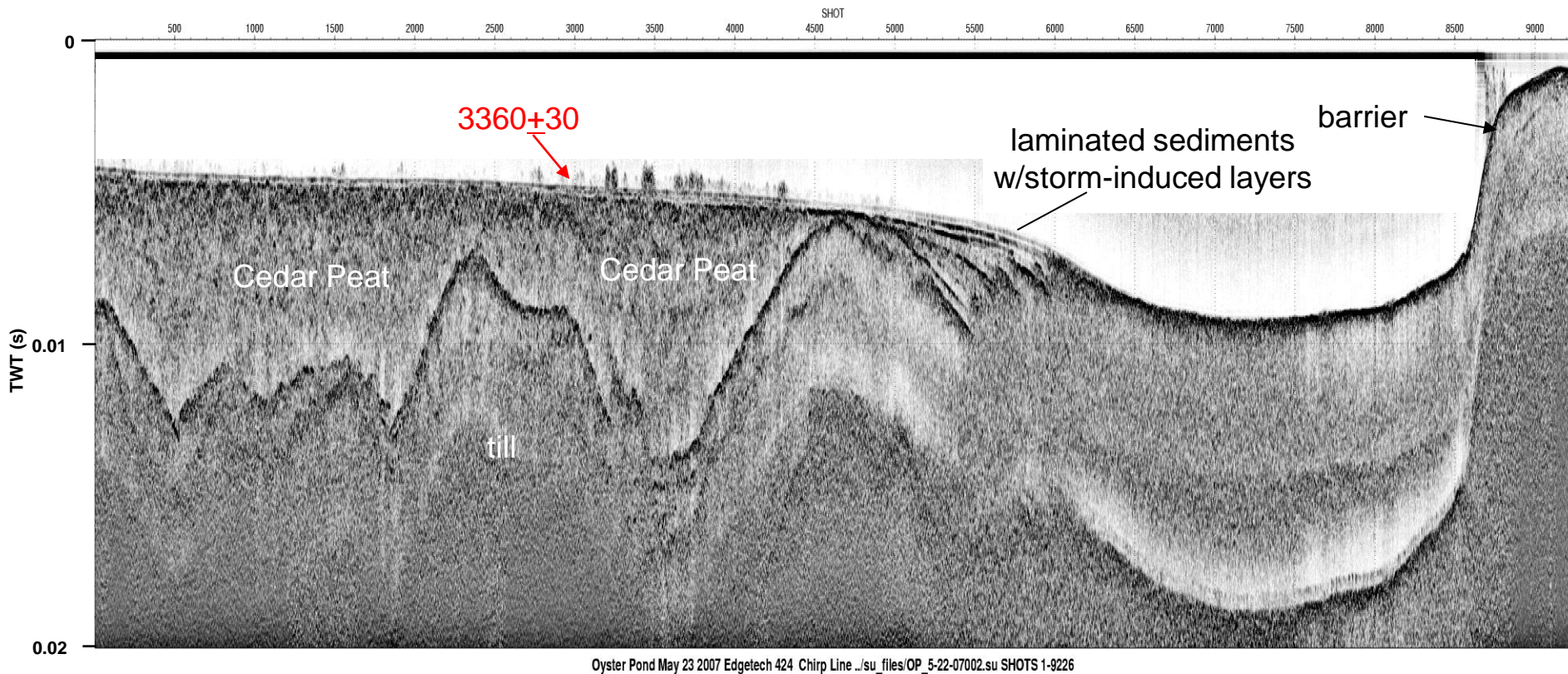
North

South



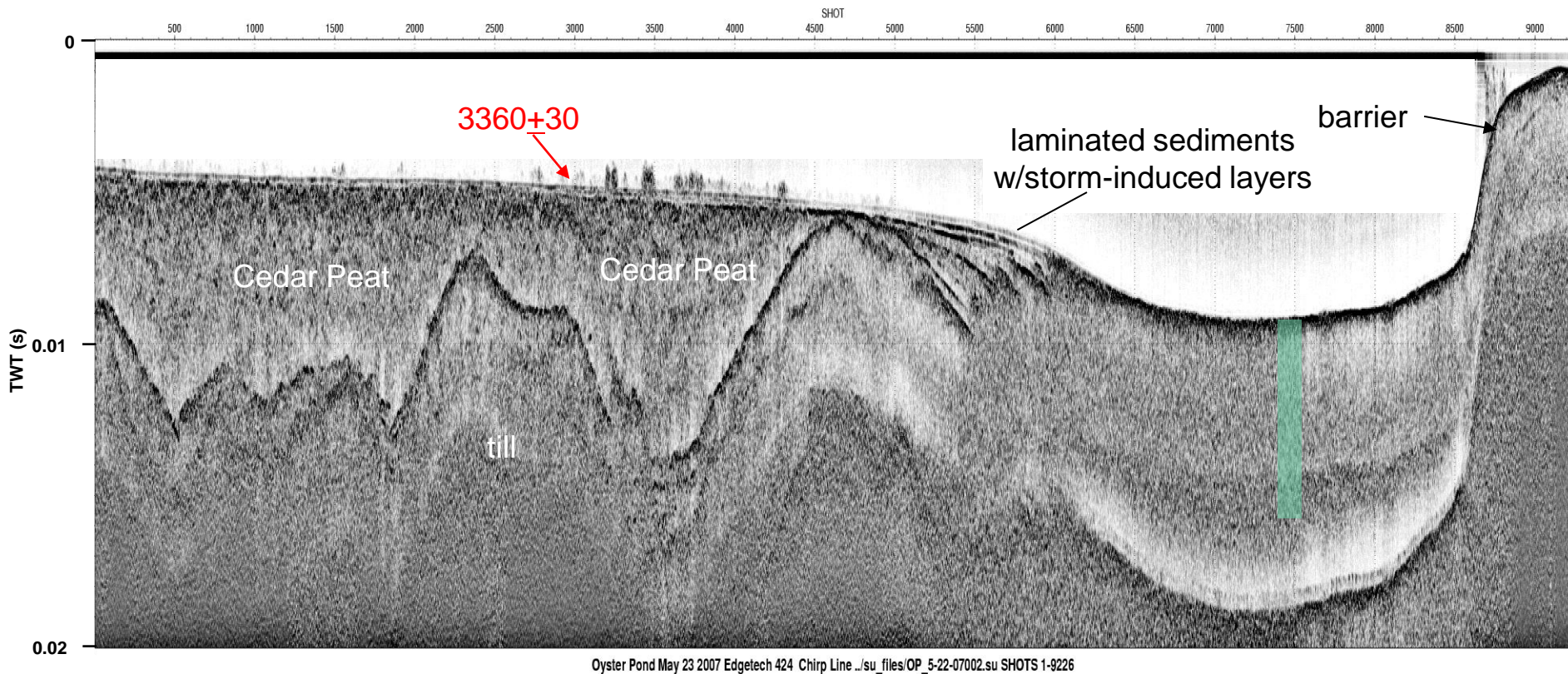
North

South



North

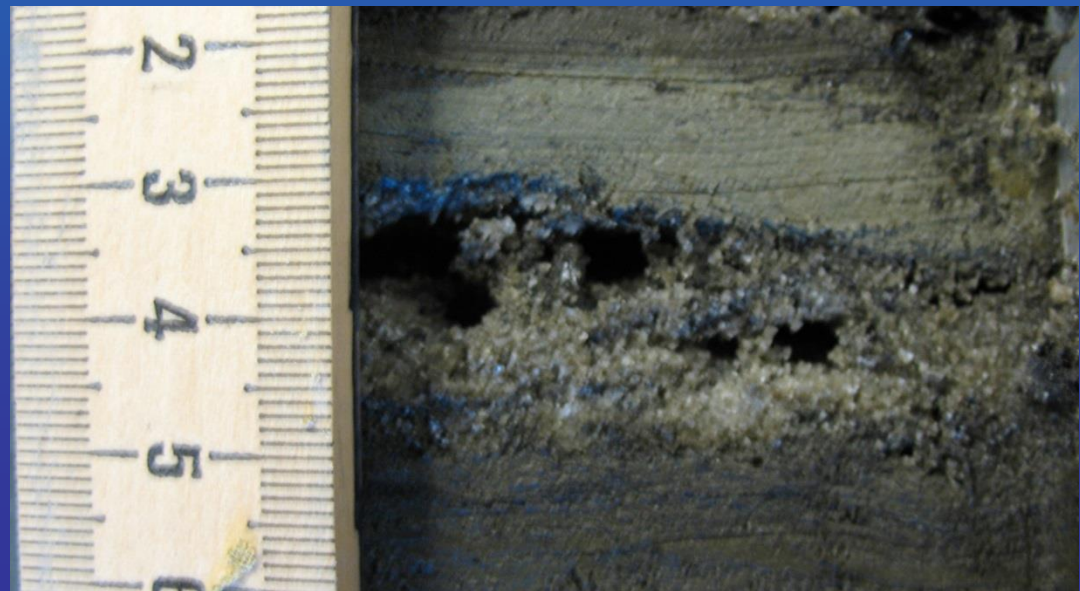
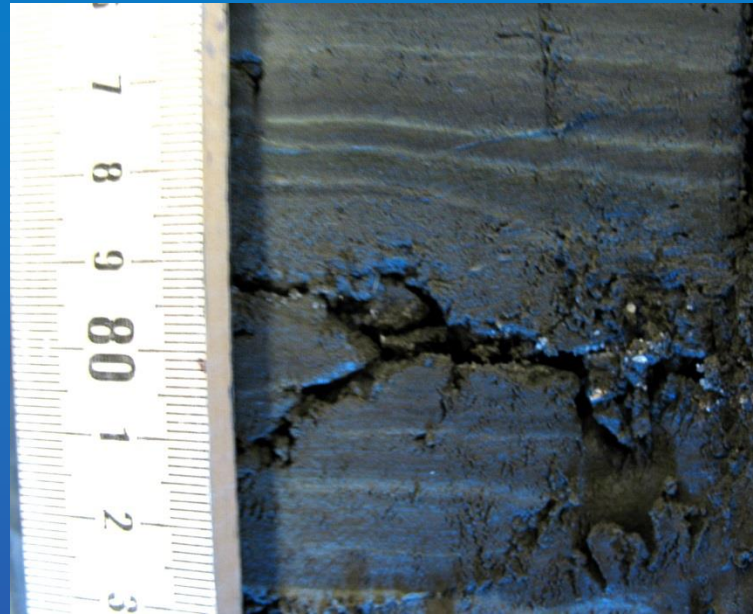
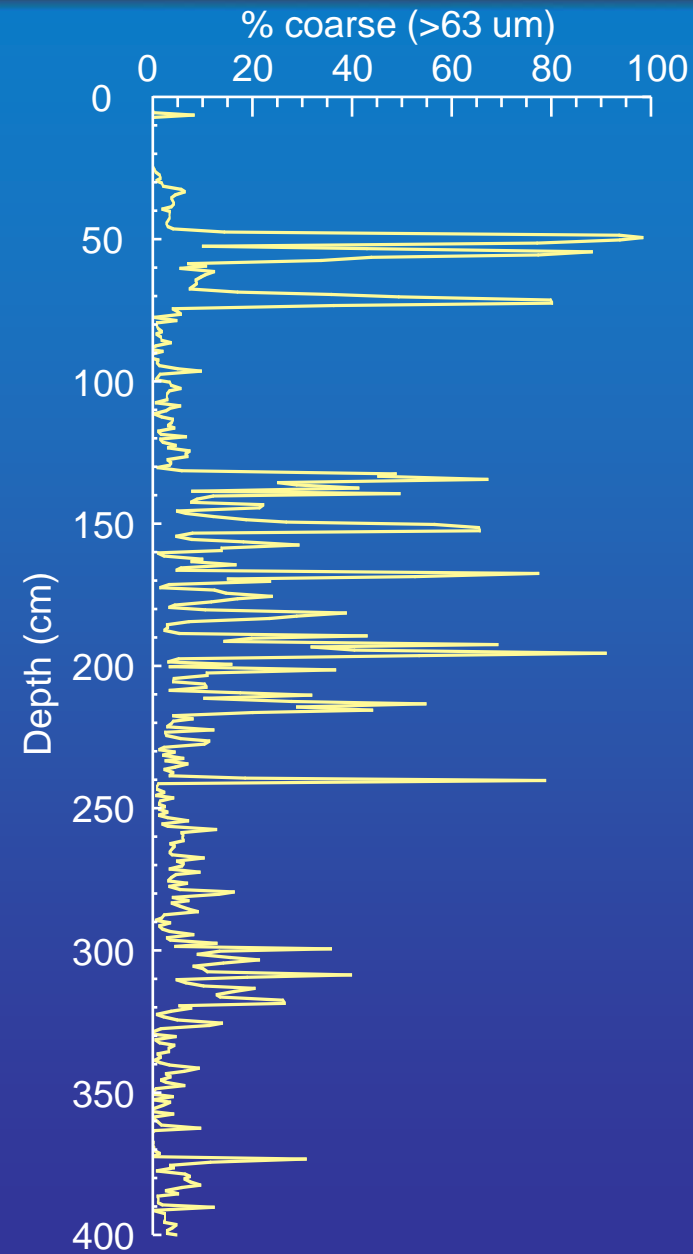
South



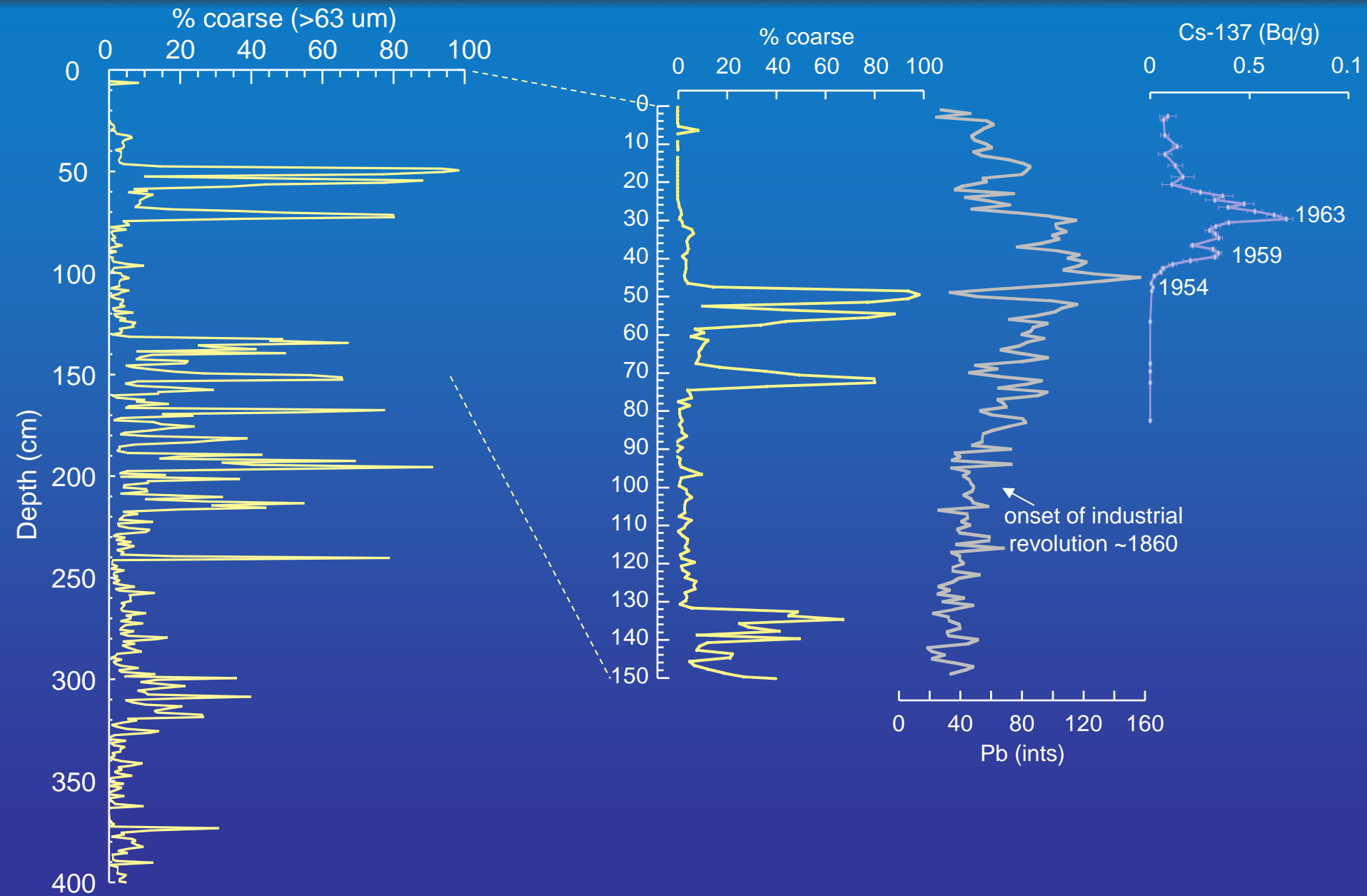
Oyster Pond, Falmouth MA



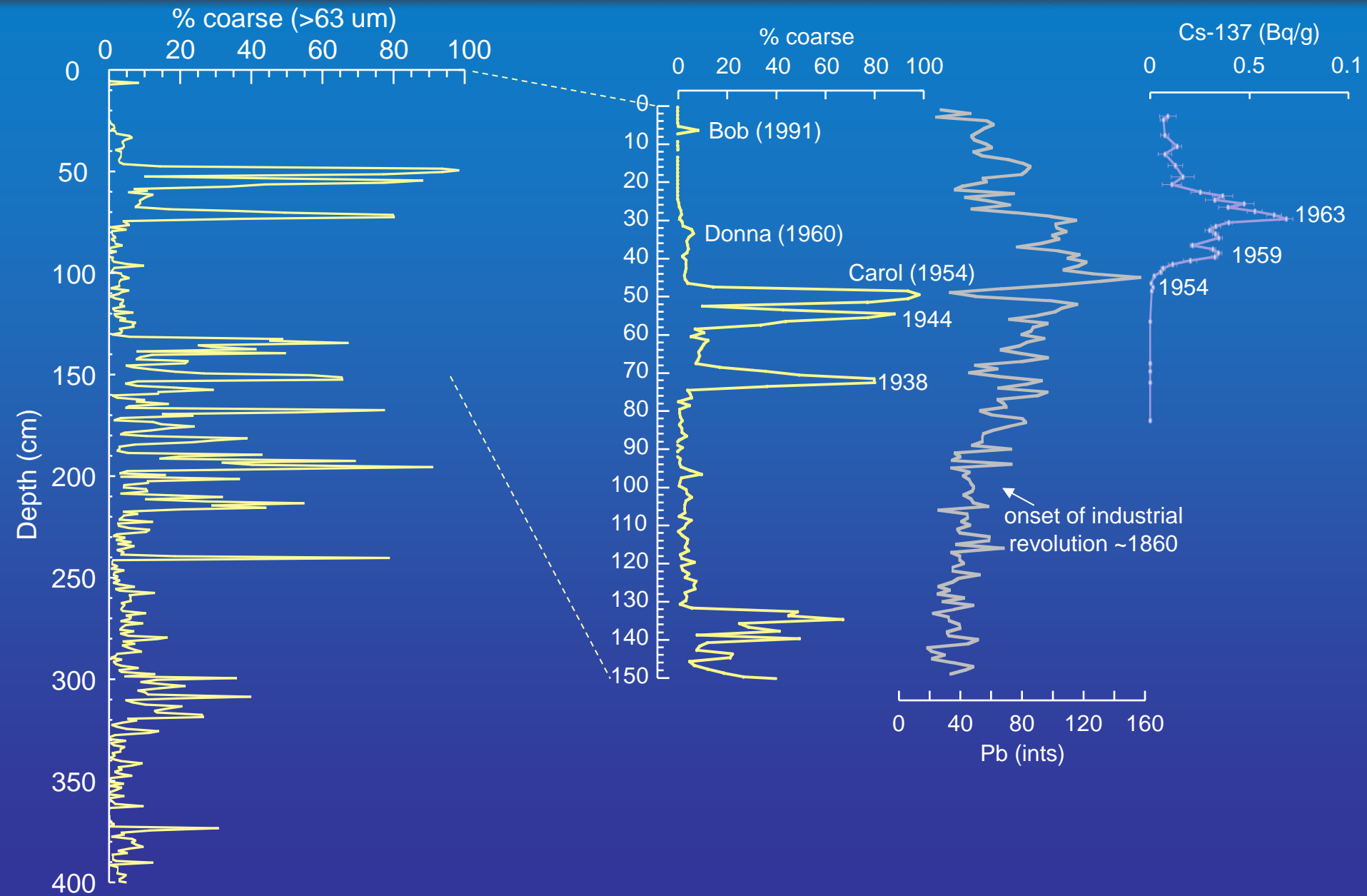
Oyster Pond, Falmouth MA (Core 13)



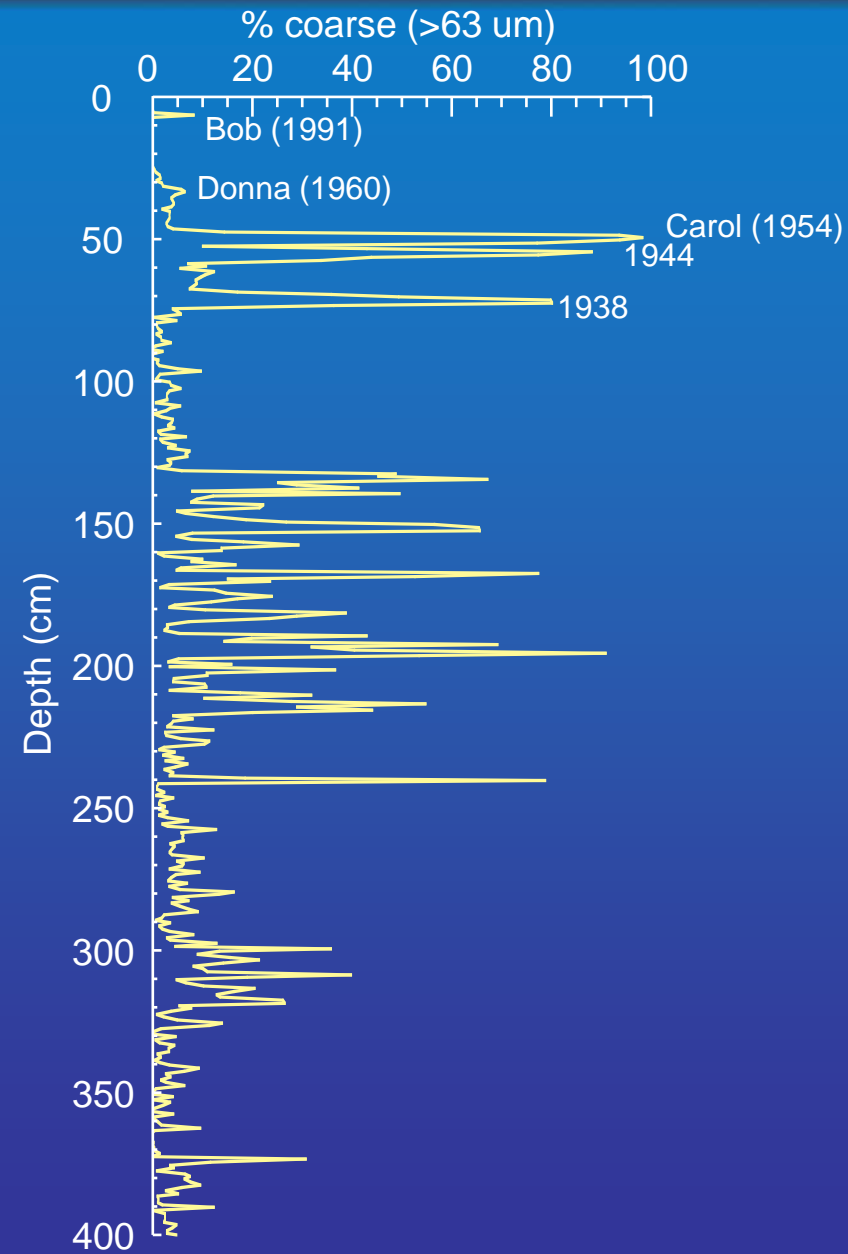
Oyster Pond, Falmouth MA (Core 13)



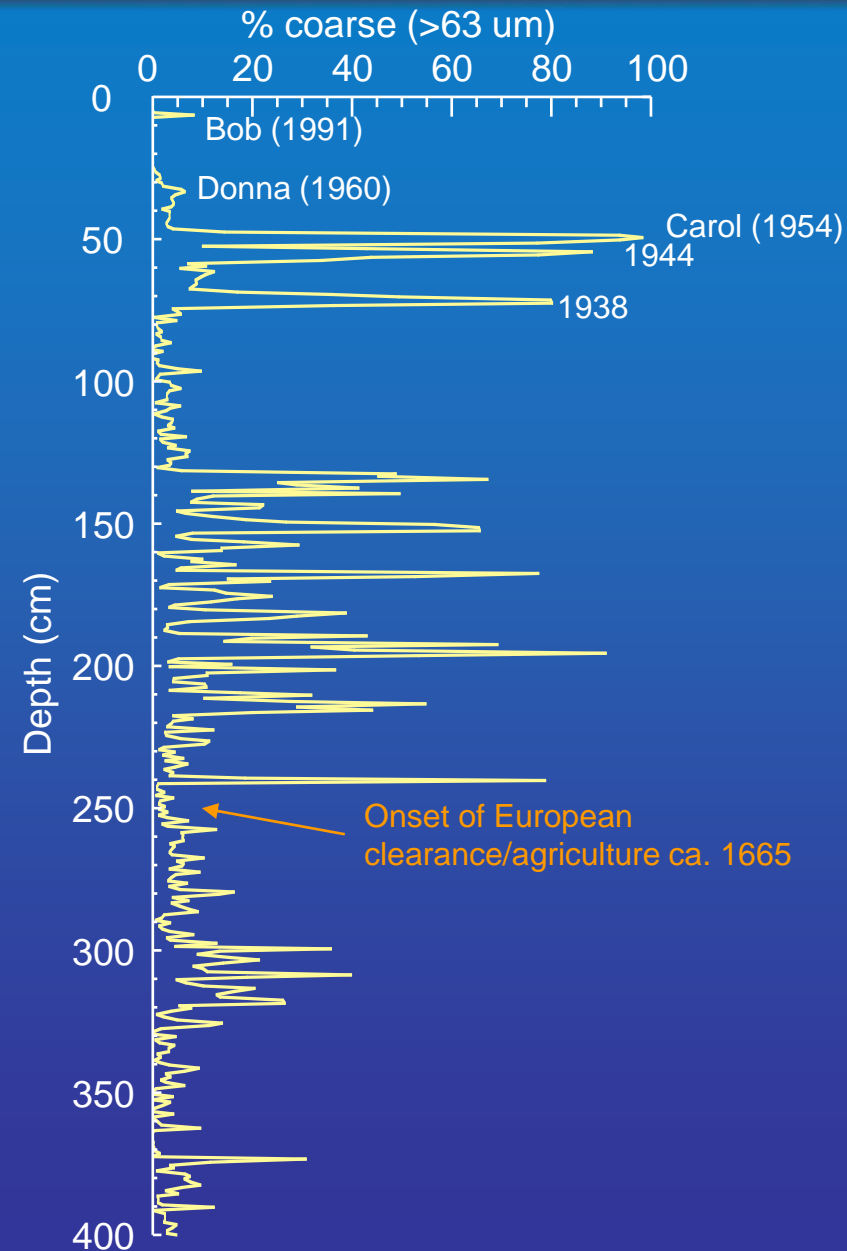
Oyster Pond, Falmouth MA (Core 13)



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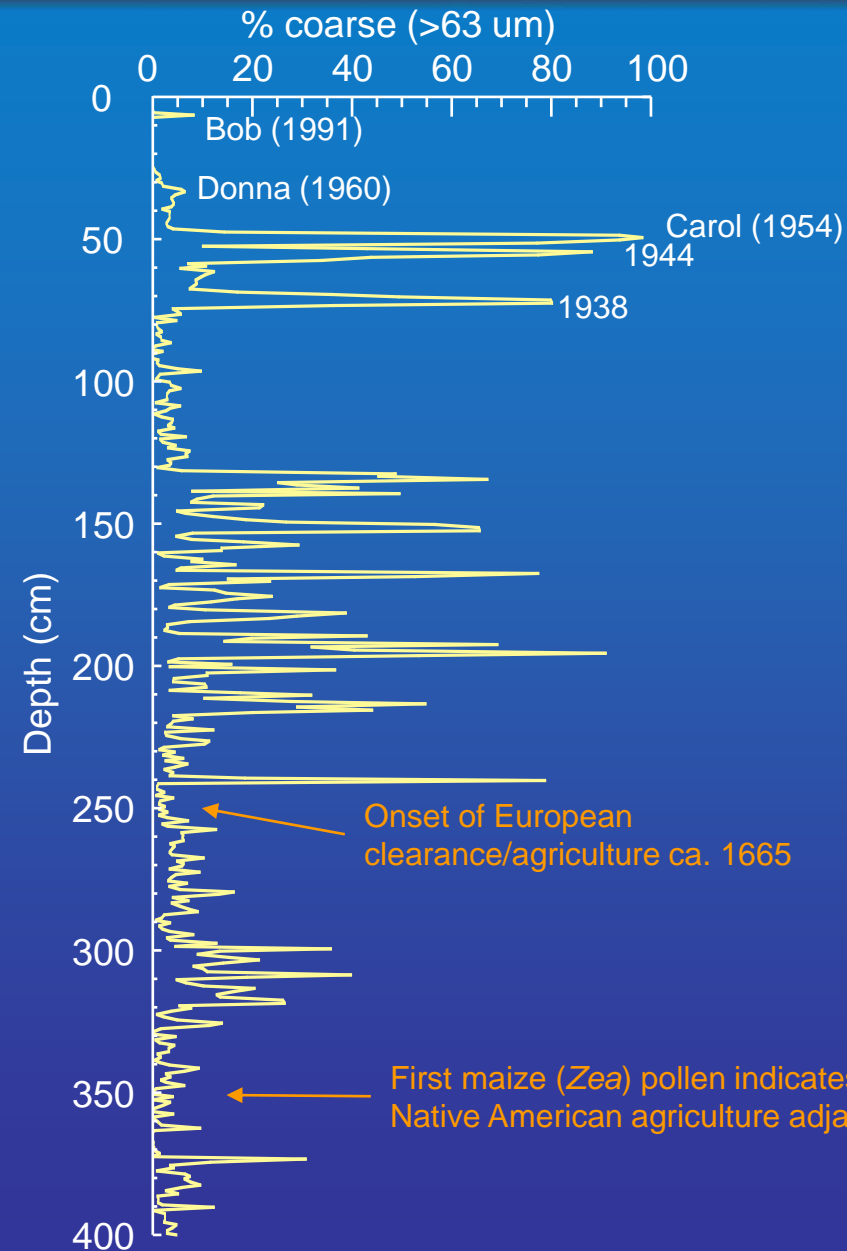
Oyster Pond, Falmouth MA (Core 13)



Jonathan Hatch and Isaac Robinson
build first houses in Falmouth 1661



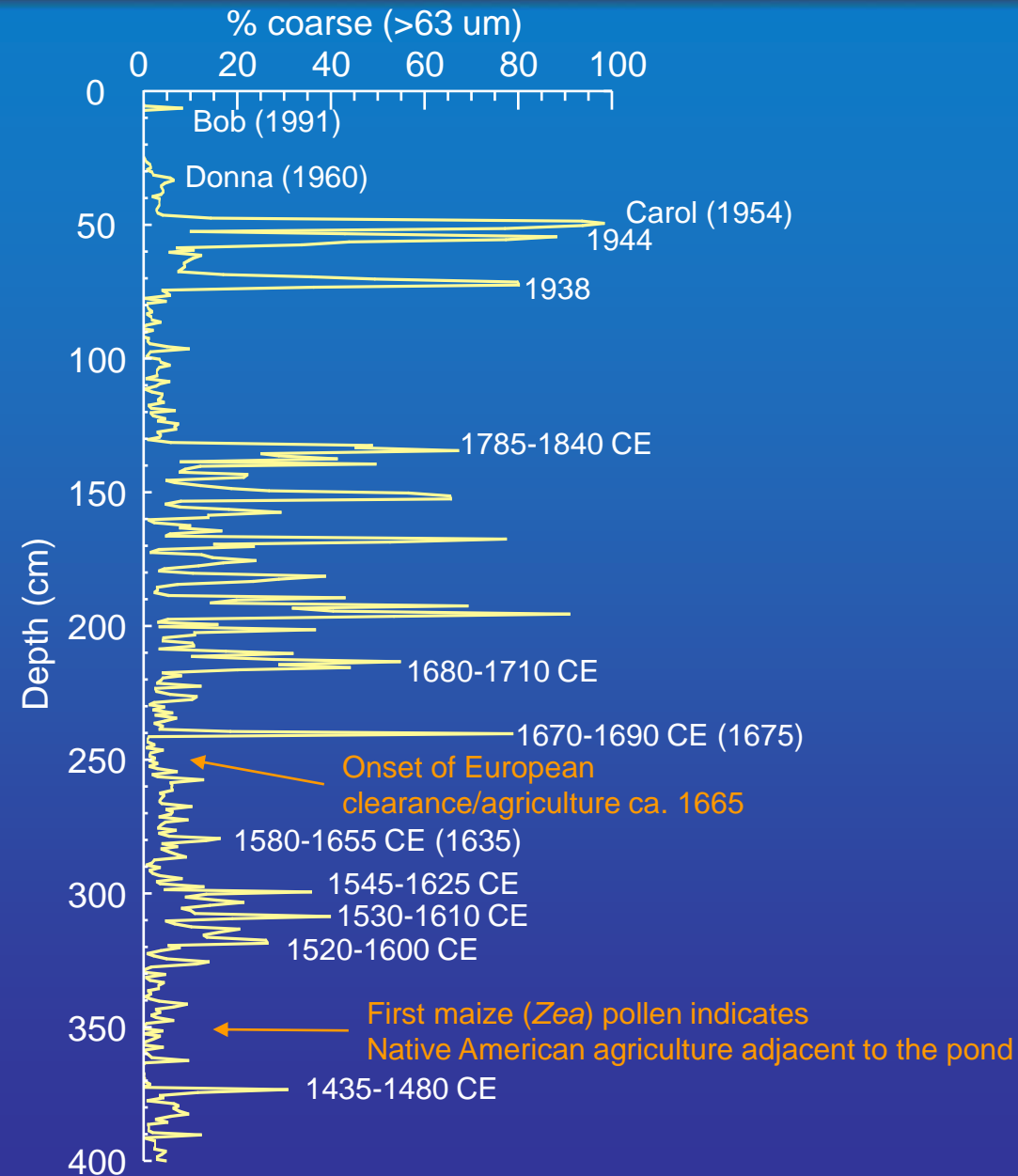
Oyster Pond, Falmouth MA (Core 13)



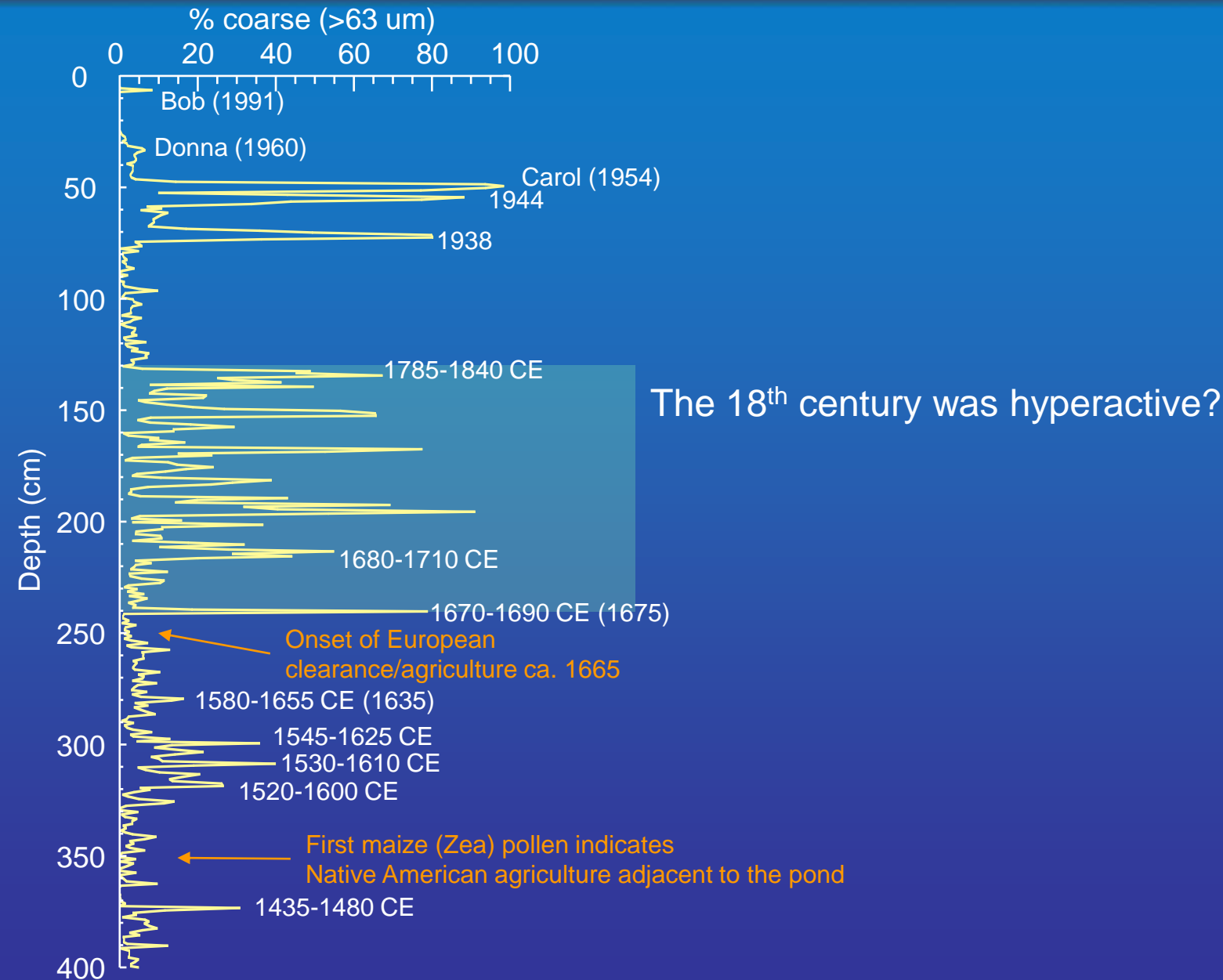
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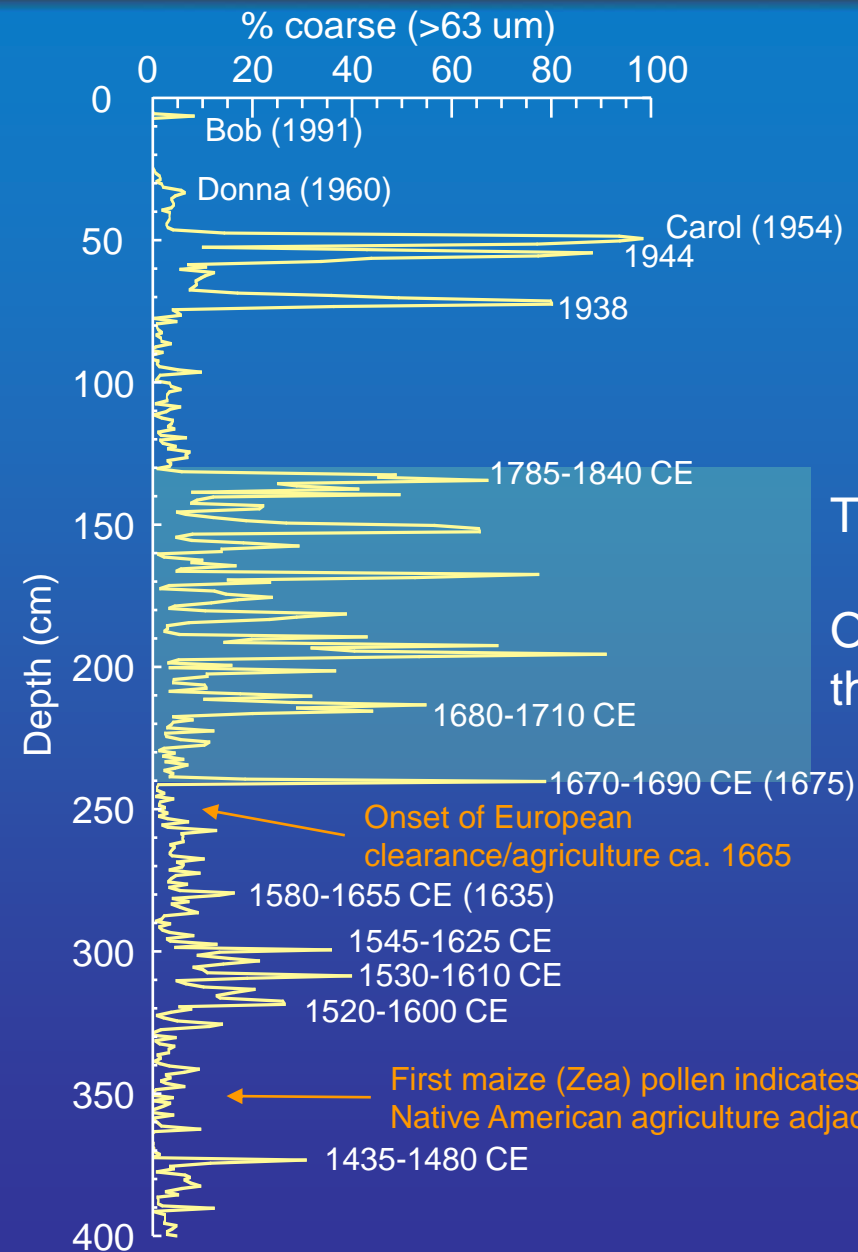
Oyster Pond, Falmouth MA (Core 13)



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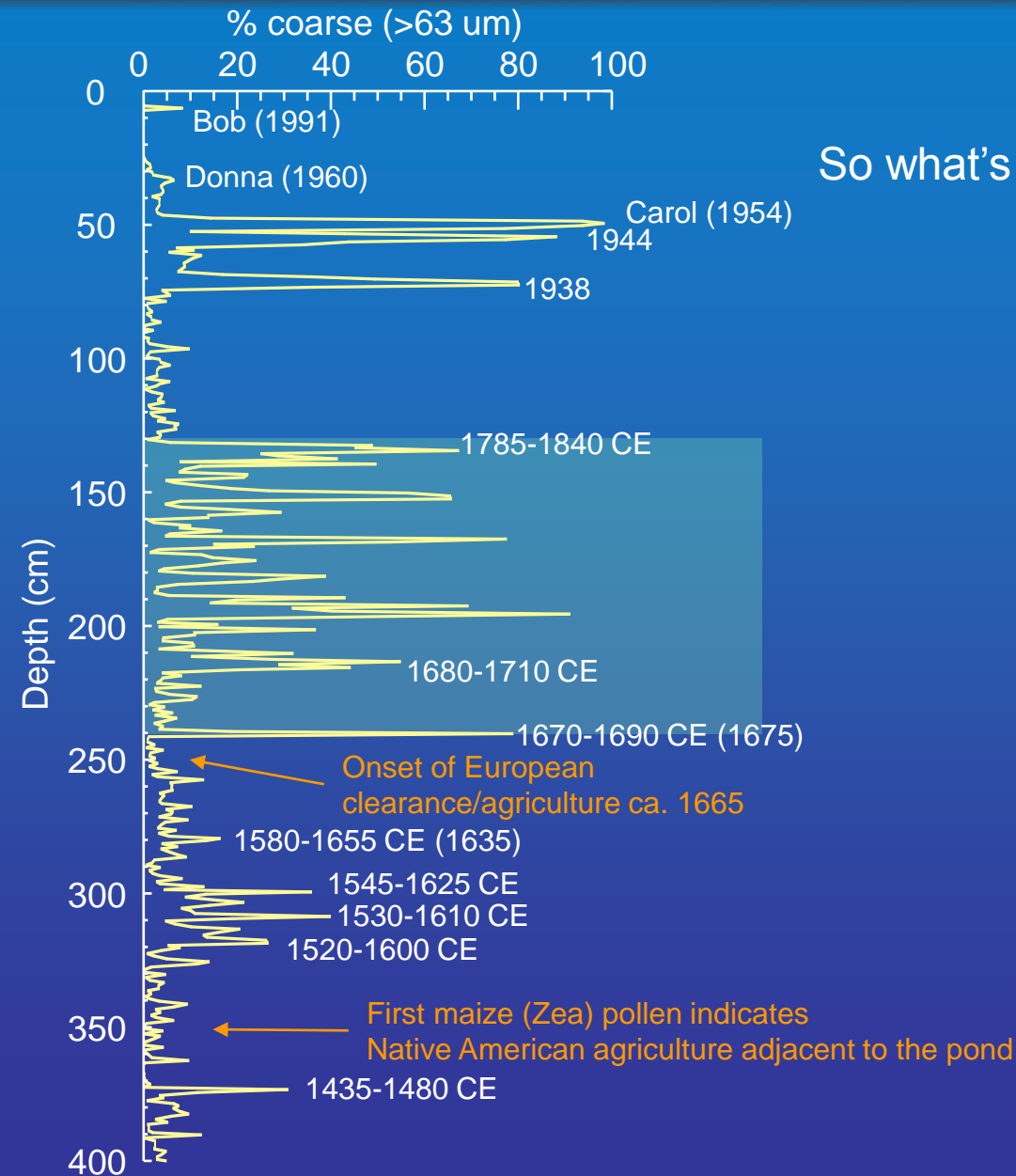
Oyster Pond, Falmouth MA (Core 13)



The 18th century was hyperactive?

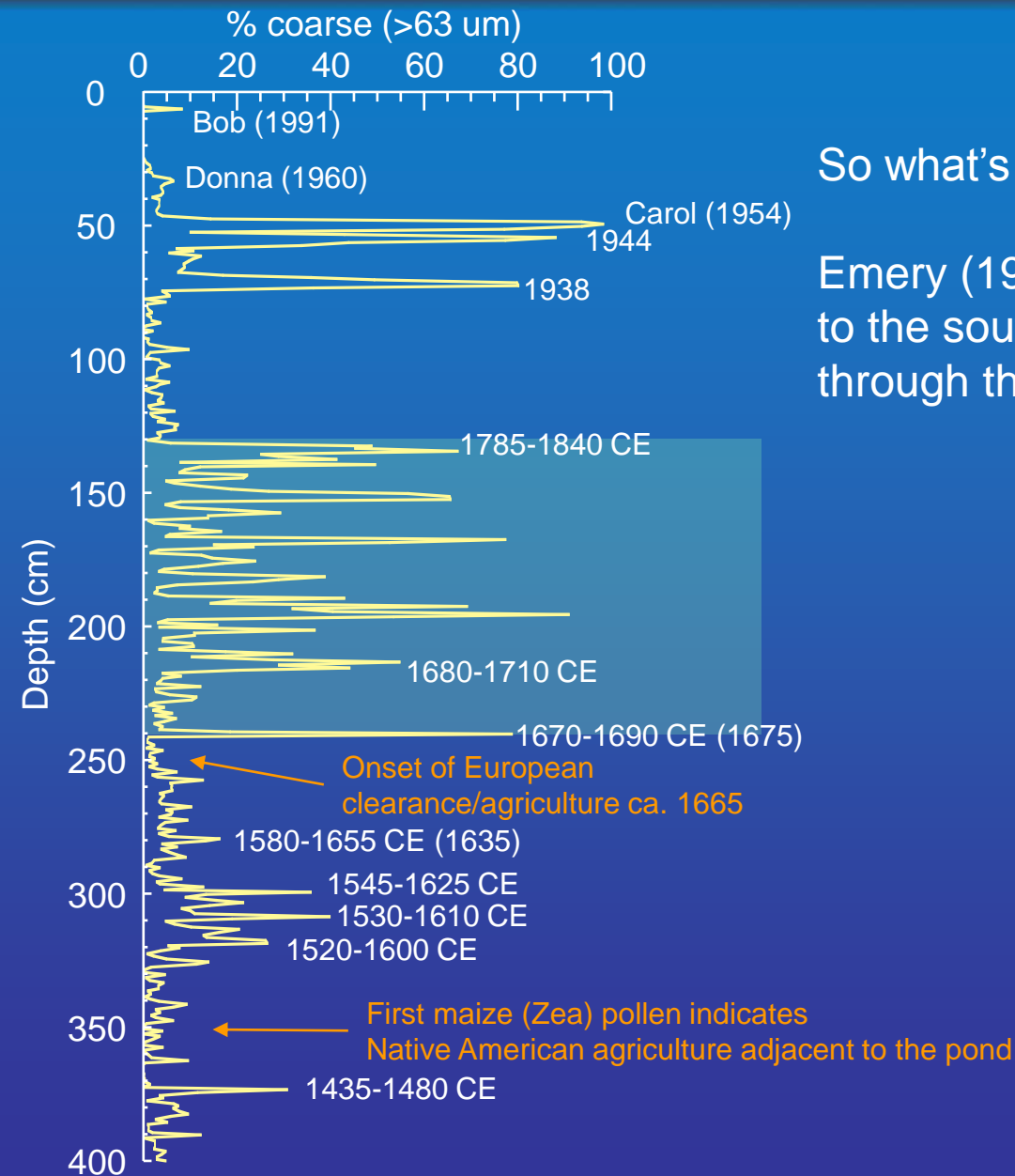
Only two significant hurricanes in the 18th century in 1727 and 1761!

Oyster Pond, Falmouth MA (Core 13)



So what's going on?

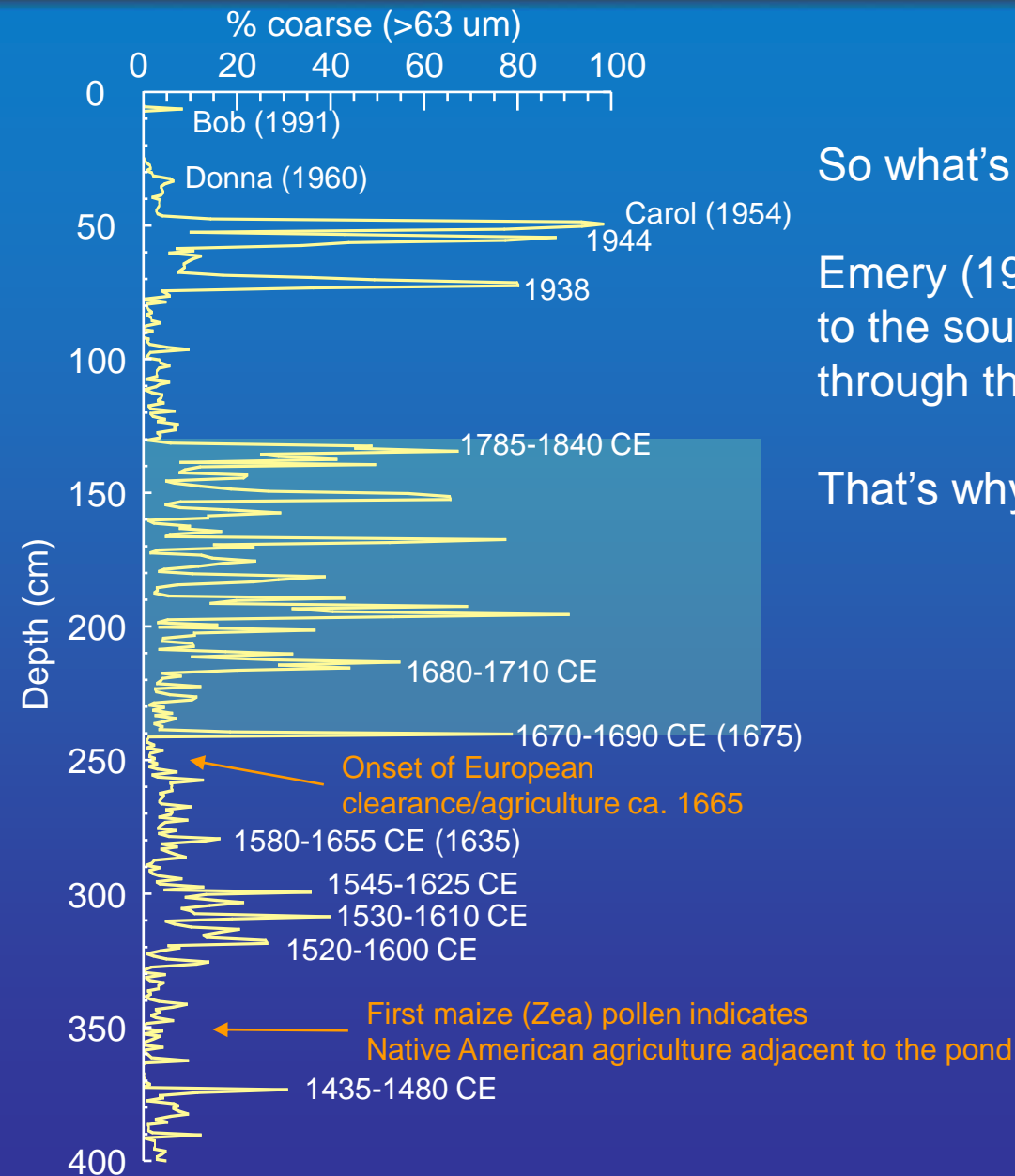
Oyster Pond, Falmouth MA (Core 13)



So what's going on?

Emery (1969) documented an inlet proximal to the southern basin of Oyster Pond existed through the 18th and early 19th centuries.

Oyster Pond, Falmouth MA (Core 13)

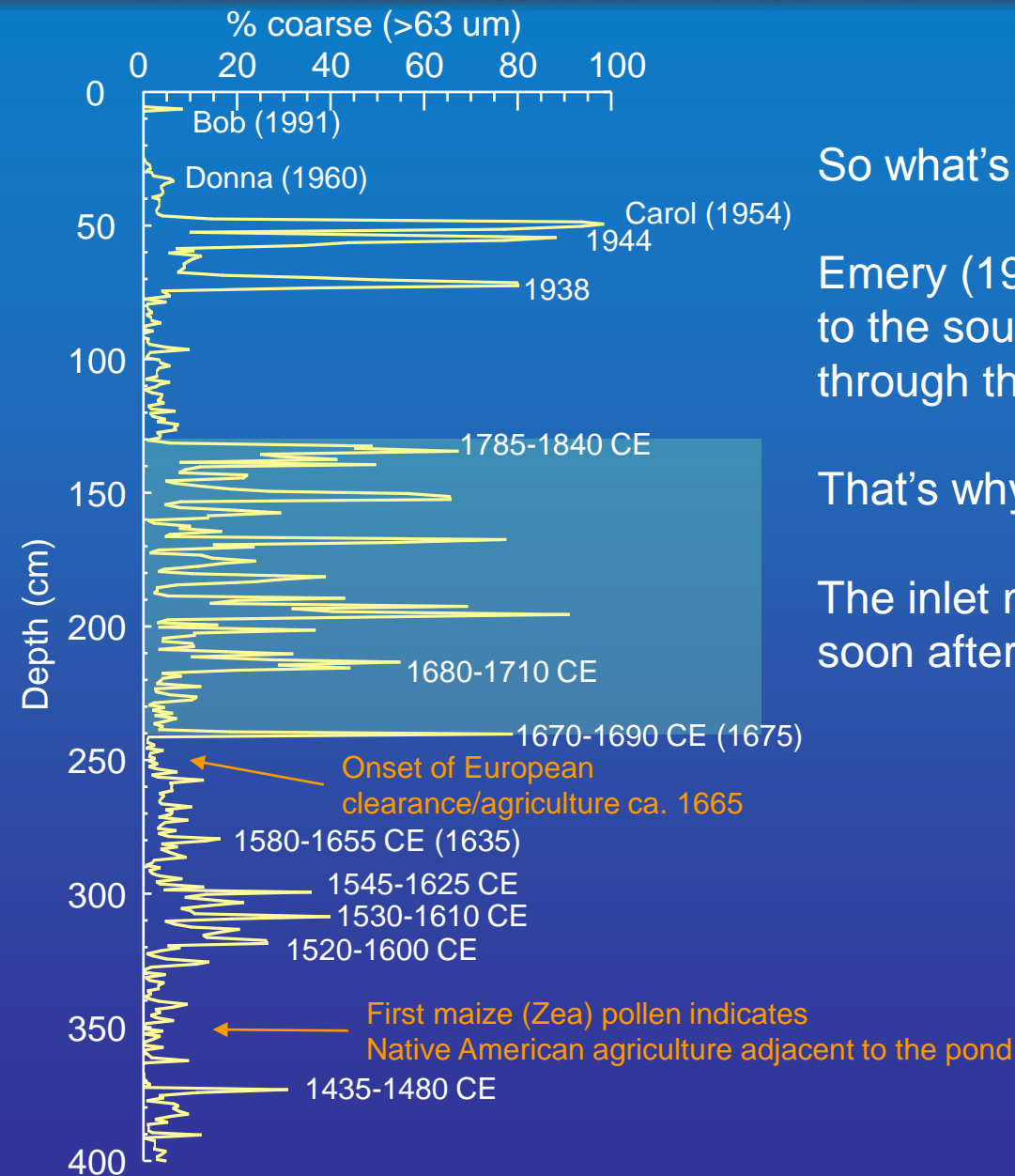


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That's why there were oysters in Oyster Pond!

Oyster Pond, Falmouth MA (Core 13)



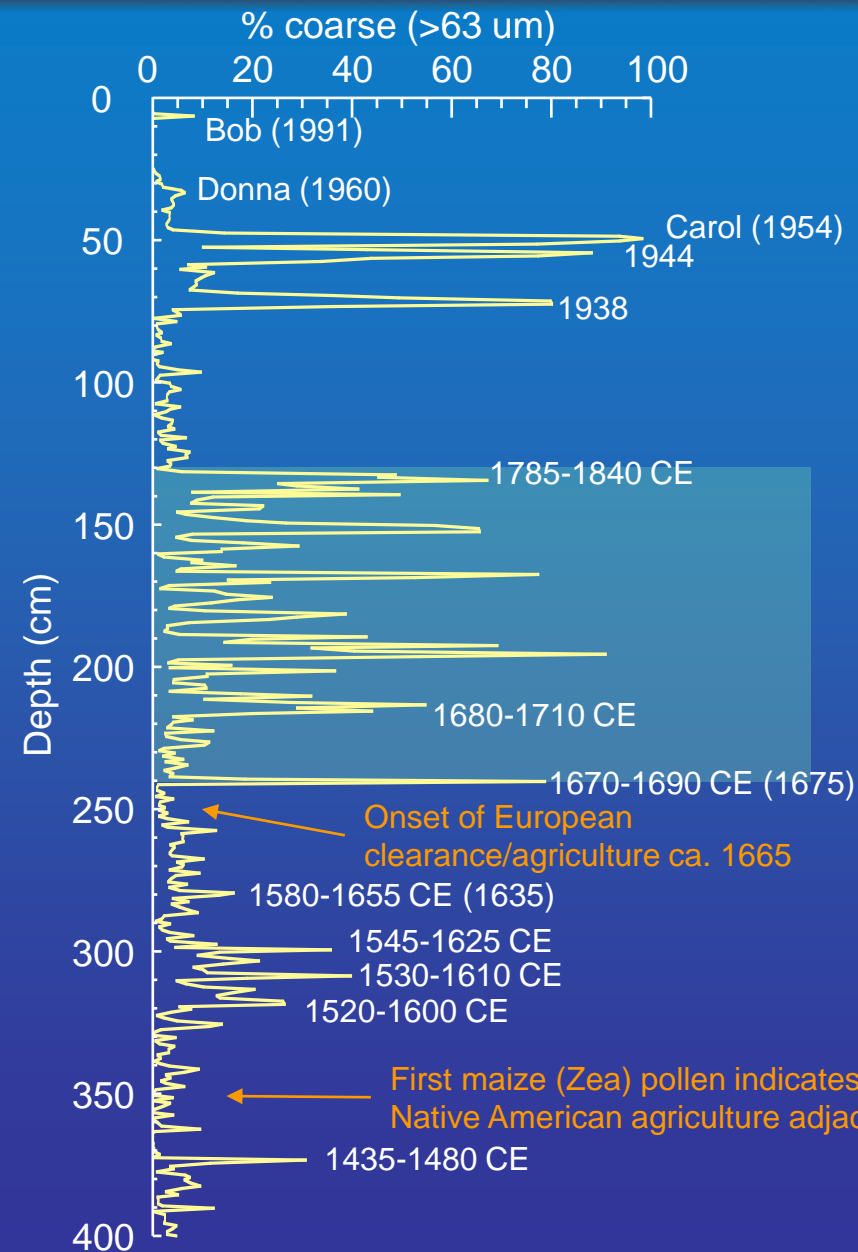
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The inlet may have formed in the 1675 hurricane soon after European settlement.

Oyster Pond, Falmouth MA (Core 13)



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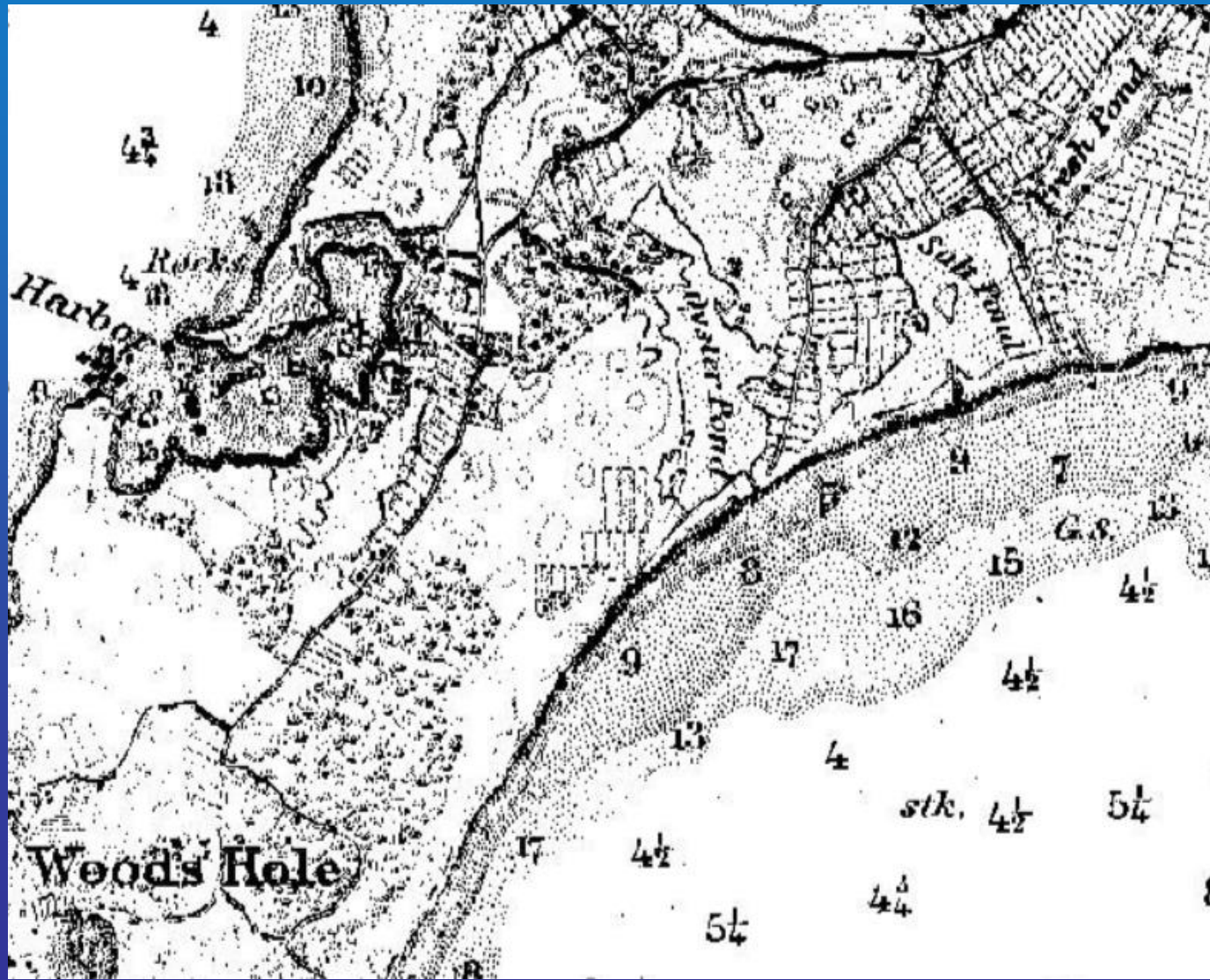
The inlet may have formed in the 1675 hurricane soon after European settlement.

The presence of the inlet likely greatly increased the sensitivity of the site to the transport of sand to the basin during the 18th and first half of the 19th centuries.

Oyster Pond, Falmouth MA (Core 13)



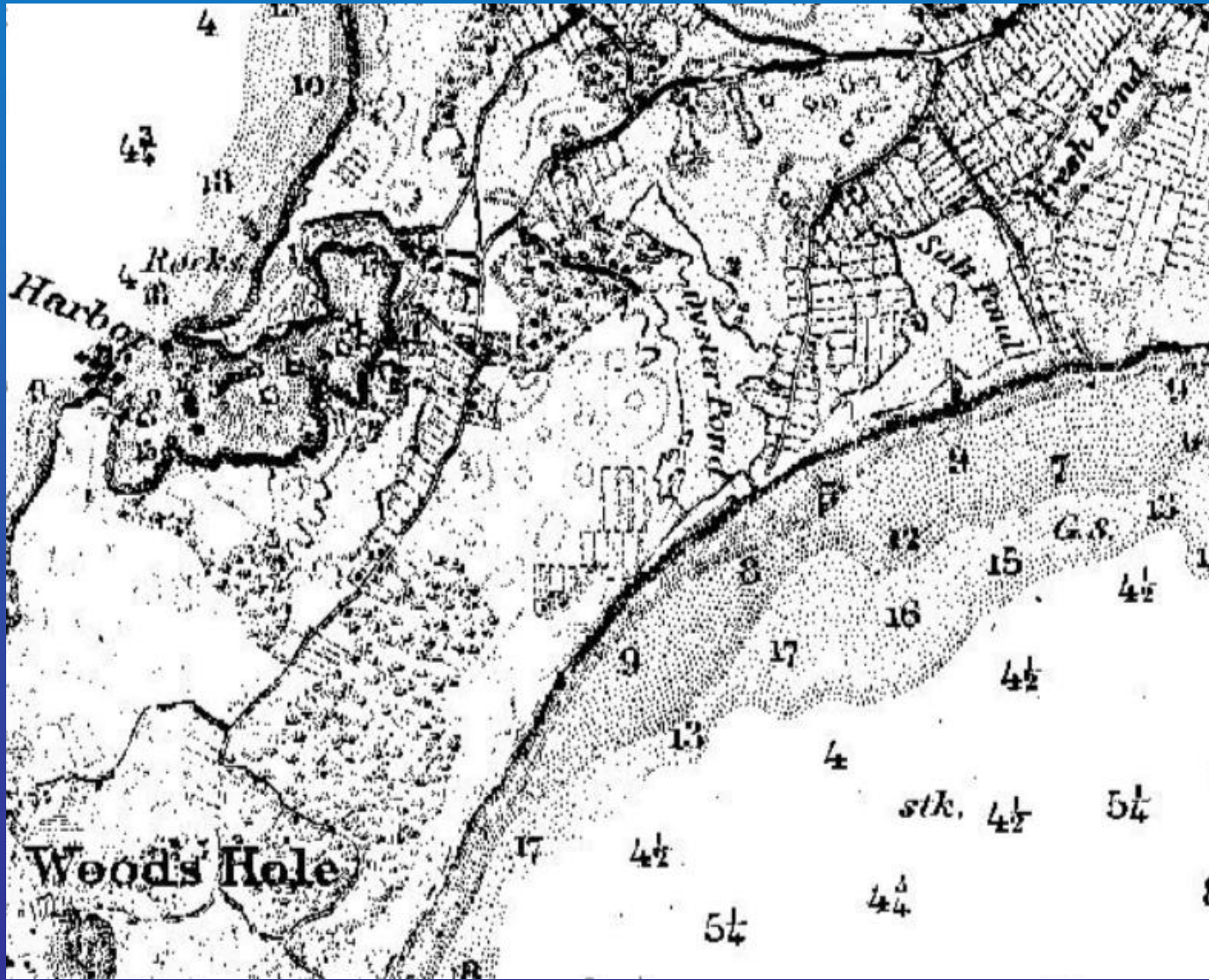
Inlet shown on charts as late as 1863. Emery postulated that gradual infilling of the inlet by longshore transport closed off the pond resulting in freshening and the decline of oysters.



Oyster Pond, Falmouth MA (Core 13)



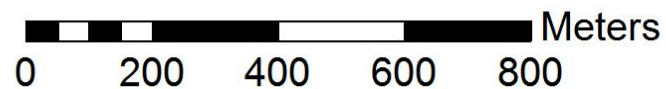
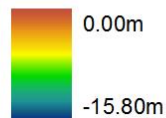
So if the intermittent presence of inlets (a dynamic barrier) can significantly alter the sensitivity of a site to storm-induced sedimentation, how are we to reconstruct a reliable history of past hurricane strikes?



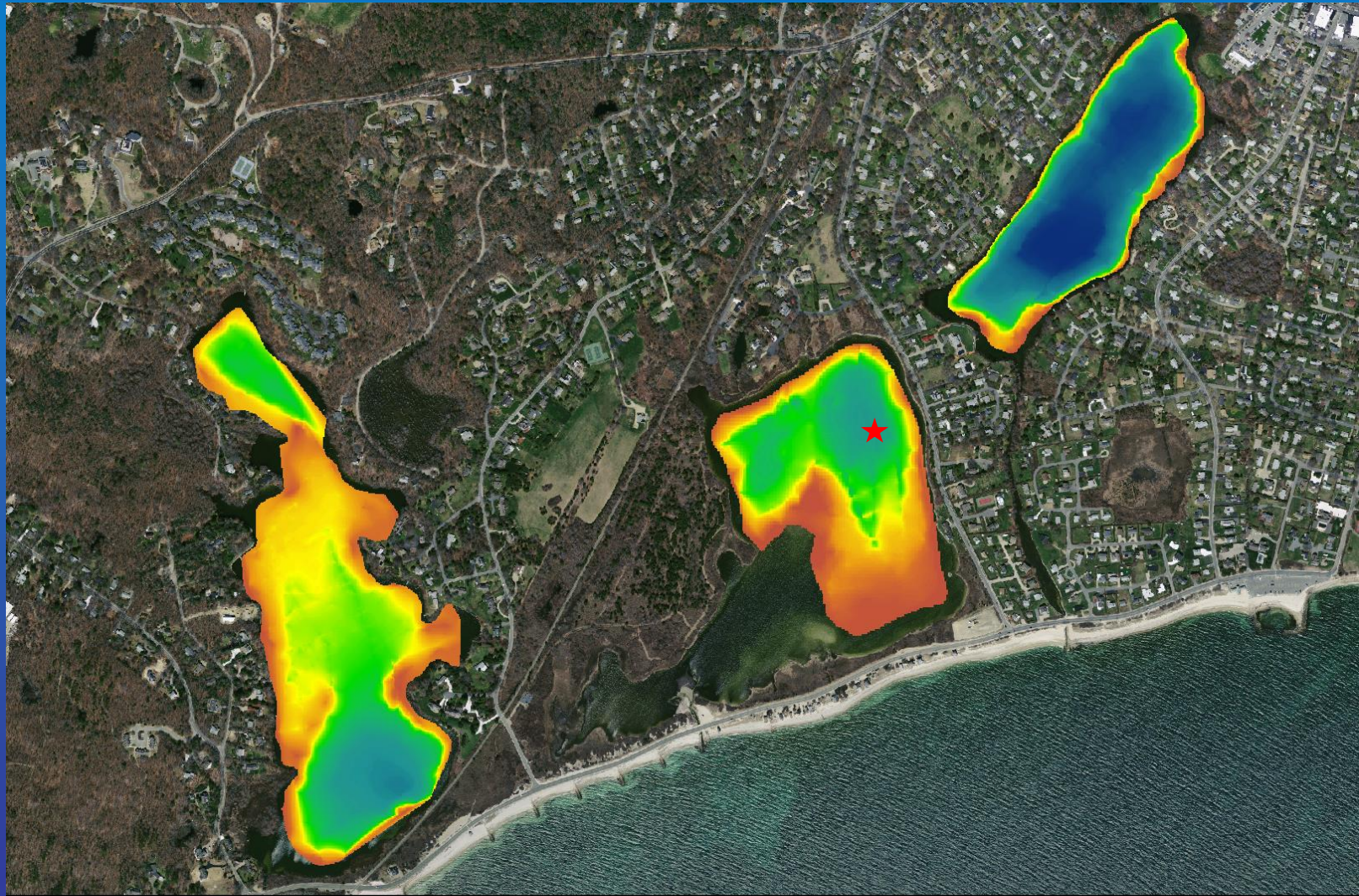
Perhaps a site a further from the barrier?



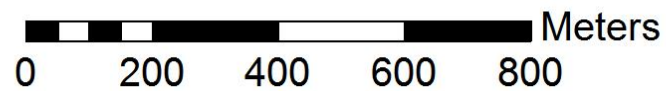
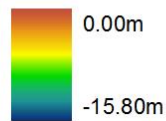
Oyster, Salt Pond, Sider Bathymetry



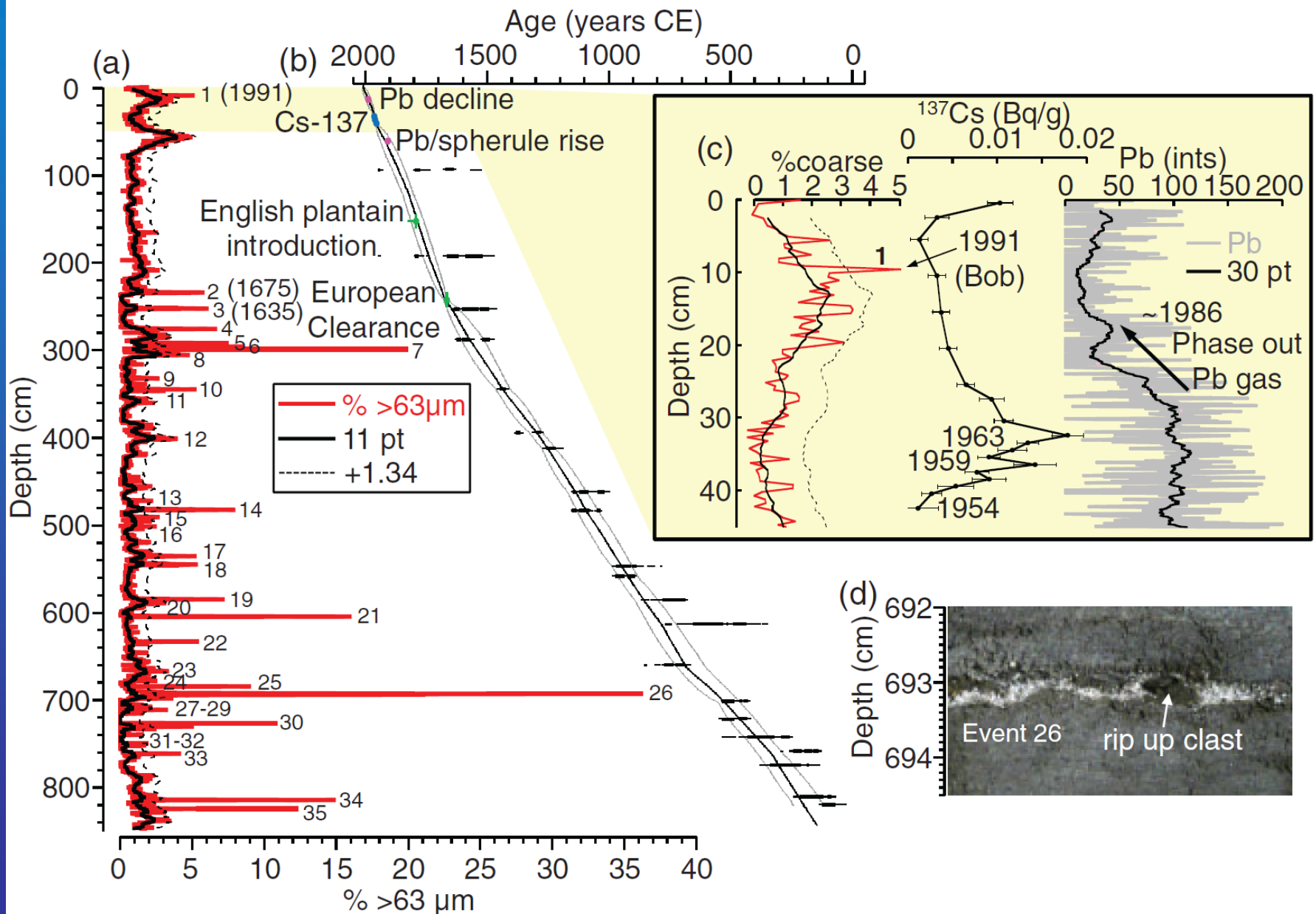
Salt Pond, Falmouth MA



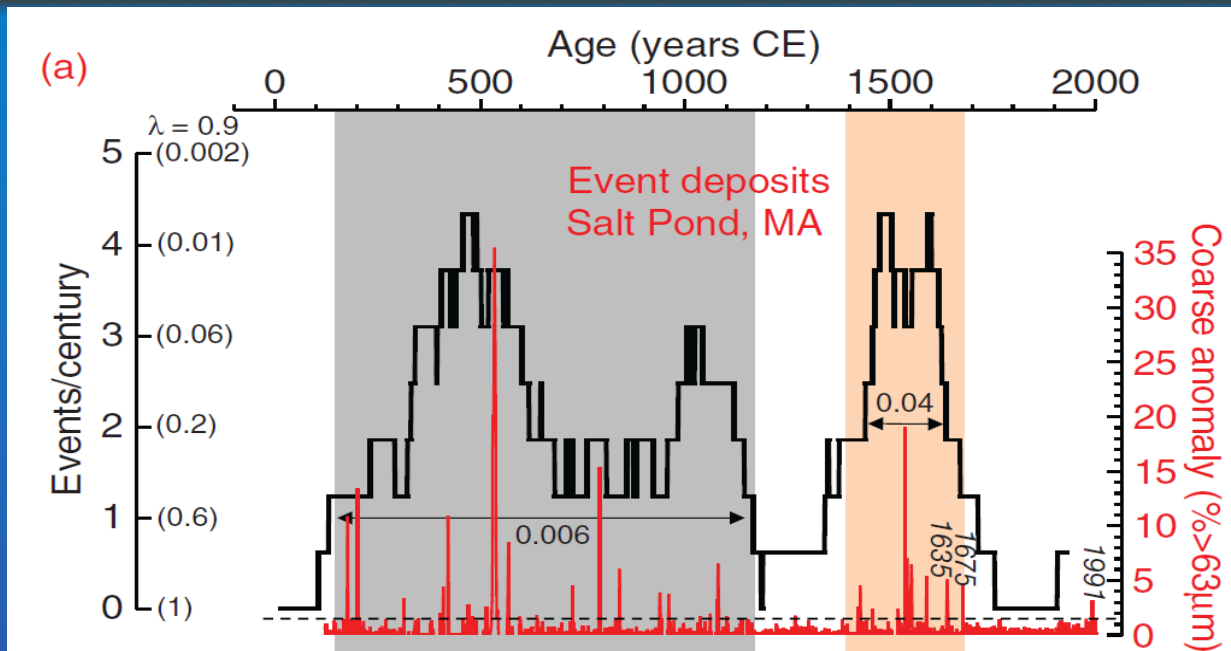
Oyster, Salt Pond, Sider Bathymetry



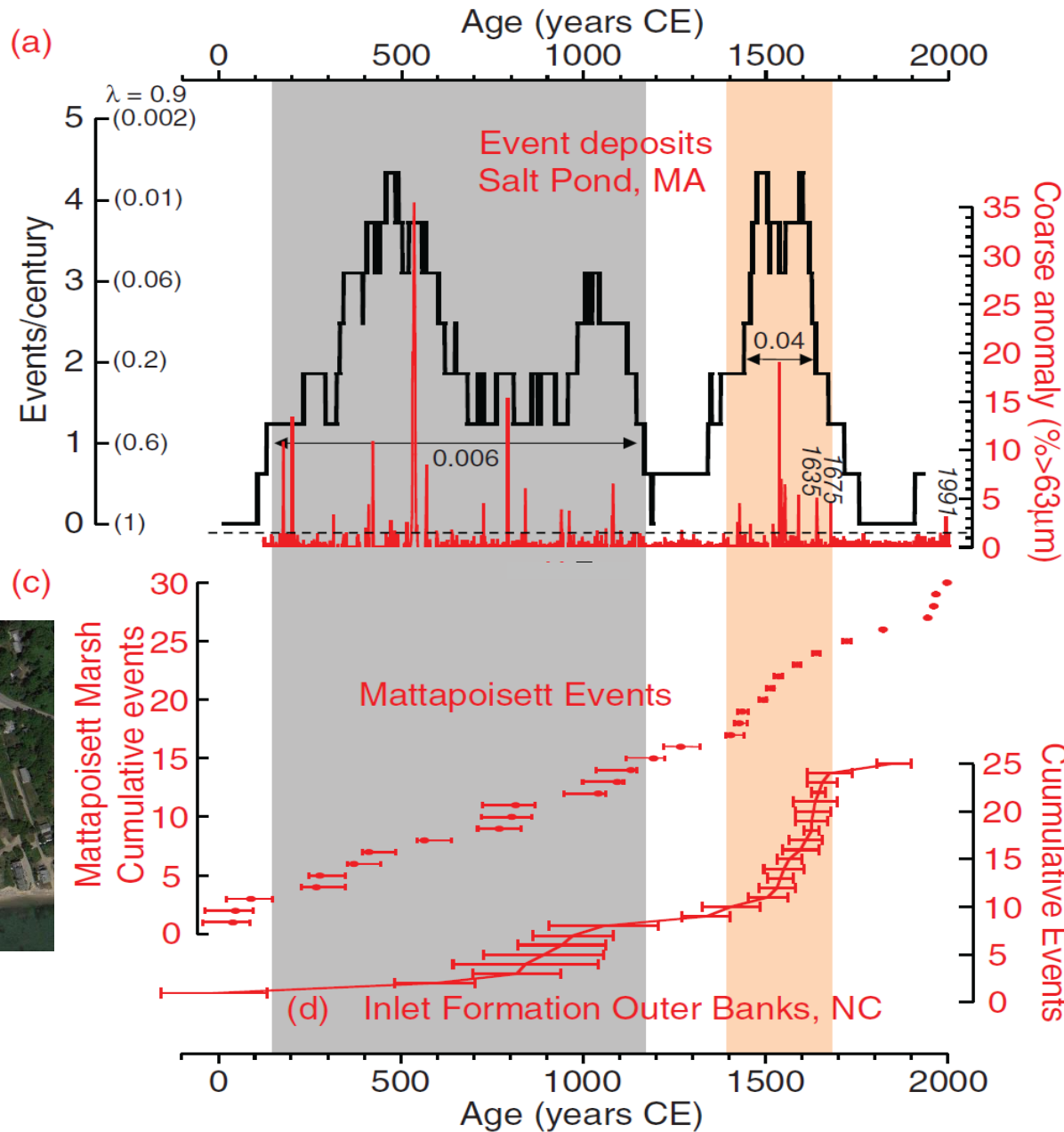
Salt Pond Reconstruction



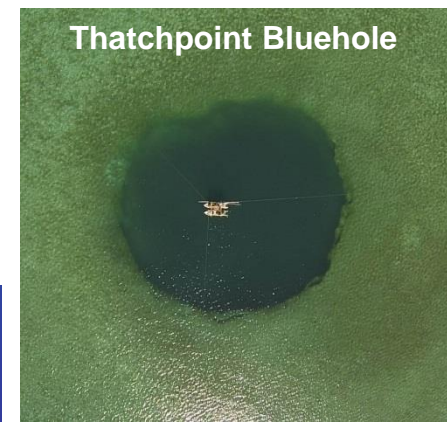
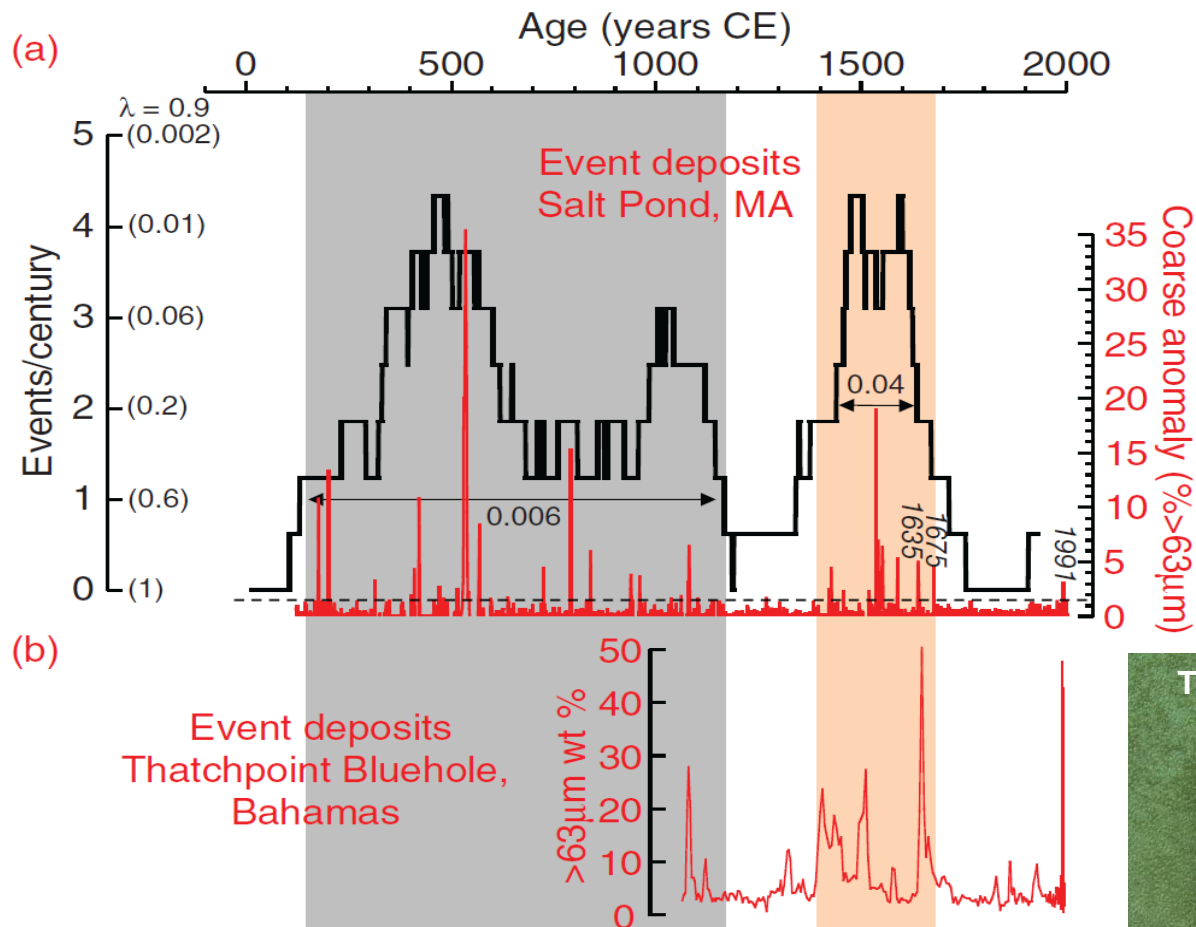
Salt Pond Reconstruction



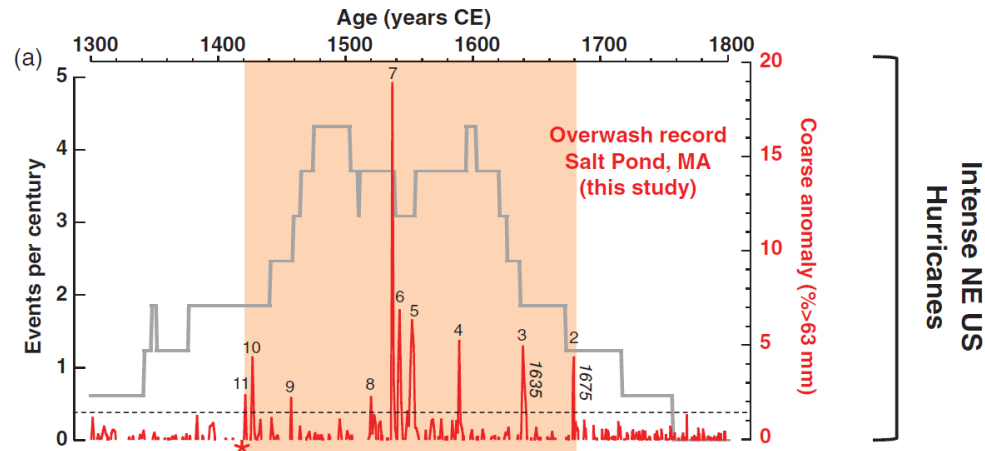
Salt Pond Reconstruction



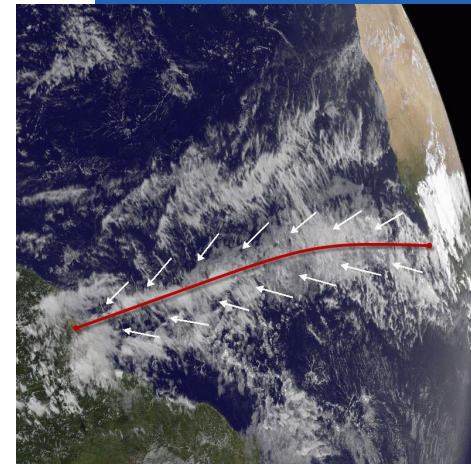
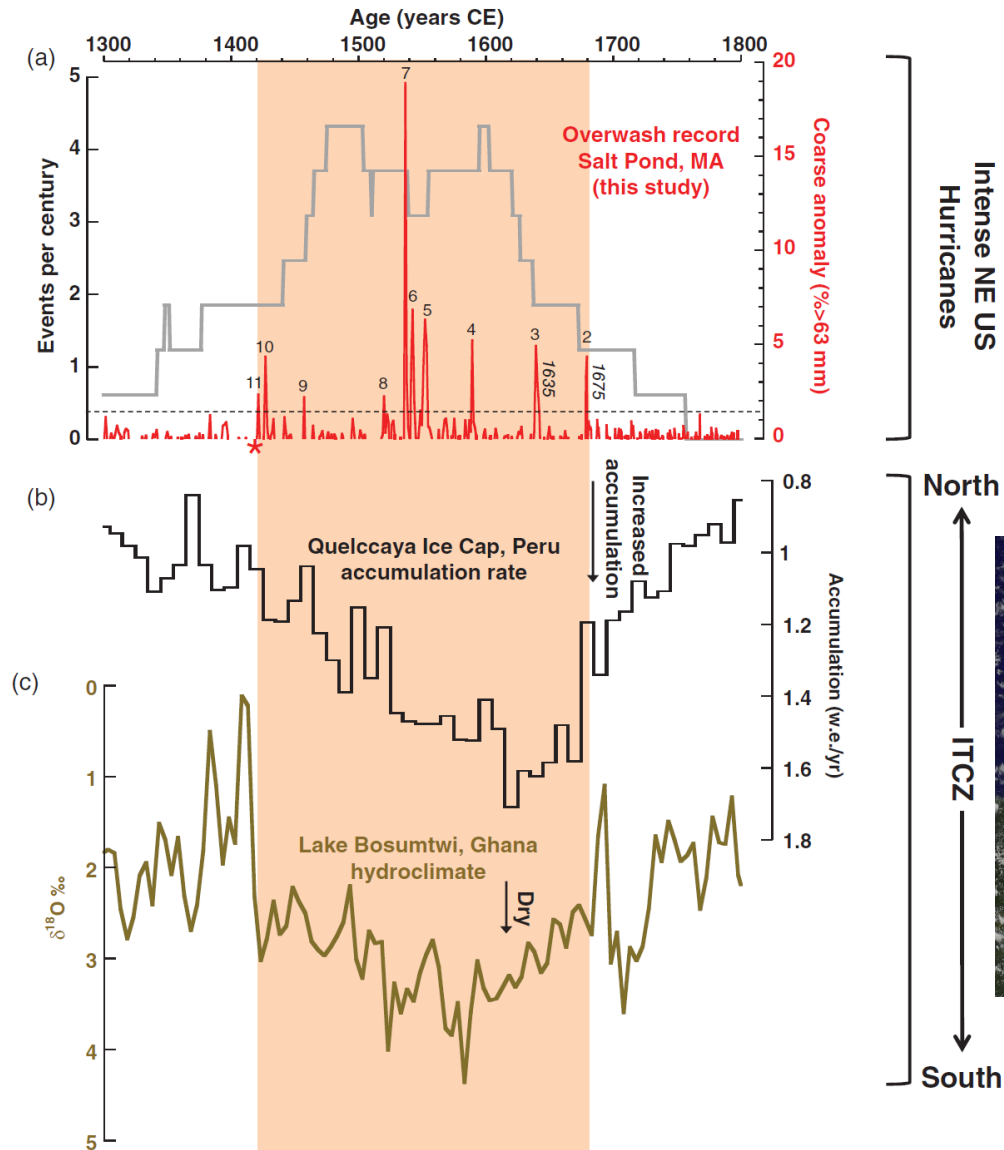
Salt Pond Reconstruction



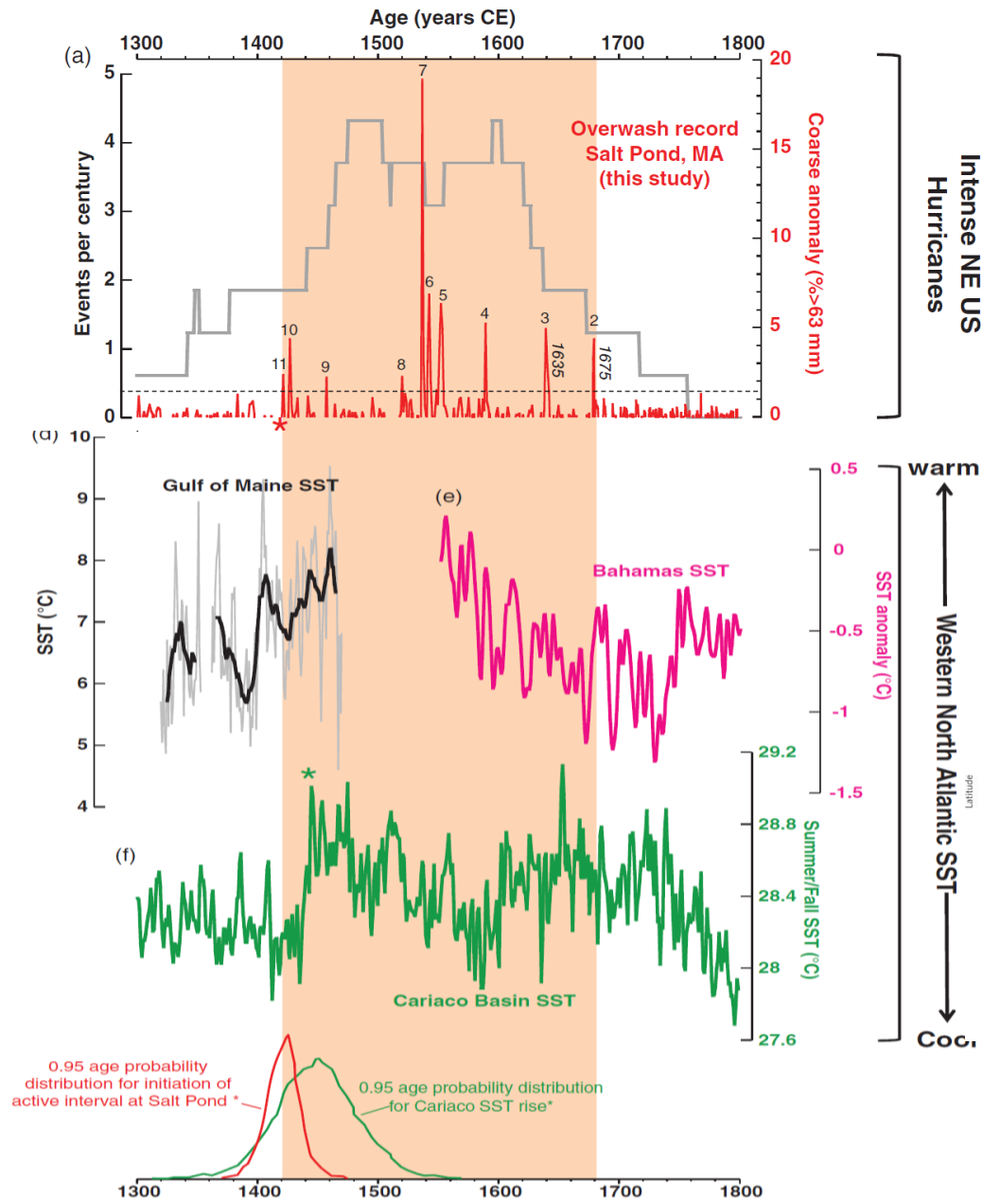
Climate Forcing



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Some answers



- How has hurricane activity varied prehistorically?

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Statistically significant variability in intense hurricane activity has occurred over the last few millennia.

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Many prehistorical intervals of heightened activity have far exceeded historical levels of activity.

- How has hurricane activity varied prehistorically?

Statistically significant variability in intense hurricane activity has occurred over the last few millennia.

Many prehistorical intervals of heightened activity have far exceeded historical levels of activity.

Some evidence for regional coherency, which suggests regional scale forcings are likely important.

Remaining questions



Remaining questions



- What are the drivers of changes in hurricane activity?
What climatic forcings combined to yield intervals of hurricane hyperactivity in the past?

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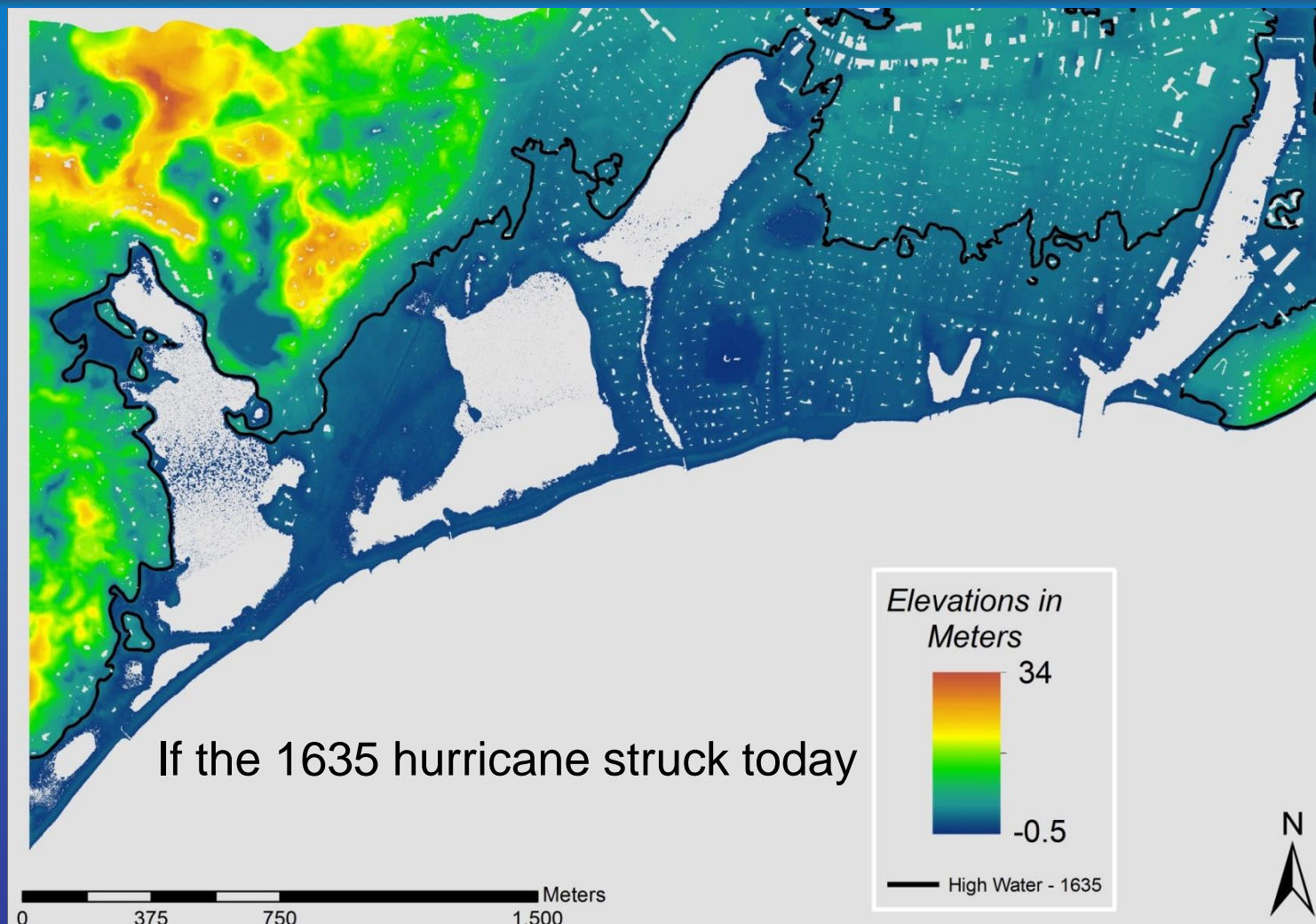
Remaining questions



- What are the drivers of changes in hurricane activity?
What climatic forcings combined to yield intervals of hurricane hyperactivity in the past?
- Is the future climate likely to also yield similar climate states?
- Does the maximum intensity of hurricanes change with climate change?
- What are the implications of changes in hurricane activity for coastal landforms, ecosystems, and humanity?

The negative 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!



Further Reading:

Early American Hurricanes, D.M. Ludlum

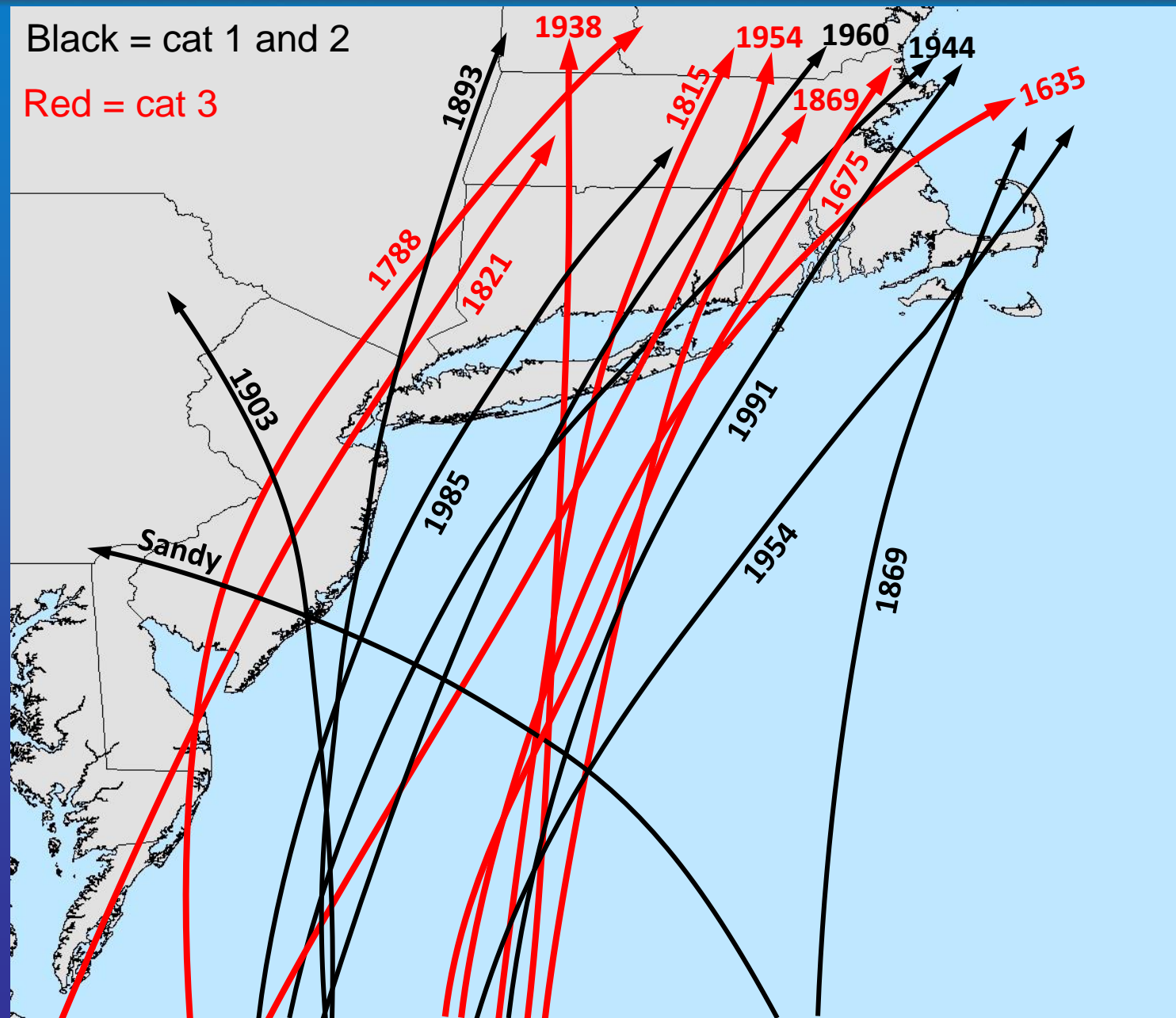
A Wind to Shake the World, E.S. Allen

Sudden Sea: The Great Hurricane of 1938, R. Scotti

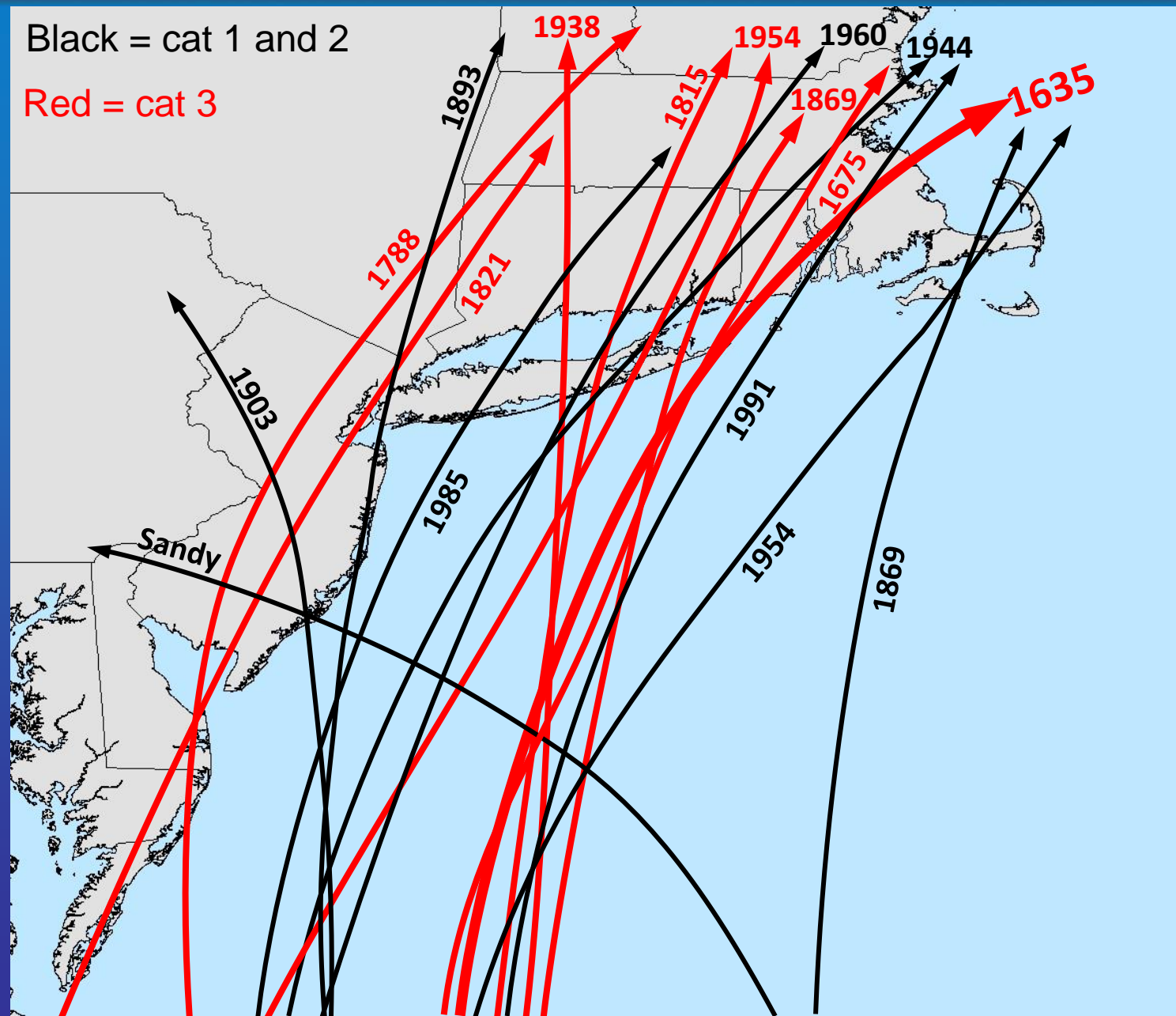
Issac's Storm, Erik Larson

Also checkout episode 2 of *Years of Living Dangerously* on National Geographic Channel, NOVA in summer 2017, and www.whoi.edu/science/GG/coastal

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"

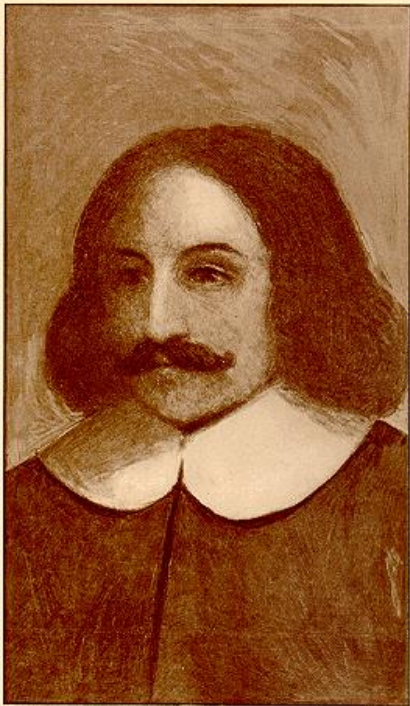


William Bradford (Governor of Plymouth Colony)

"...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

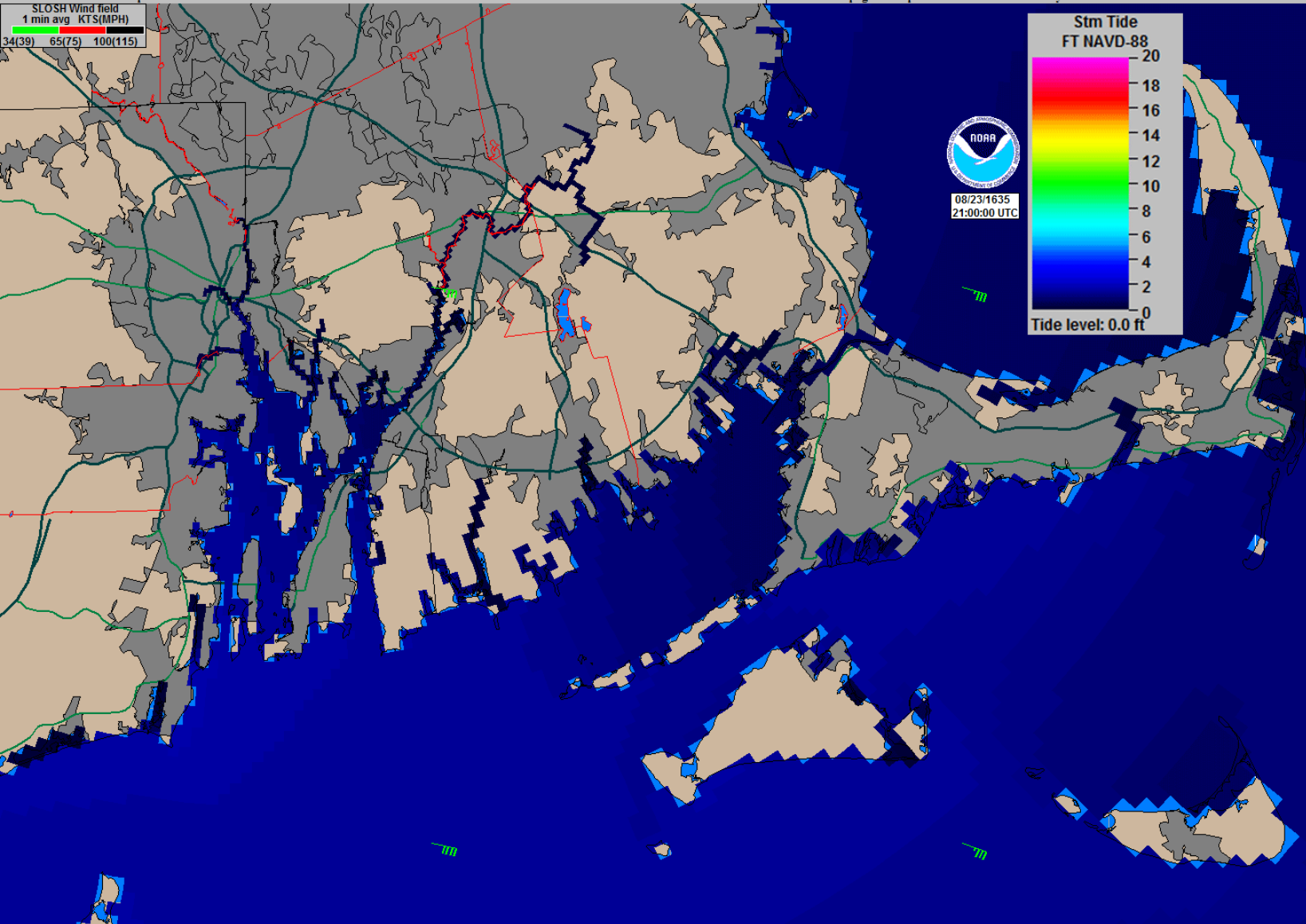
Storm surge from the Great Colonial Hurricane of 1635



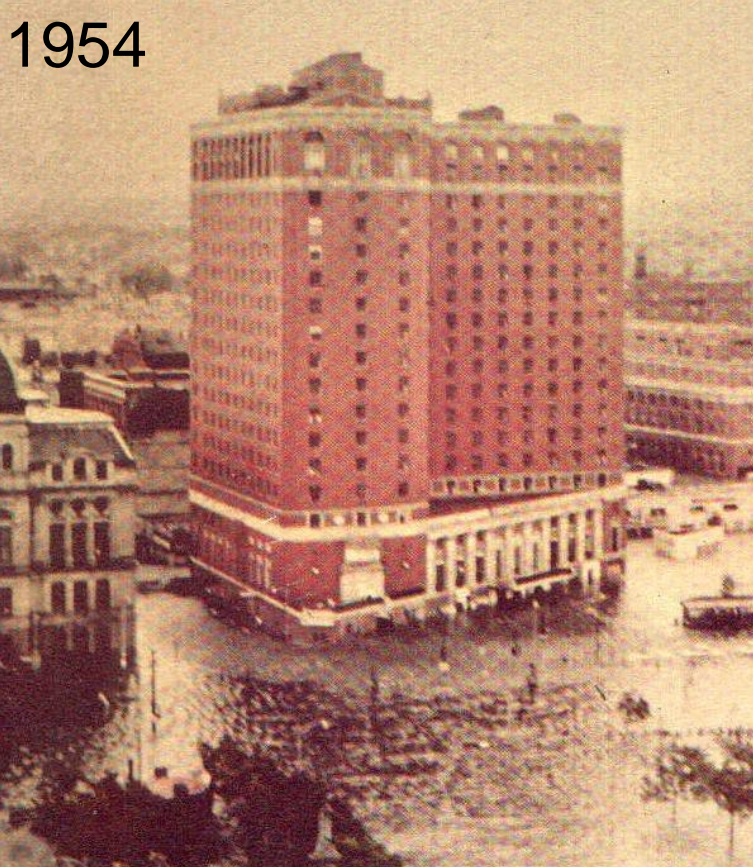
Basin: Providence/Boston <pr2>

SLOSH Wind field
1 min avg KTS(MPH)
34(39) 65(75) 100(115)

Storm: C:/slosh/pkg/sloshdsp/rexfiles/GreatColonial1635byRMS.rex



1954



1938



Providence, RI

1815



Thank you!

Further Reading:

Early American Hurricanes, D.M. Ludlum

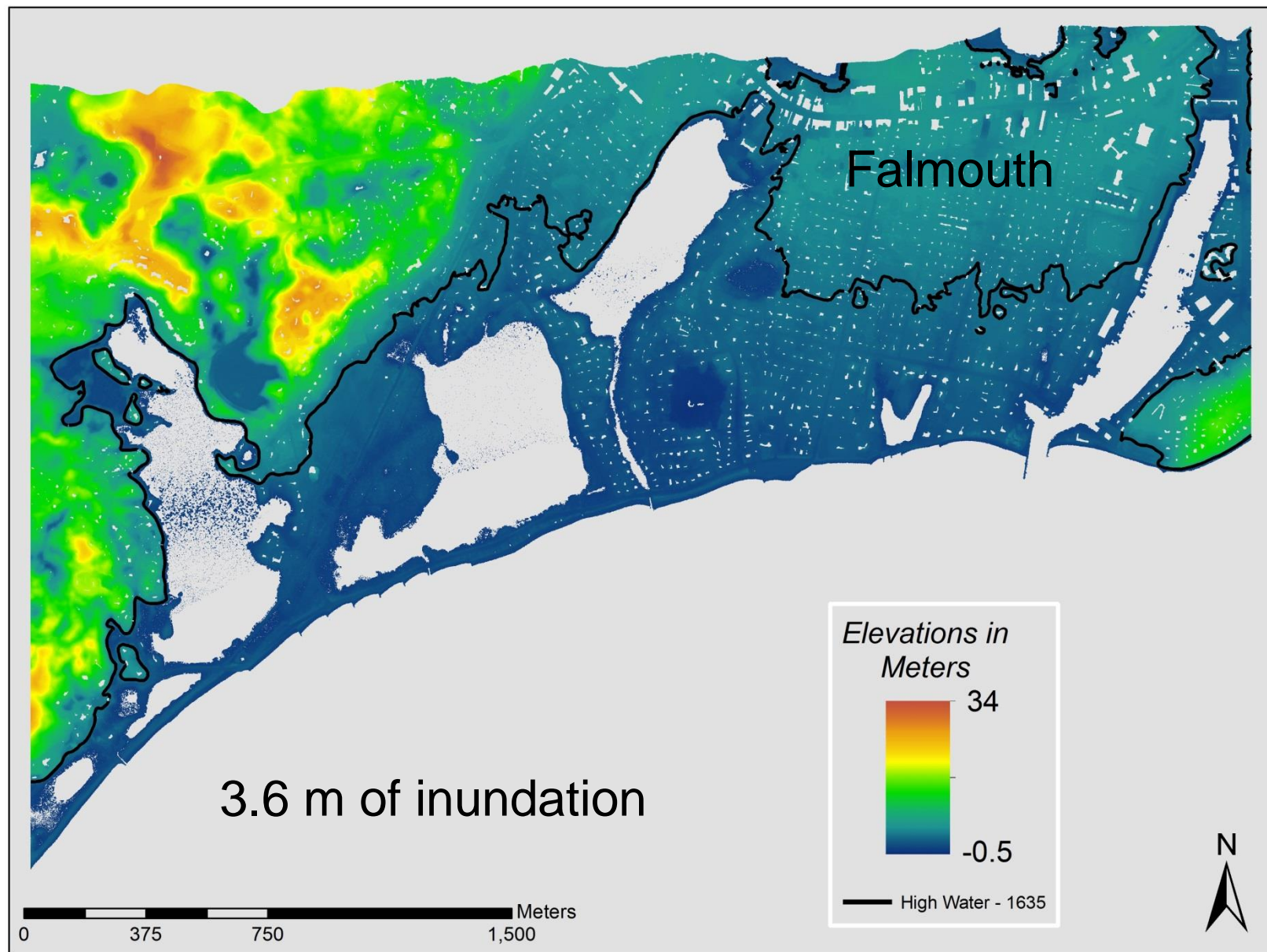
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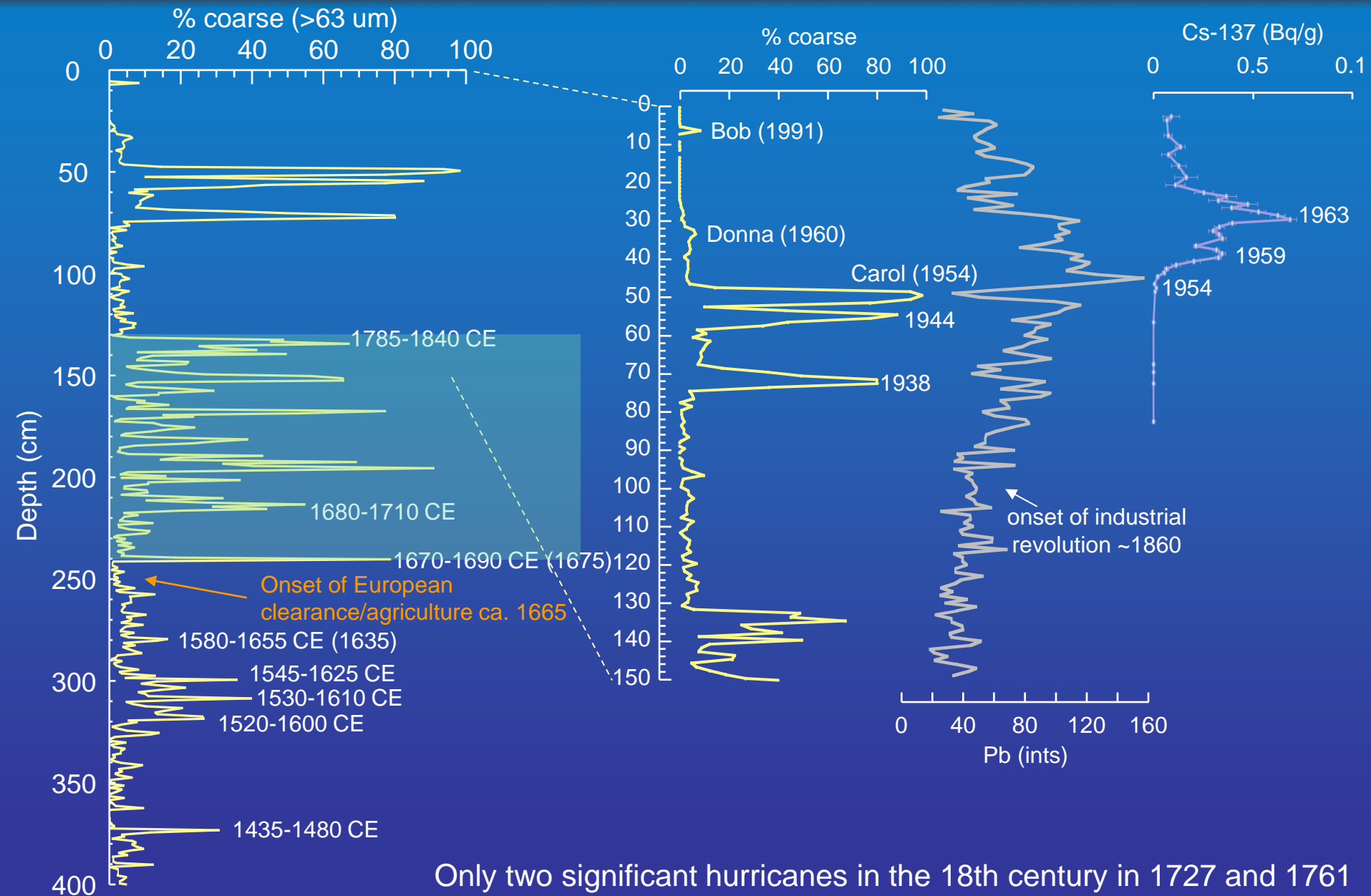
Issac's Storm, Erik Larson

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What if the 1635 hurricane hit today?

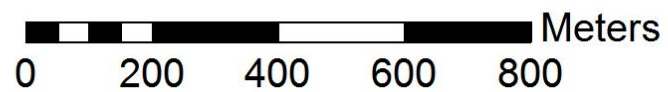
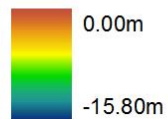


Oyster Pond, Falmouth MA (Core 13)





Oyster, Salt Pond, Sider Bathymetry



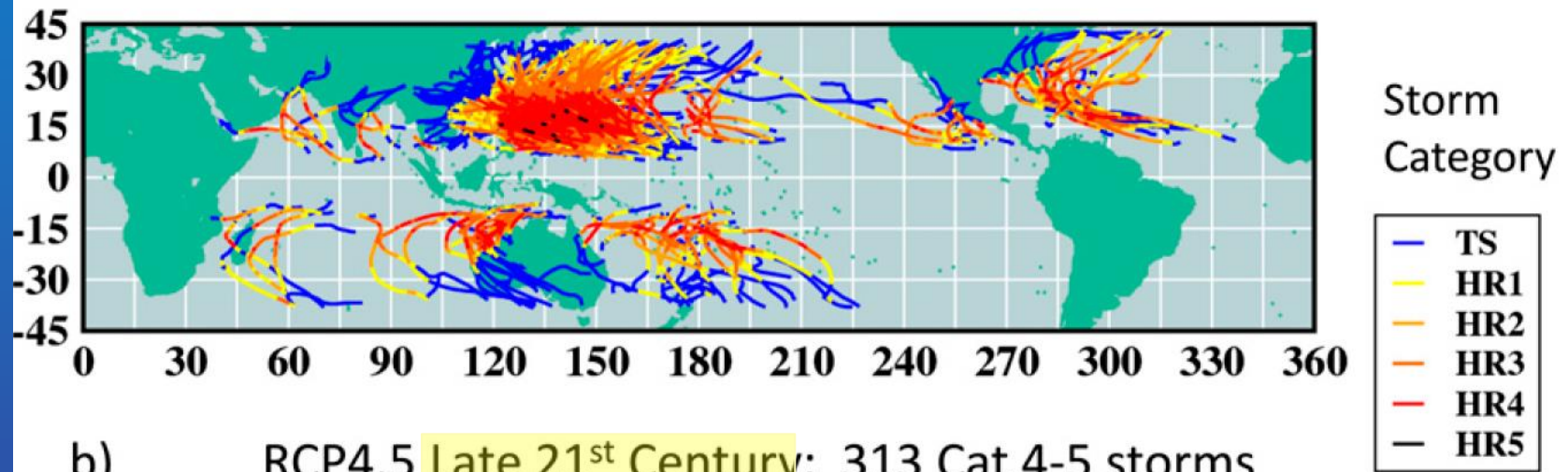
What Might the Future Hold?



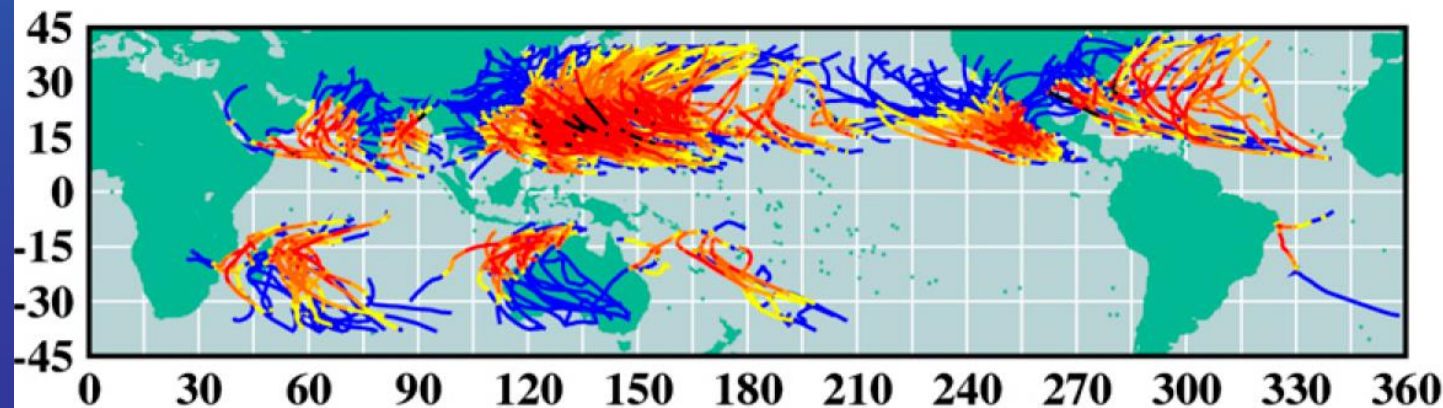
KNUTSON ET AL.

28% increase globally
42% increase in Atlantic

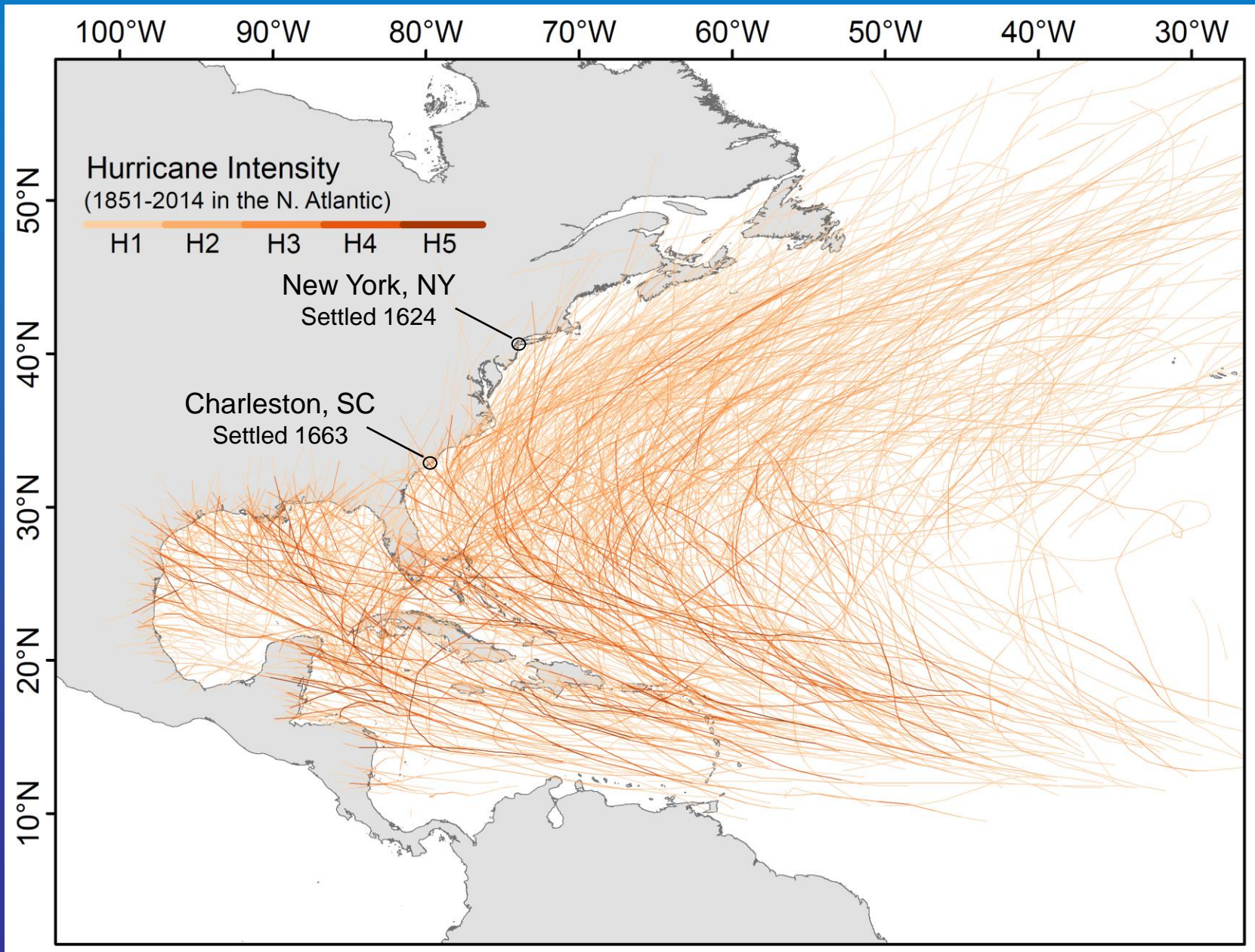
a) **Present Day** Simulation: 244 Cat 4-5 storms



b) **RCP4.5 Late 21st Century**: 313 Cat 4-5 storms



Historical record for some locations goes back much further



Historical Hurricanes



Historical Hurricanes

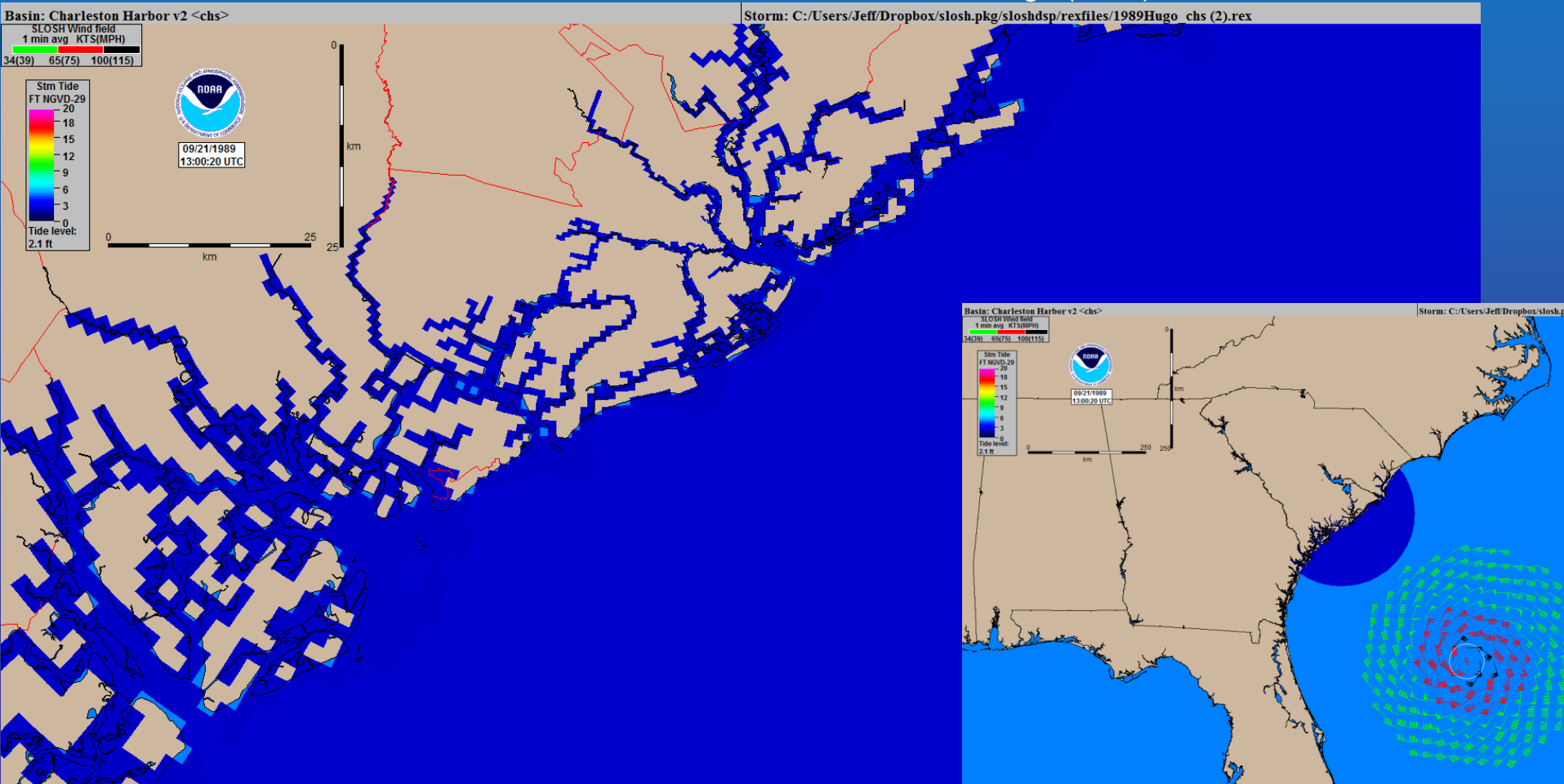


Year
1500 1600 1700 1800 1900 2000 2100

Charleston hurricanes



Hugo (1989)



Historical Hurricanes



Charleston hurricanes

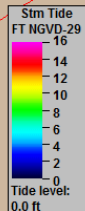


The Great Hurricane of 1752 (September 14)

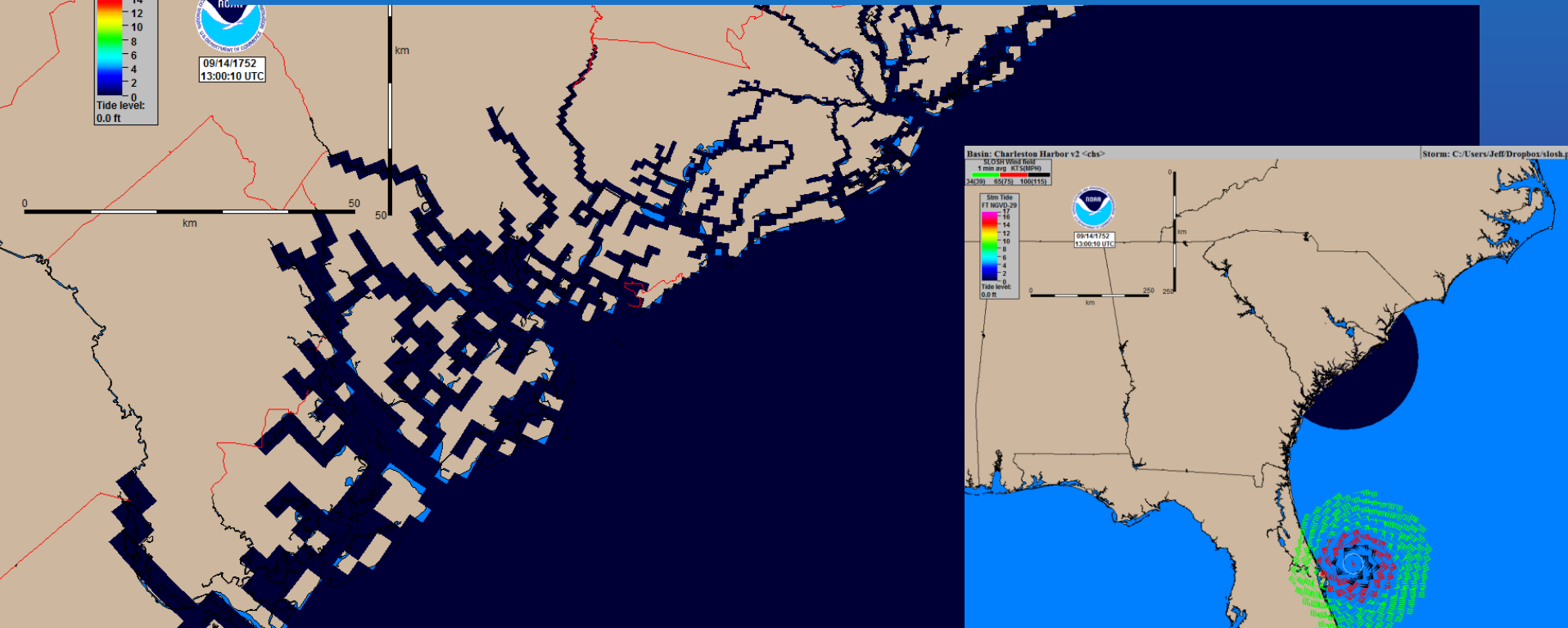
“The town was likewise overflowed, the tide or sea having rose Ten feet above the high-water mark at spring tides...”

“All our roads are so filled with trees blown and broke down...”

Basin: Charleston Harbor v2 <chs>
SLOSH Wind field
1 min avg KTS(MPH)
04(39) 65(75) 100(115)

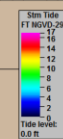


09/14/1752
13:00:10 UTC

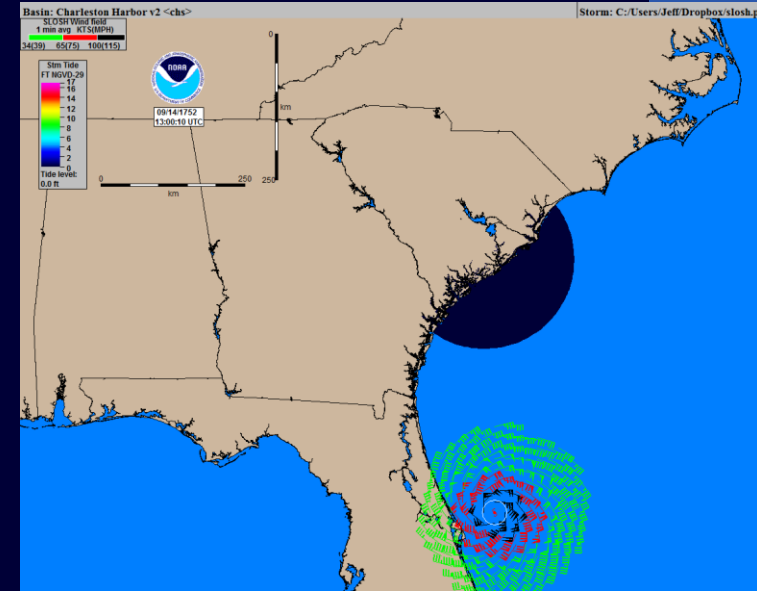


Basin: Charleston Harbor v2 <chs>

SLOSH Wind field
1 min avg KTS(MPH)
25(39) 65(75) 100(115)



09/14/1752
13:00:10 UTC



Historical Hurricanes



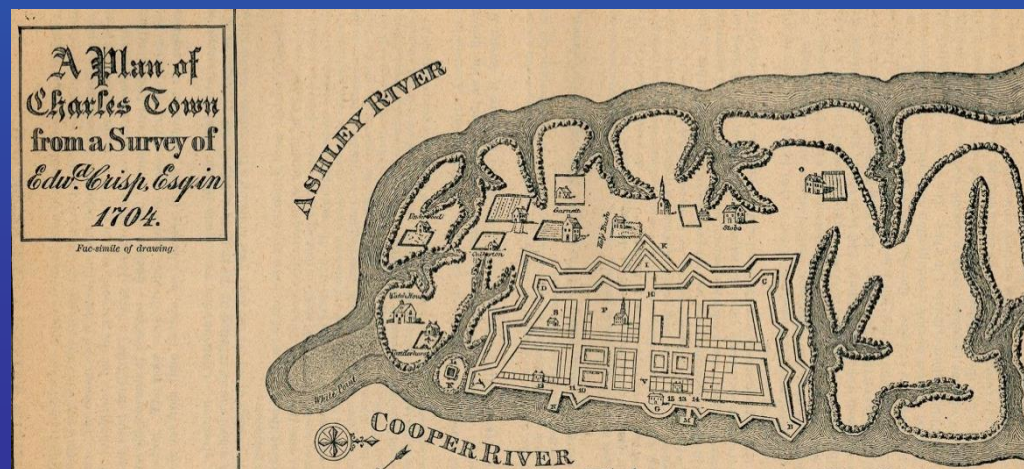
The Spanish Repulse Hurricane of 1686 (September 4)

Thwarted Spanish Invasion from Saint Augustine

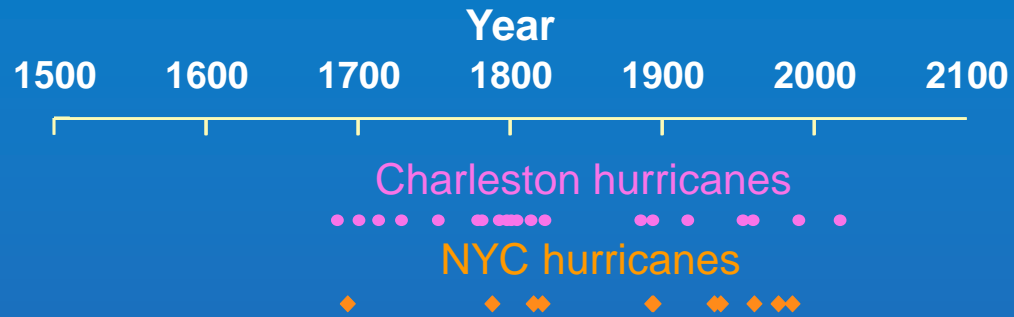
“All the ships and vessels in the road and harbors were driven up on land...”

“In some places for 3 or 4 miles together there is scarce one great tree standing.”

“The Indians told the English that they knew of one that raised the water over the tops of trees where the town now stands.”



Historical Hurricanes



Historical Hurricanes



Year
1500 1600 1700 1800 1900 2000 2100

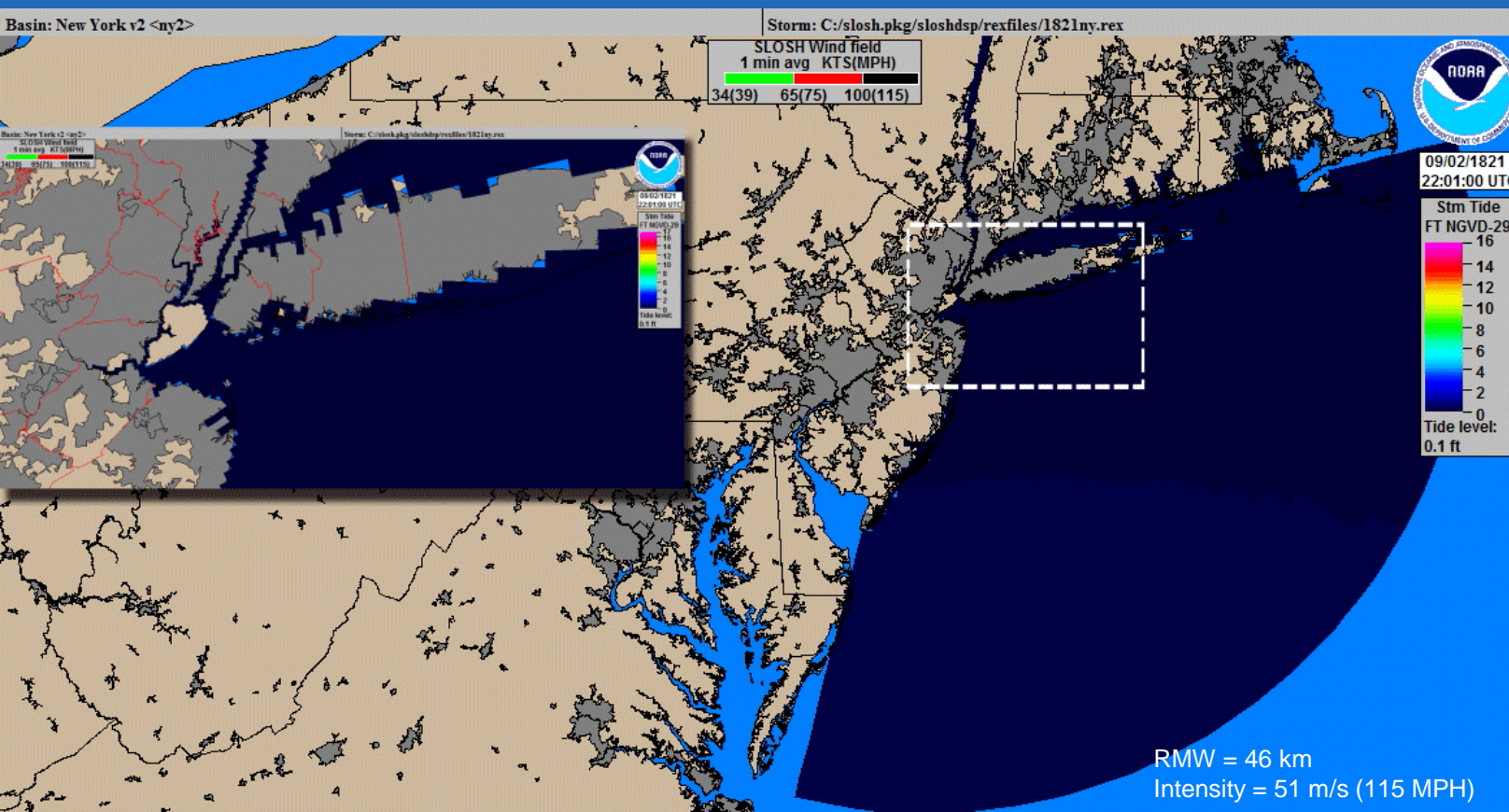
Charleston hurricanes

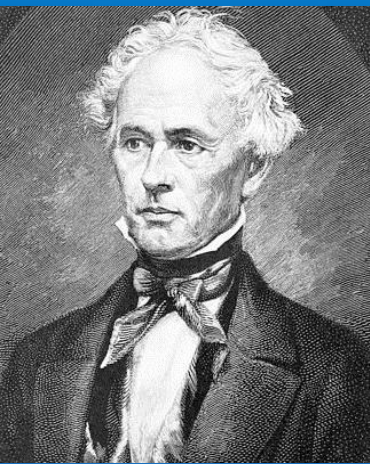


NYC hurricanes



1821 Hurricane



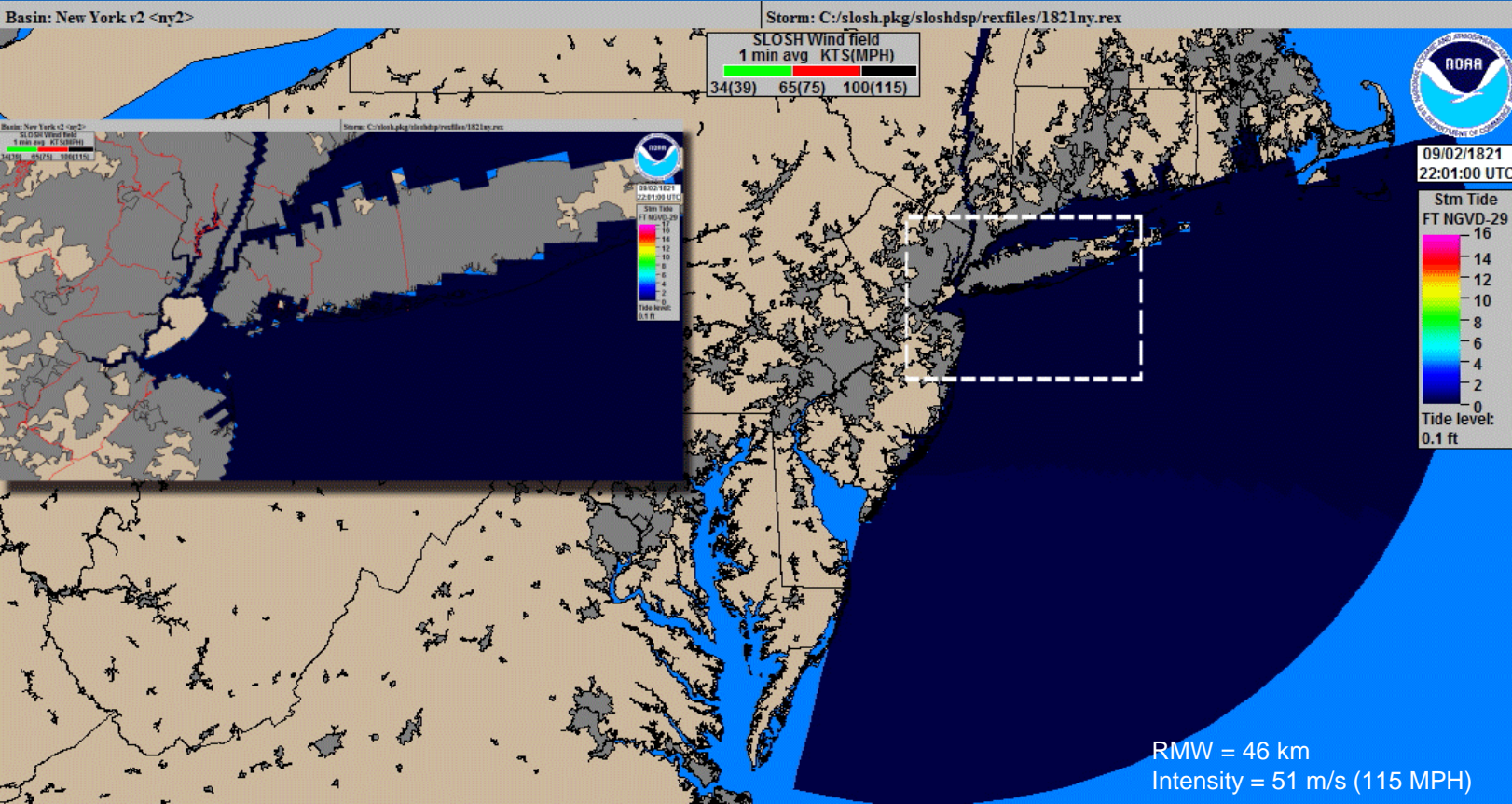


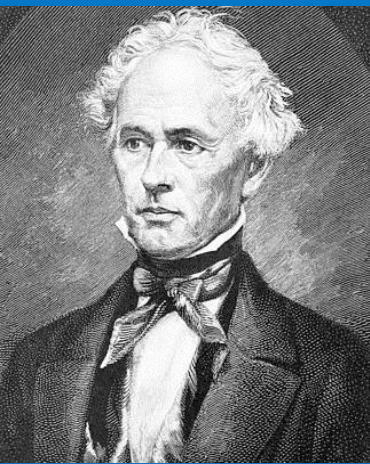
William C. Redfield
1789-1857

Historical Hurricanes



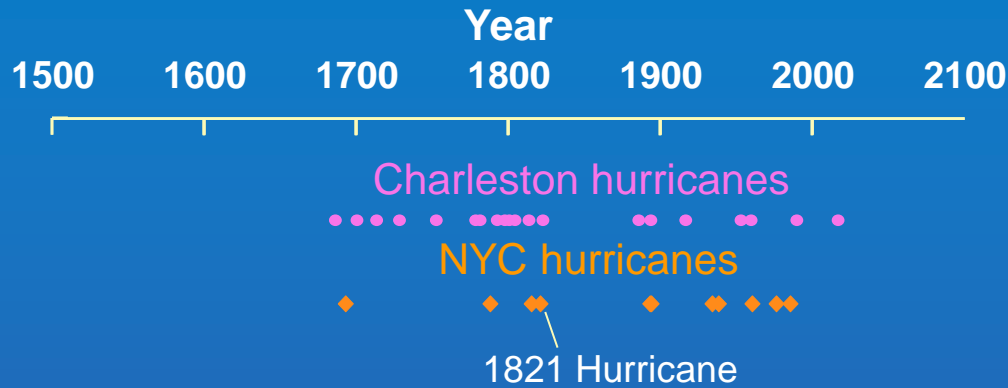
Year
1500 1600 1700 1800 1900 2000 2100





William C. Redfield
1789-1857

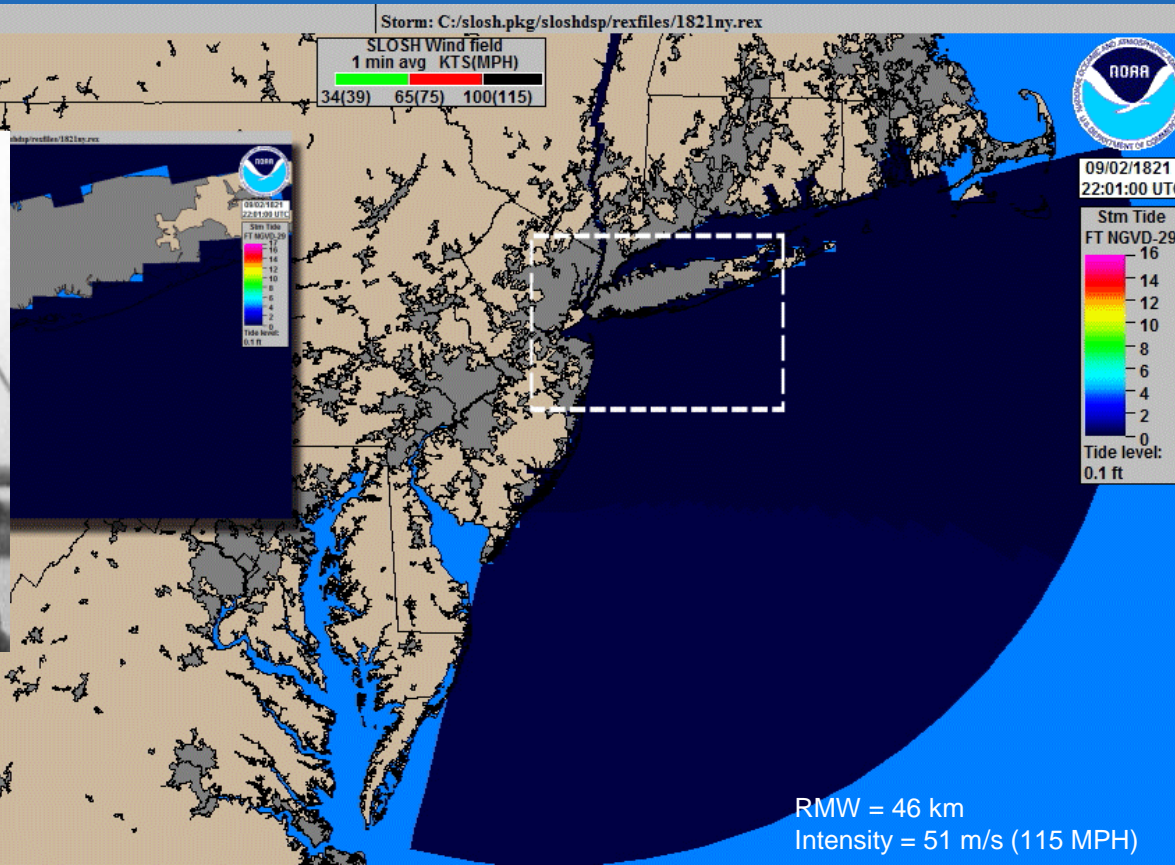
Historical Hurricanes



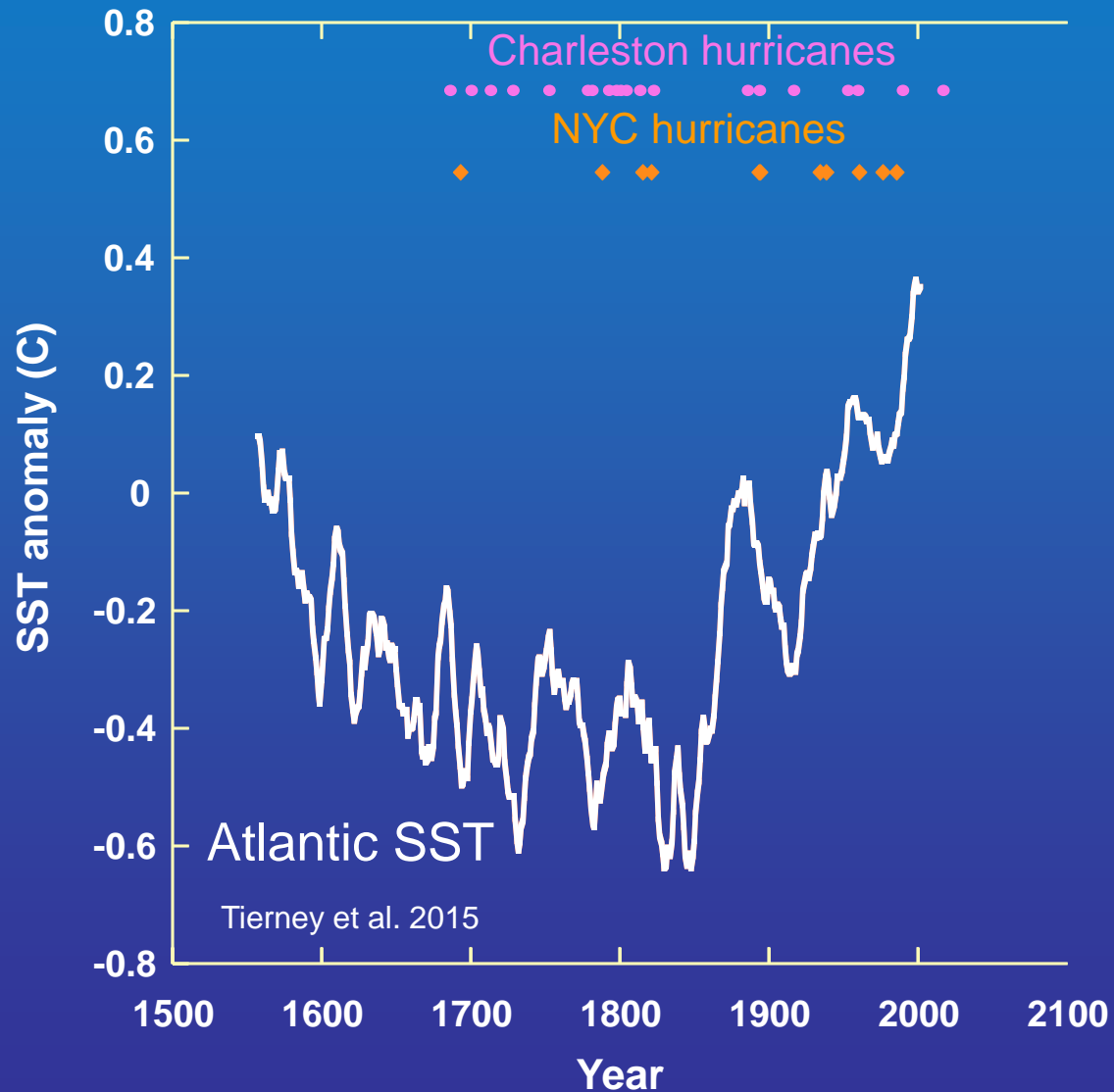
Basin: New York v2 <ny2>



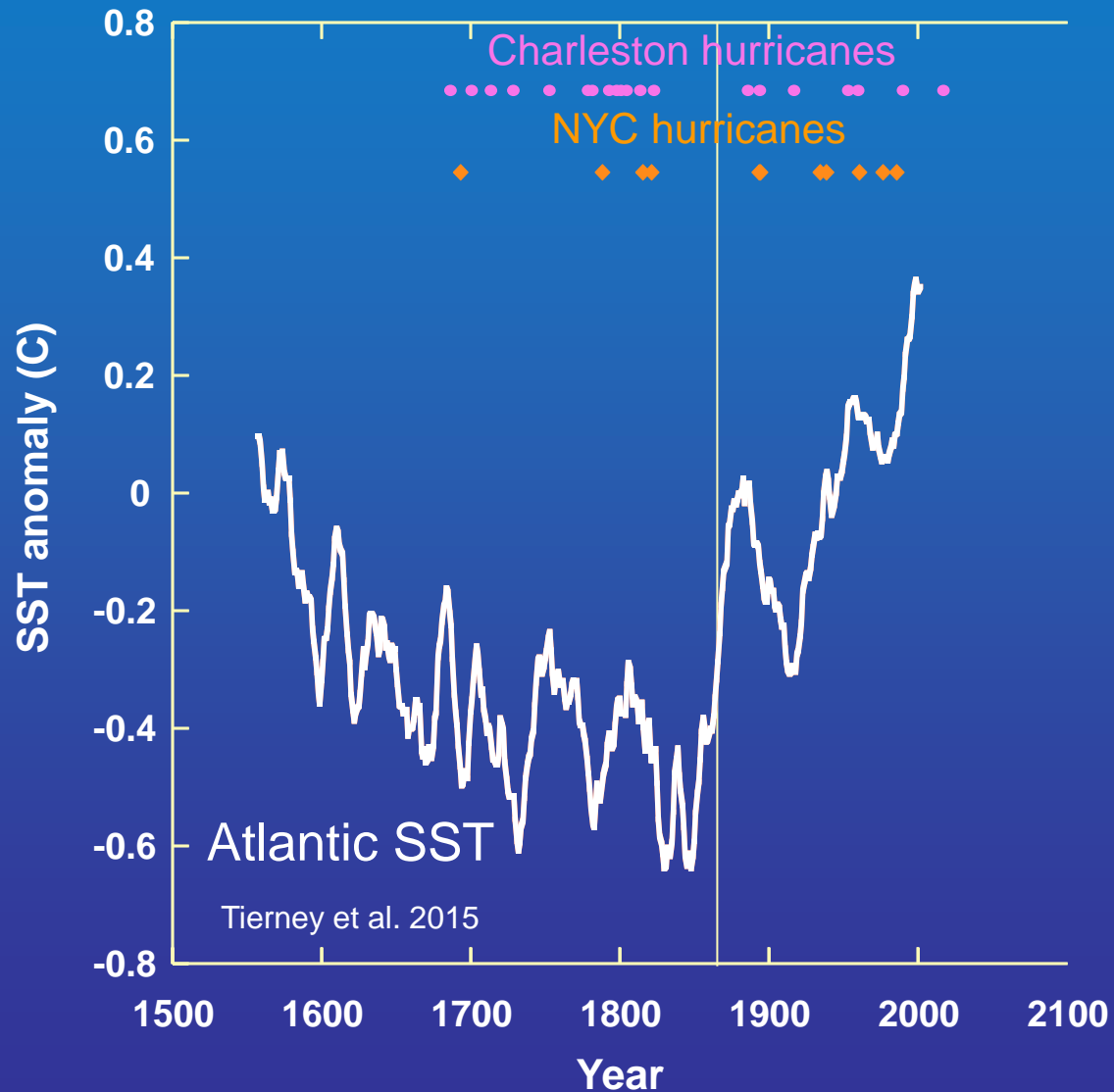
Alfred C. Redfield
1890-1983



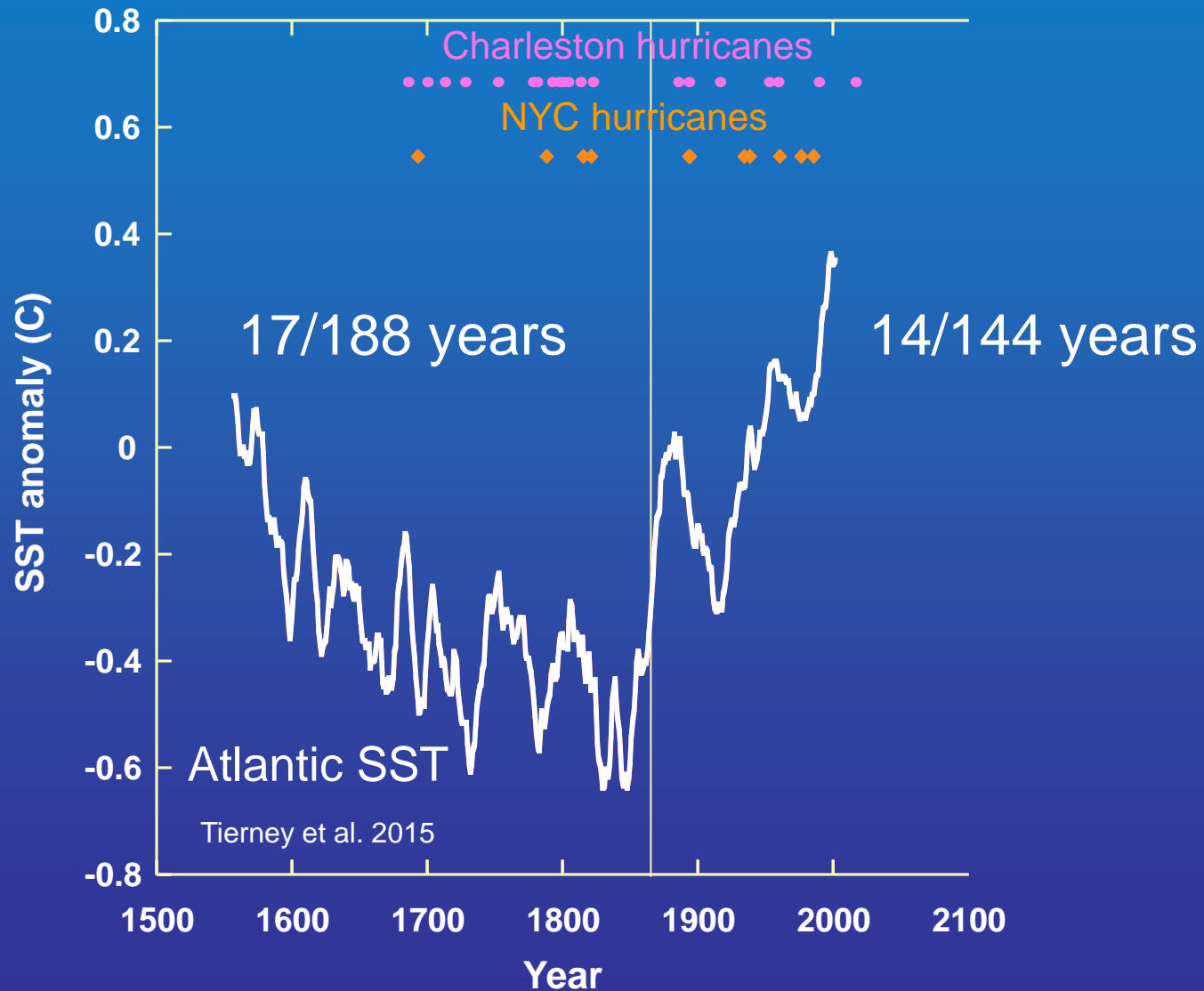
Historical Hurricanes and Sea Surface Temperature



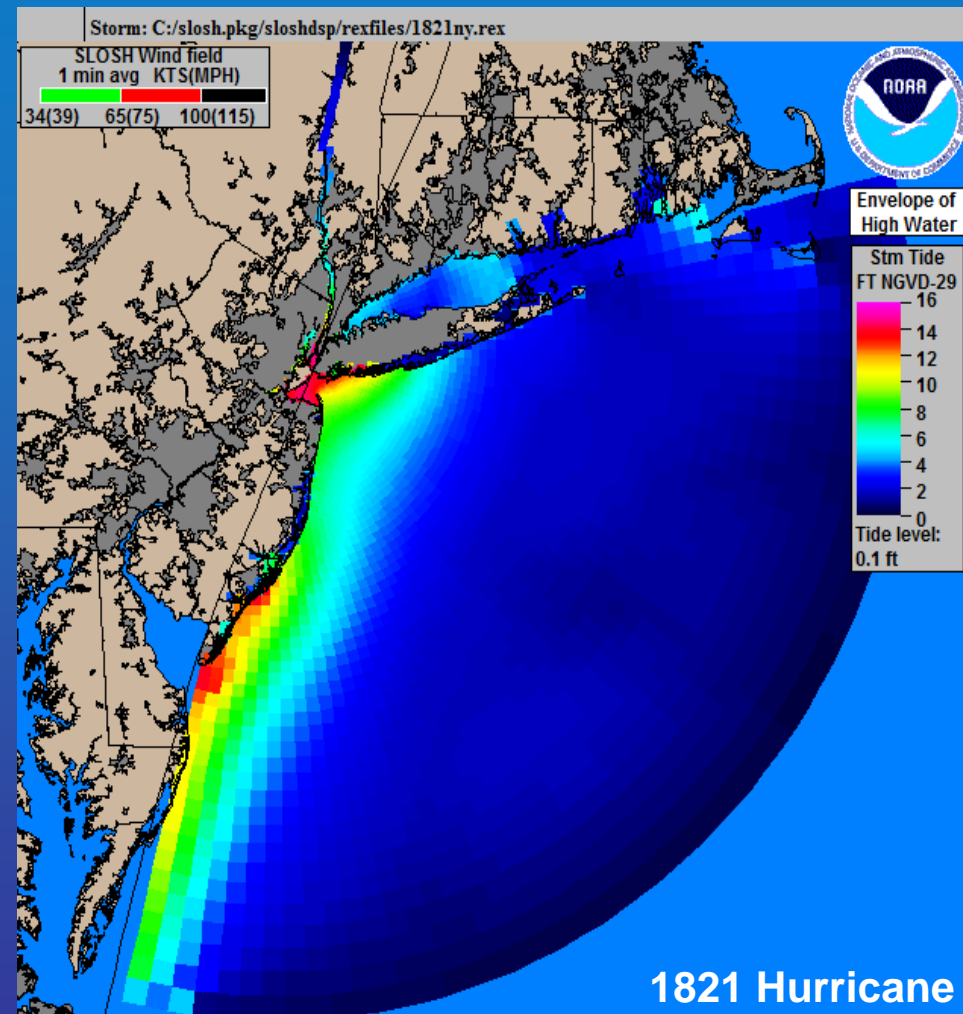
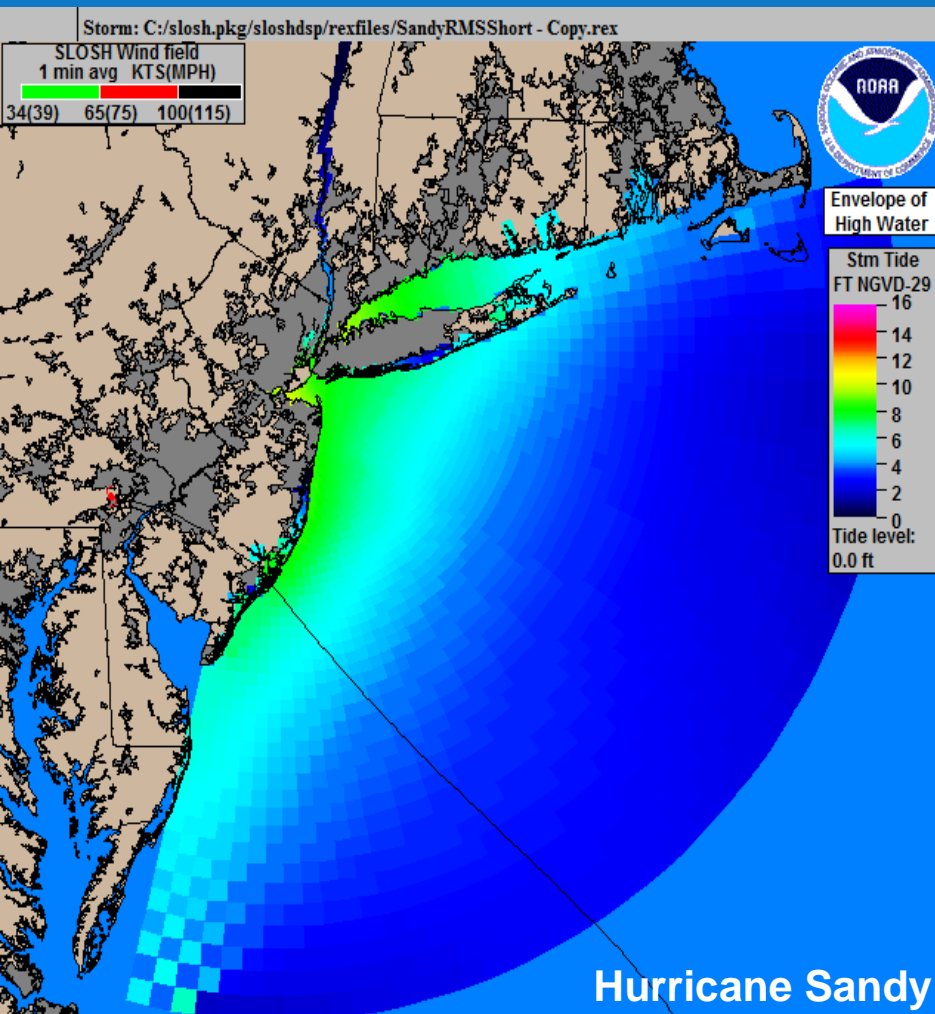
Historical Hurricanes and Sea Surface Temperature



Historical Hurricanes and Sea Surface Temperature



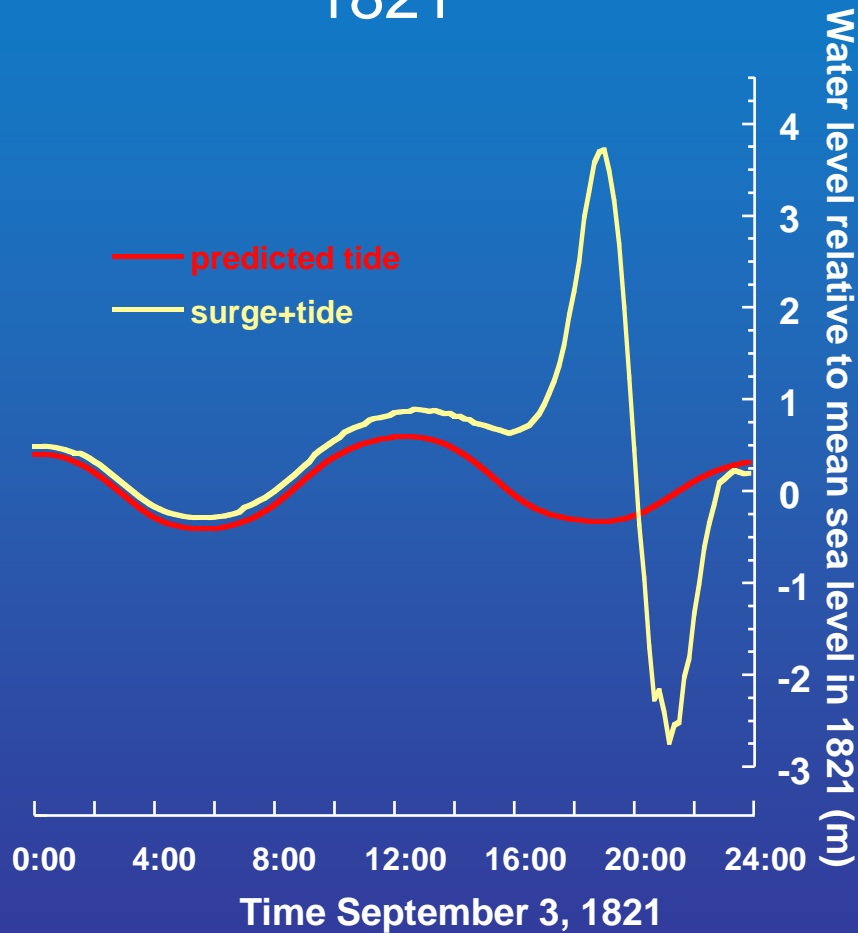
1821 Hurricane vs. Sandy



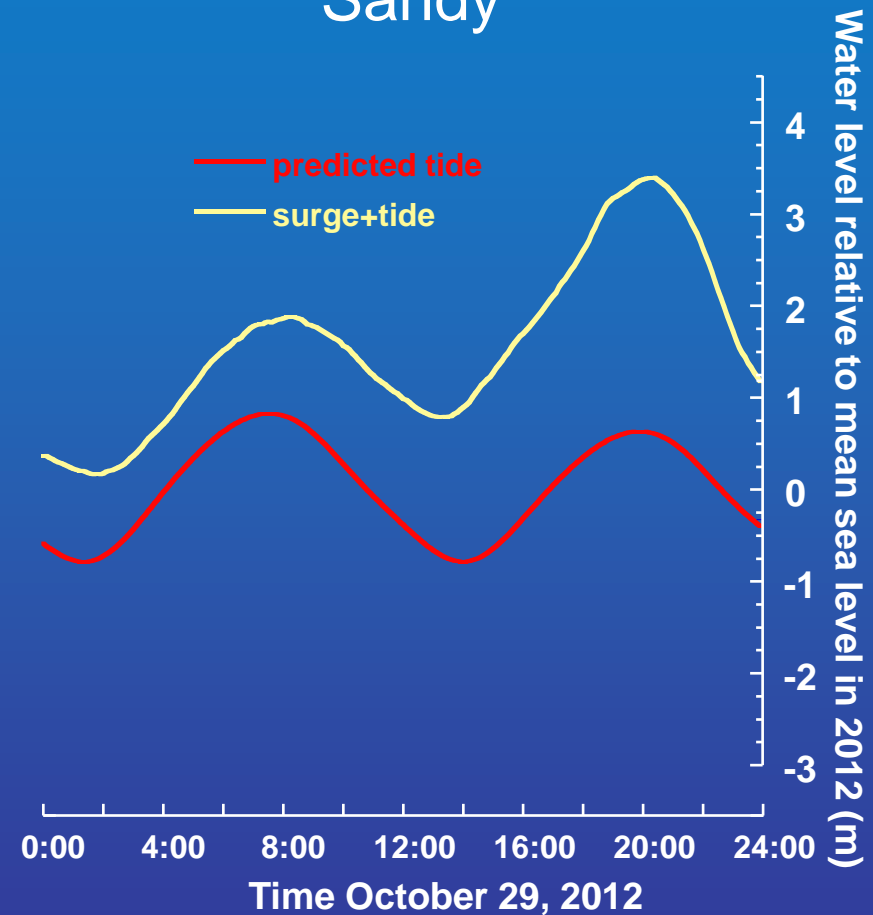
1821 Hurricane vs. Sandy in NYC



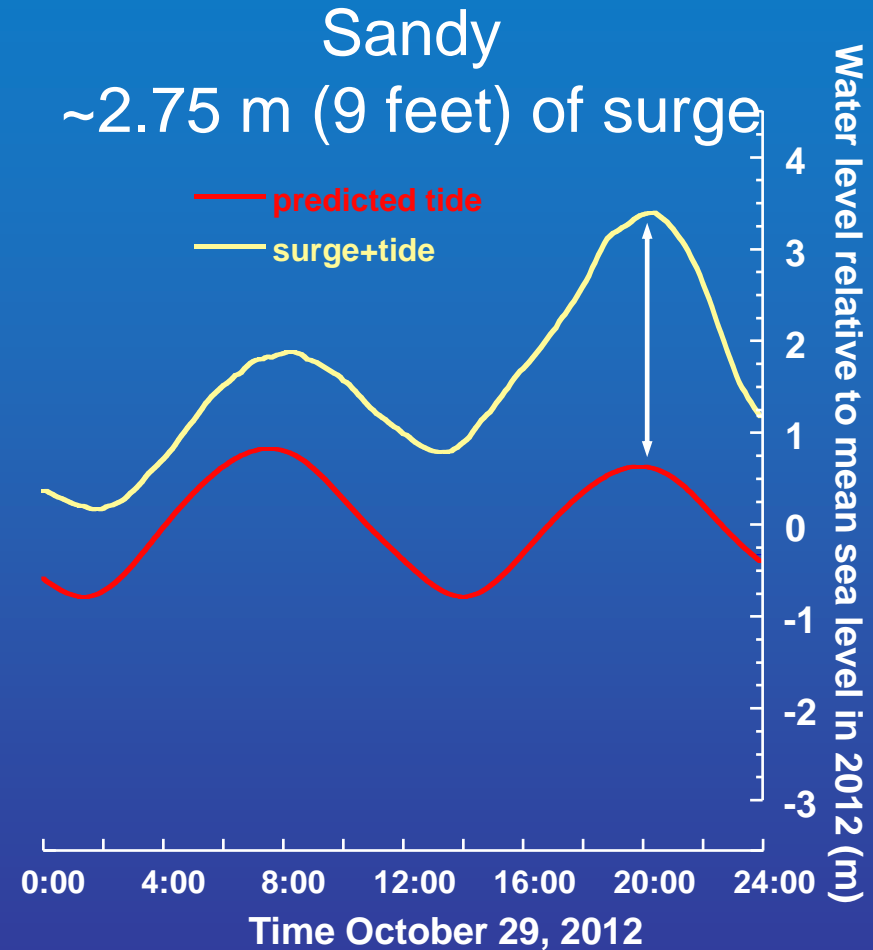
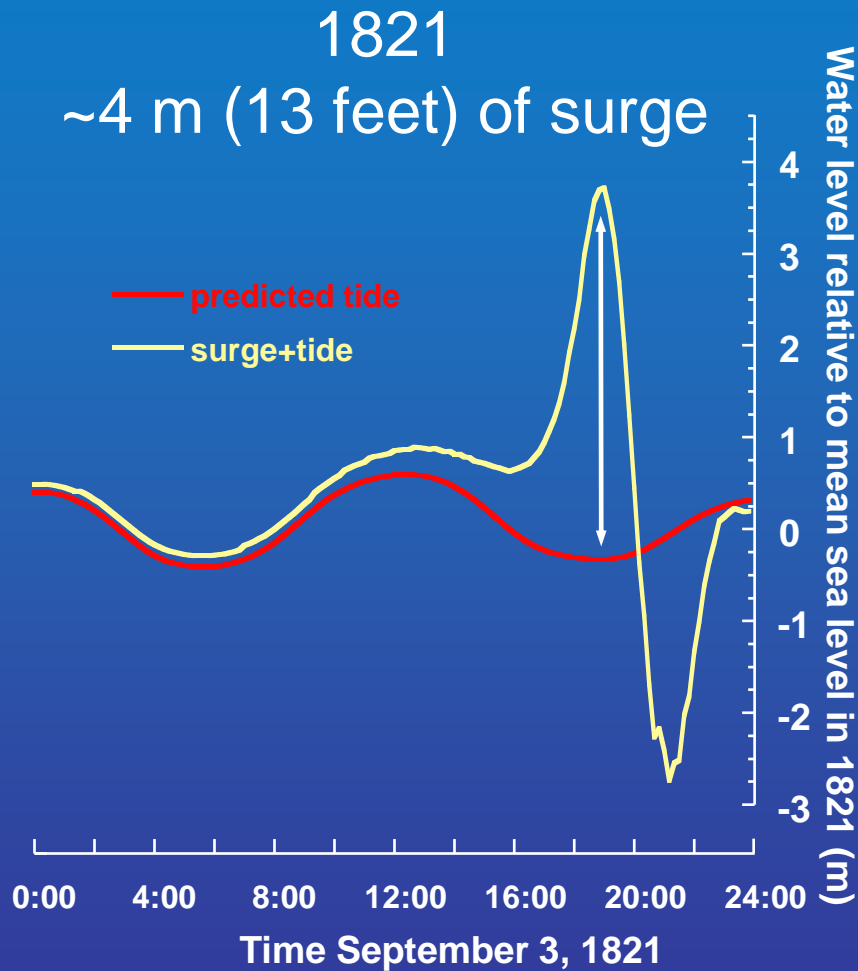
1821



Sandy



1821 Hurricane vs. Sandy in NYC



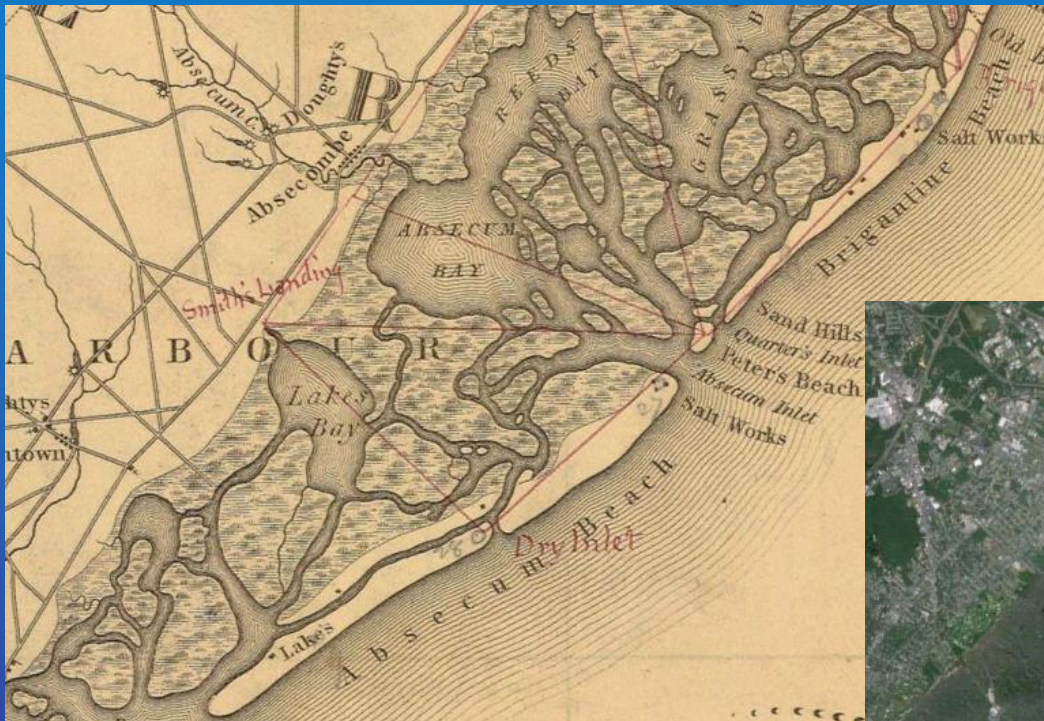
Why so much damage from Sandy?



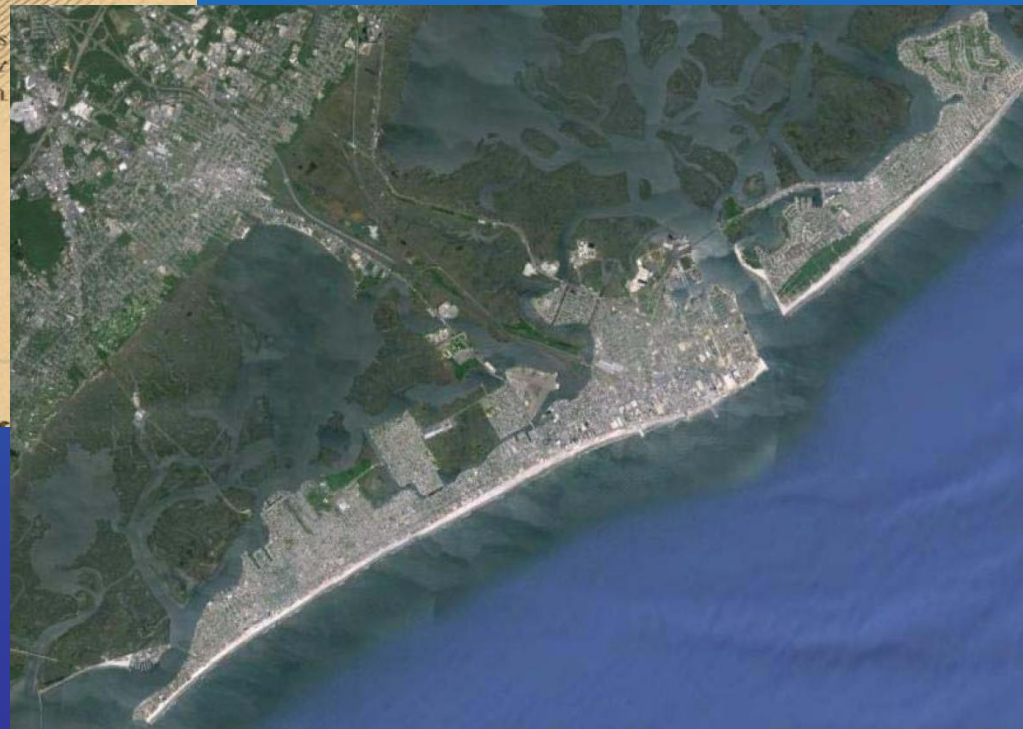
Why so much damage from Sandy?



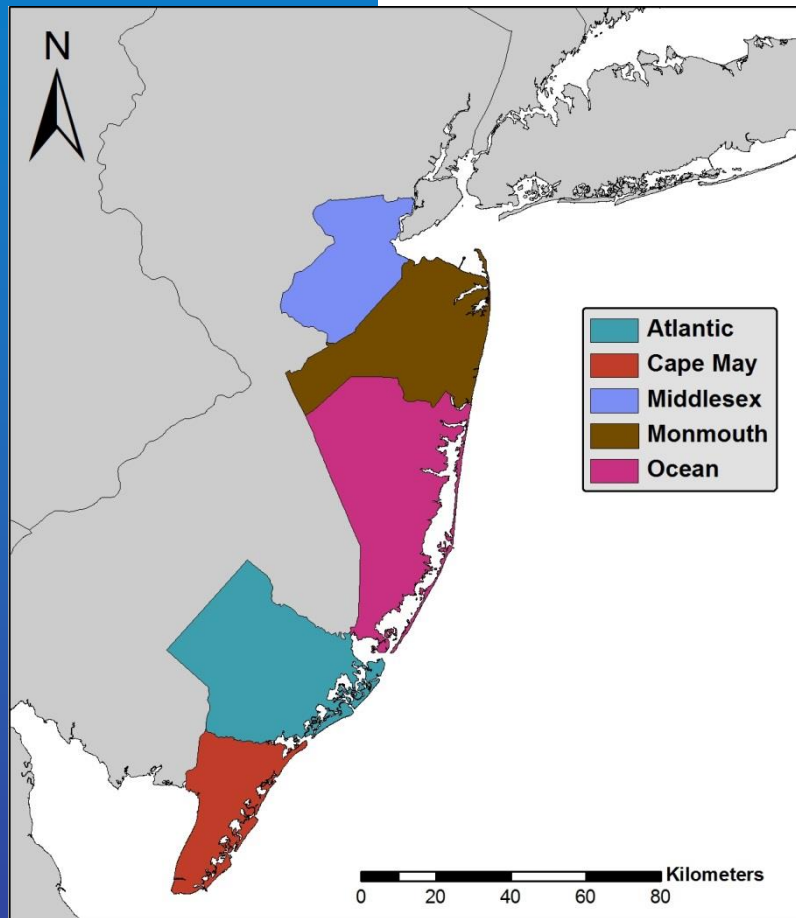
Future home of
Atlantic City (ca. 1833)



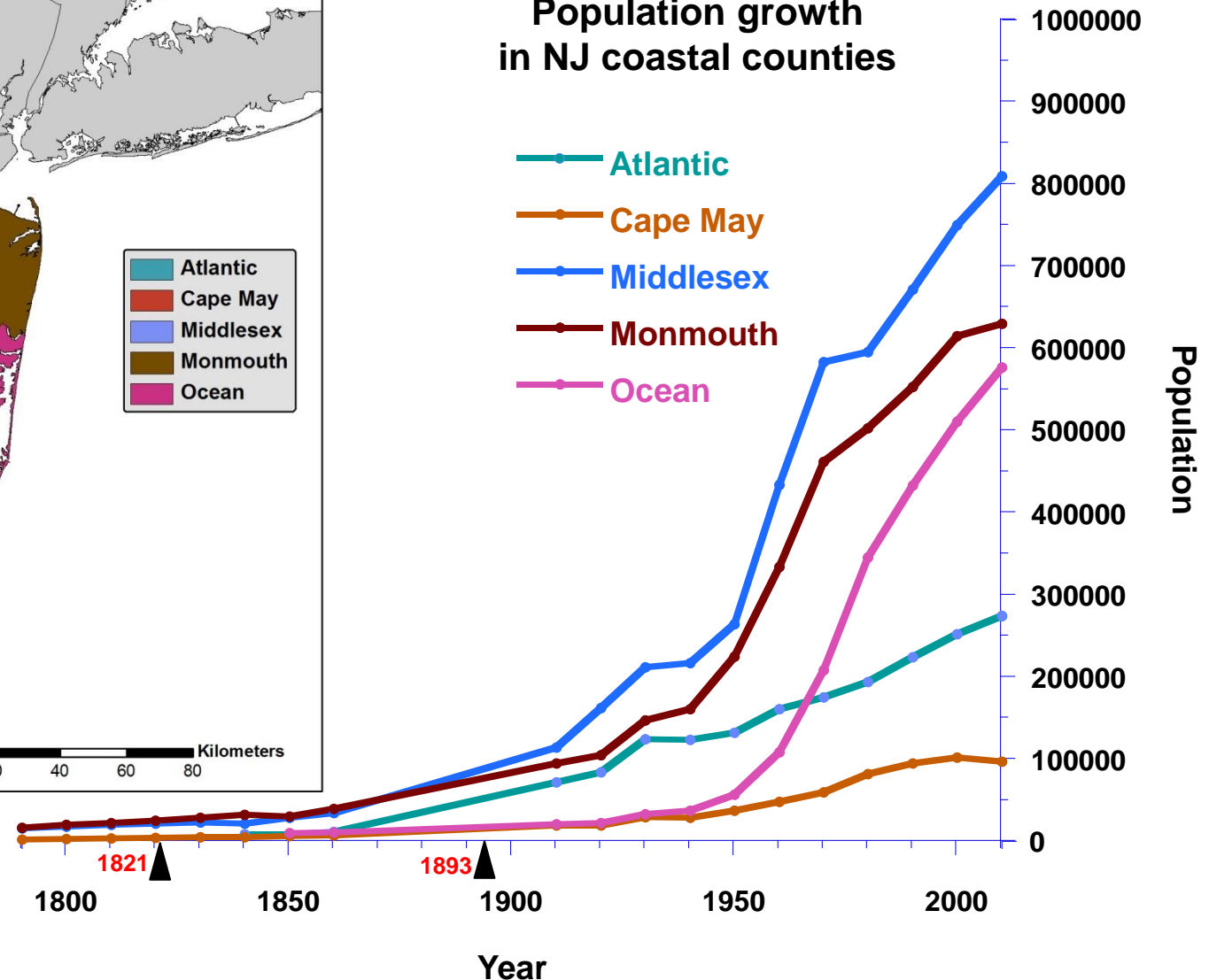
today



Why so much damage from Sandy?

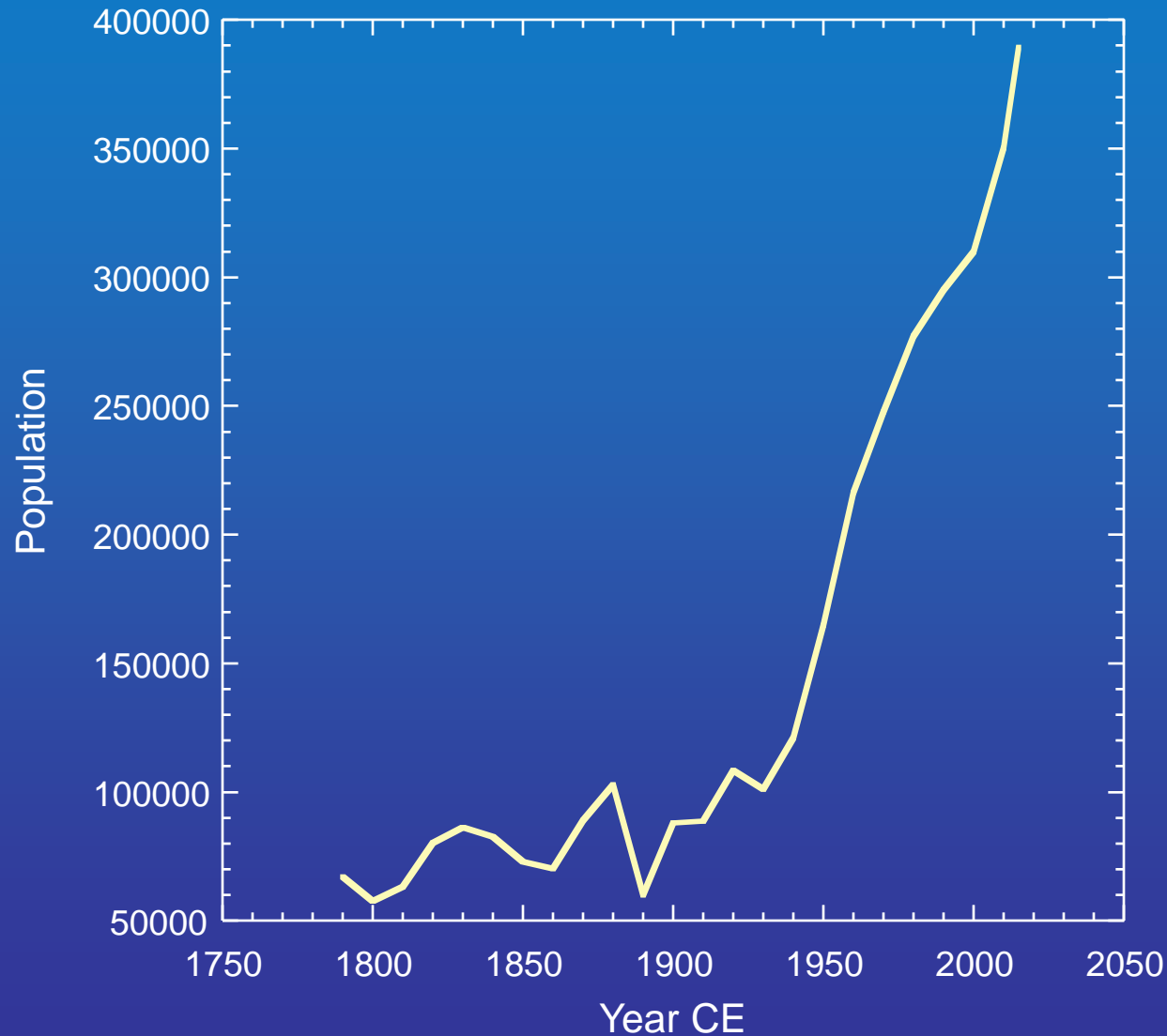


Population growth
in NJ coastal counties

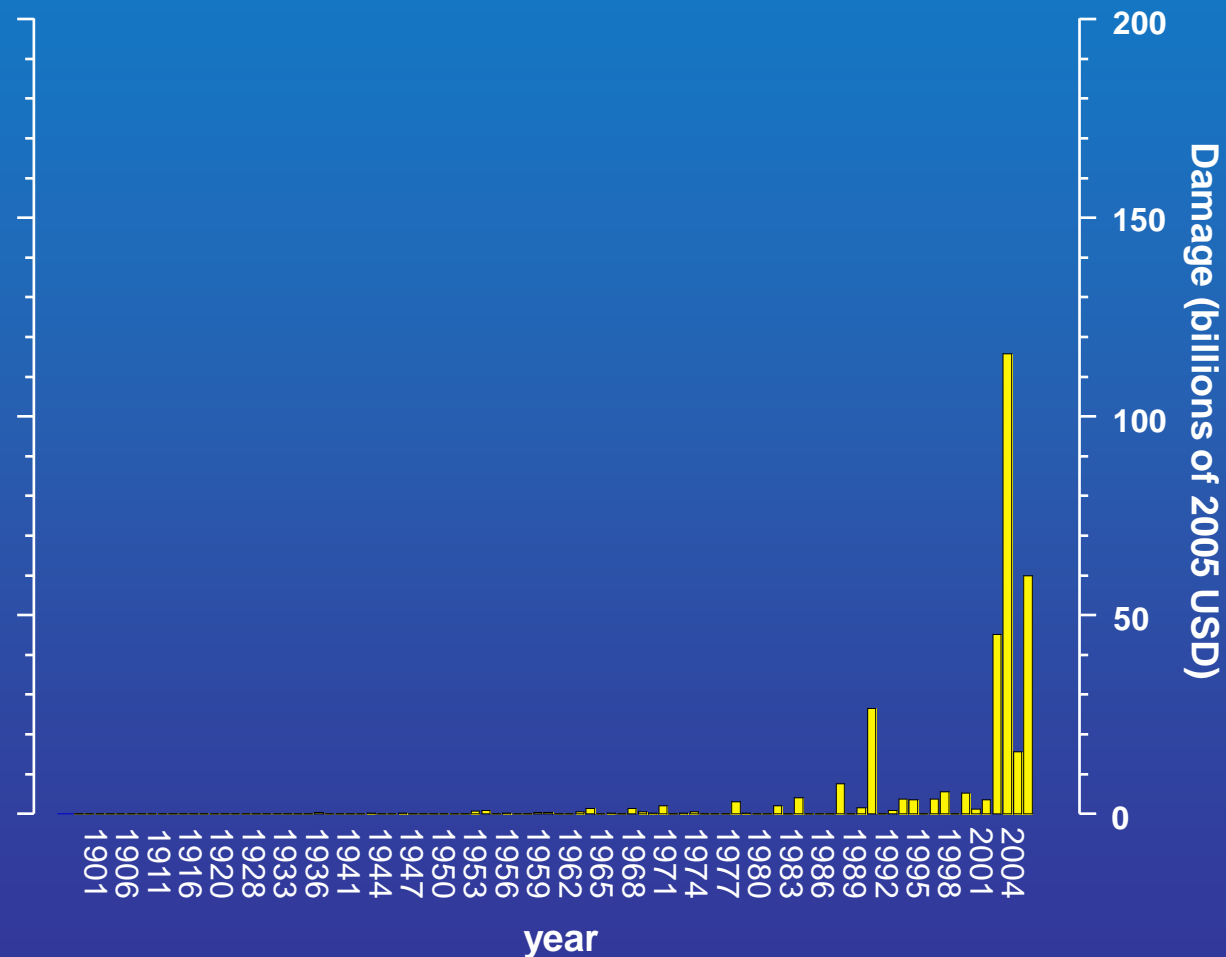


Source: New Jersey Department of Labor and Workforce Development

Charleston County, SC Population



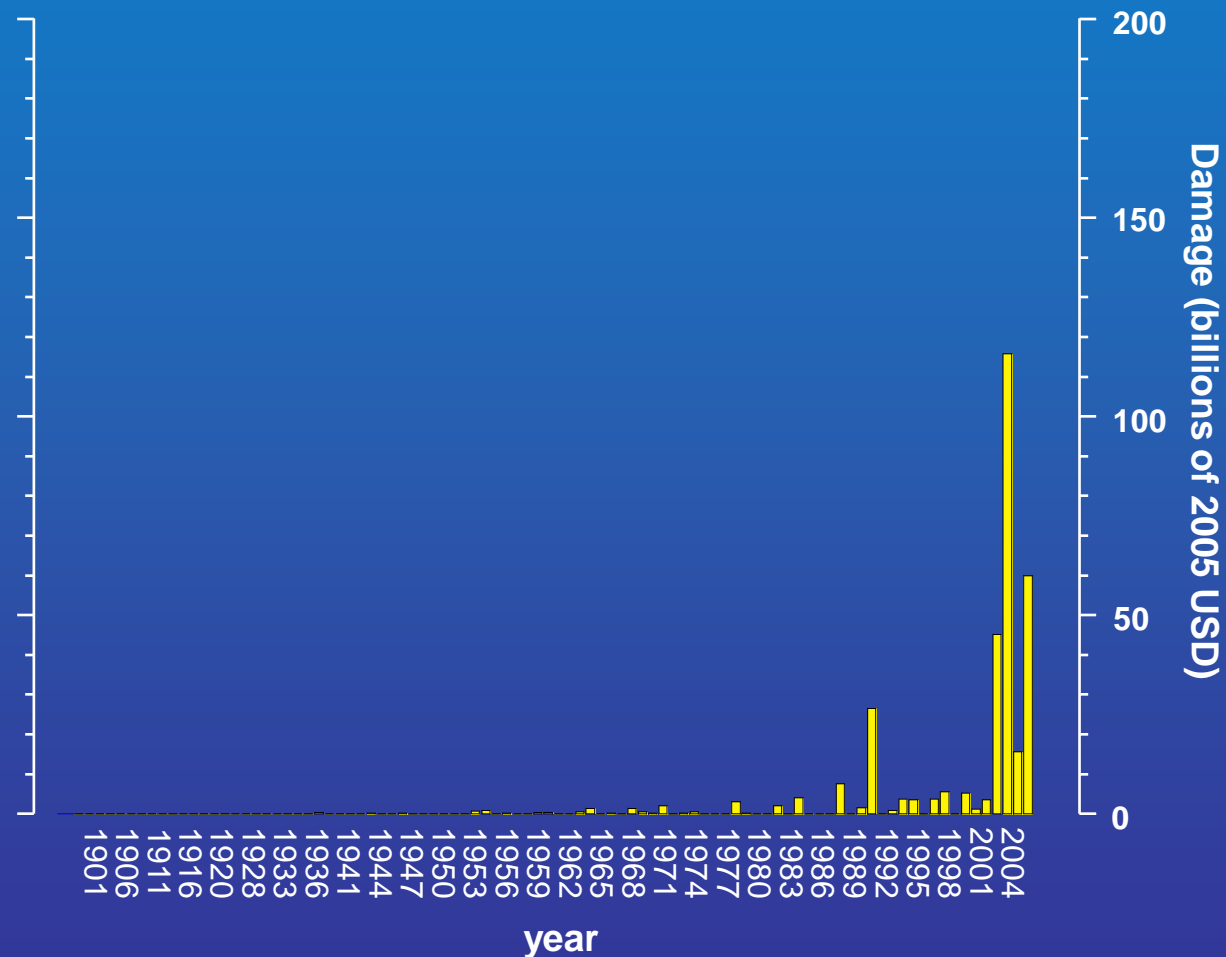
1900-2013 US Hurricane Damage in 2005 USD



1900-2013 US Hurricane Damage in 2005 USD



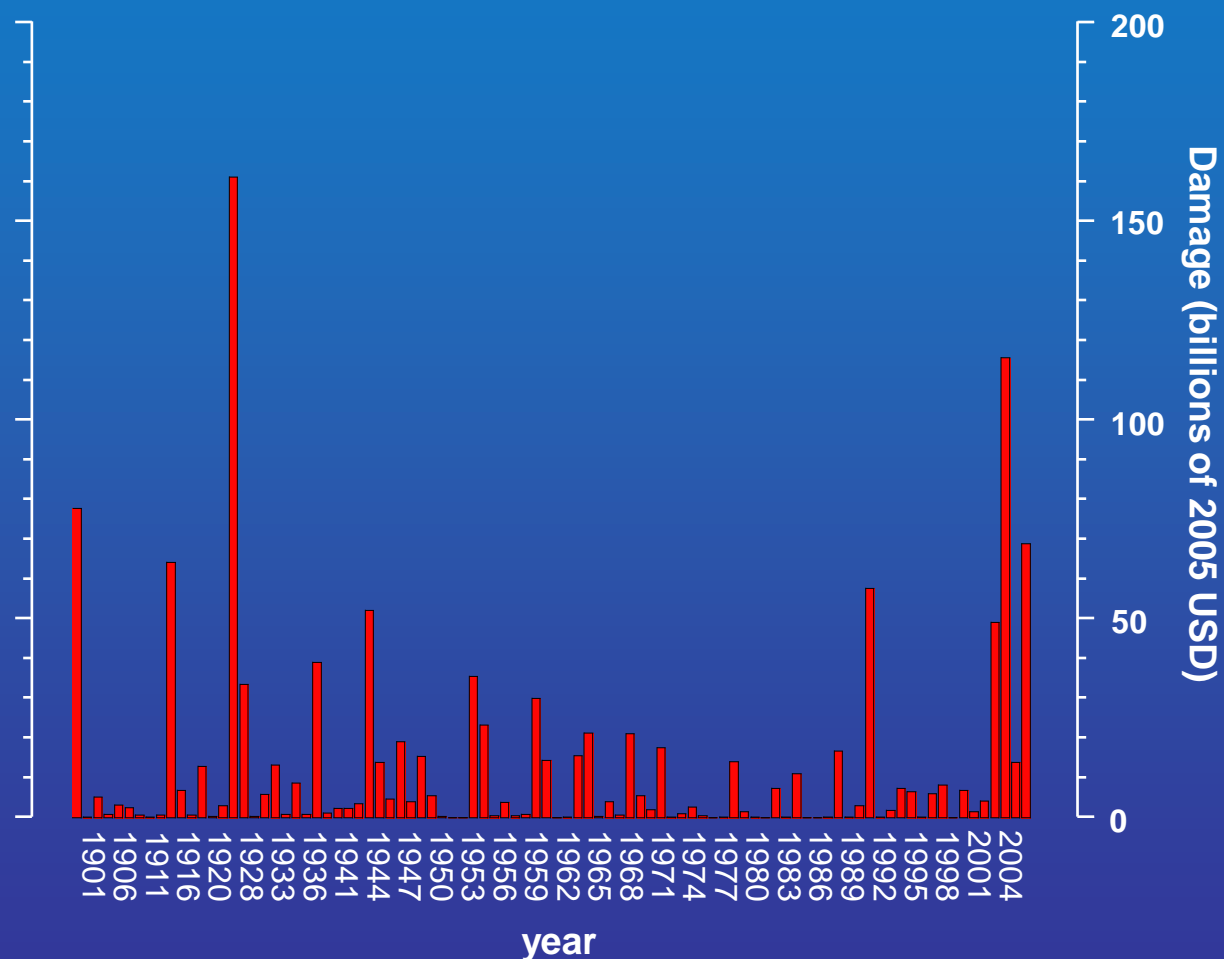
But what if these storms were to strike today?



1900-2013 US Hurricane Damage in 2005 USD



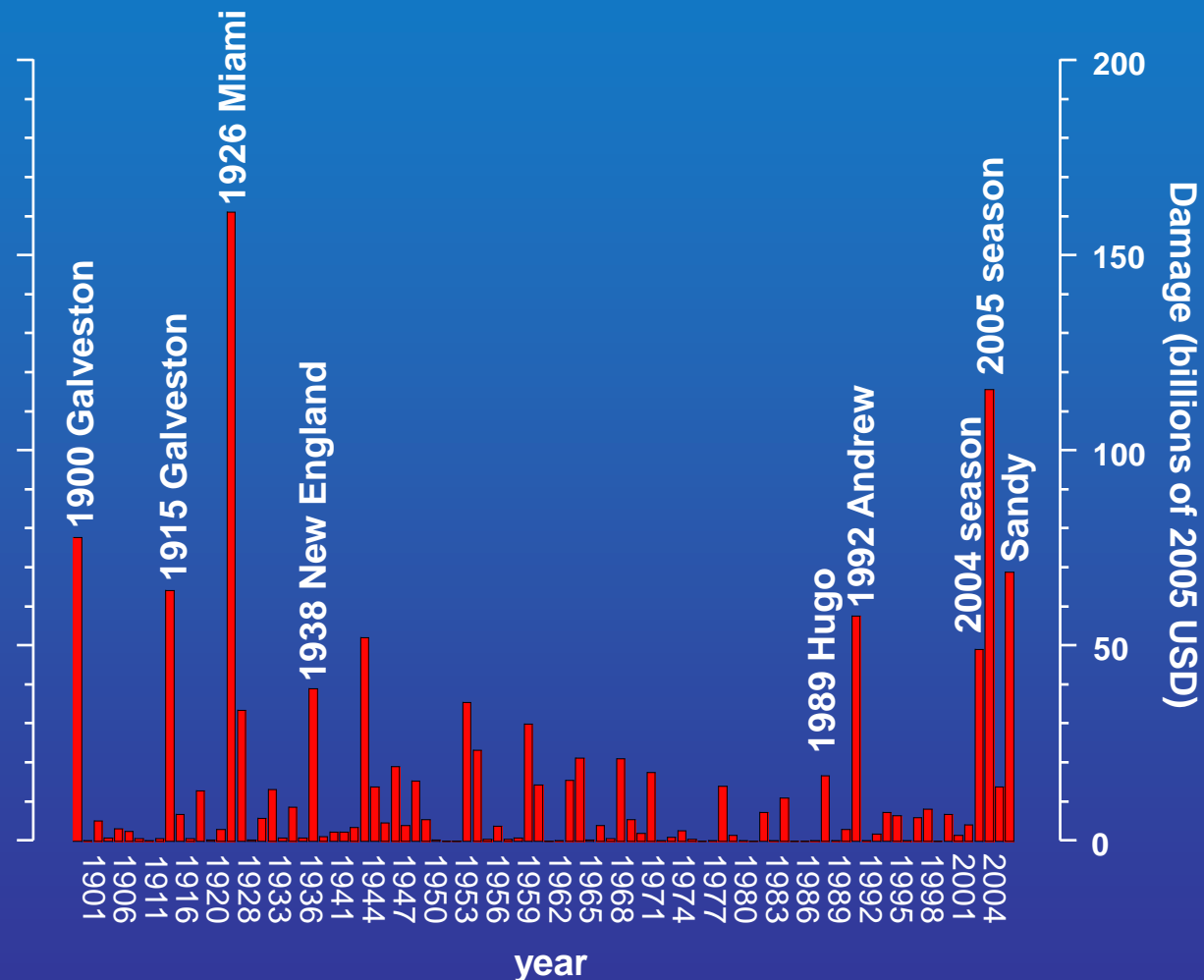
Damage accounting for increased wealth and population



1900-2013 US Hurricane Damage in 2005 USD



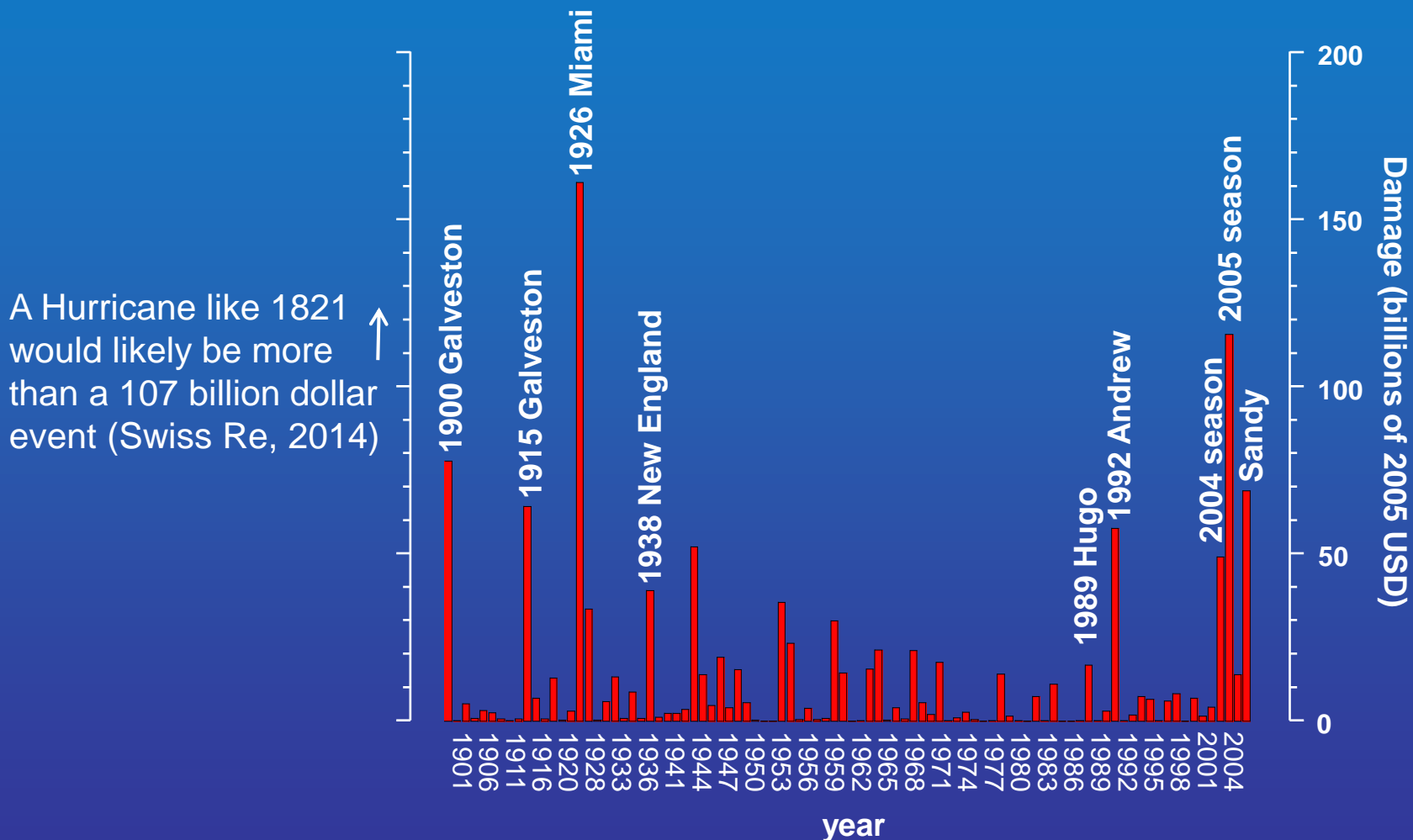
Damage accounting for increased wealth and population



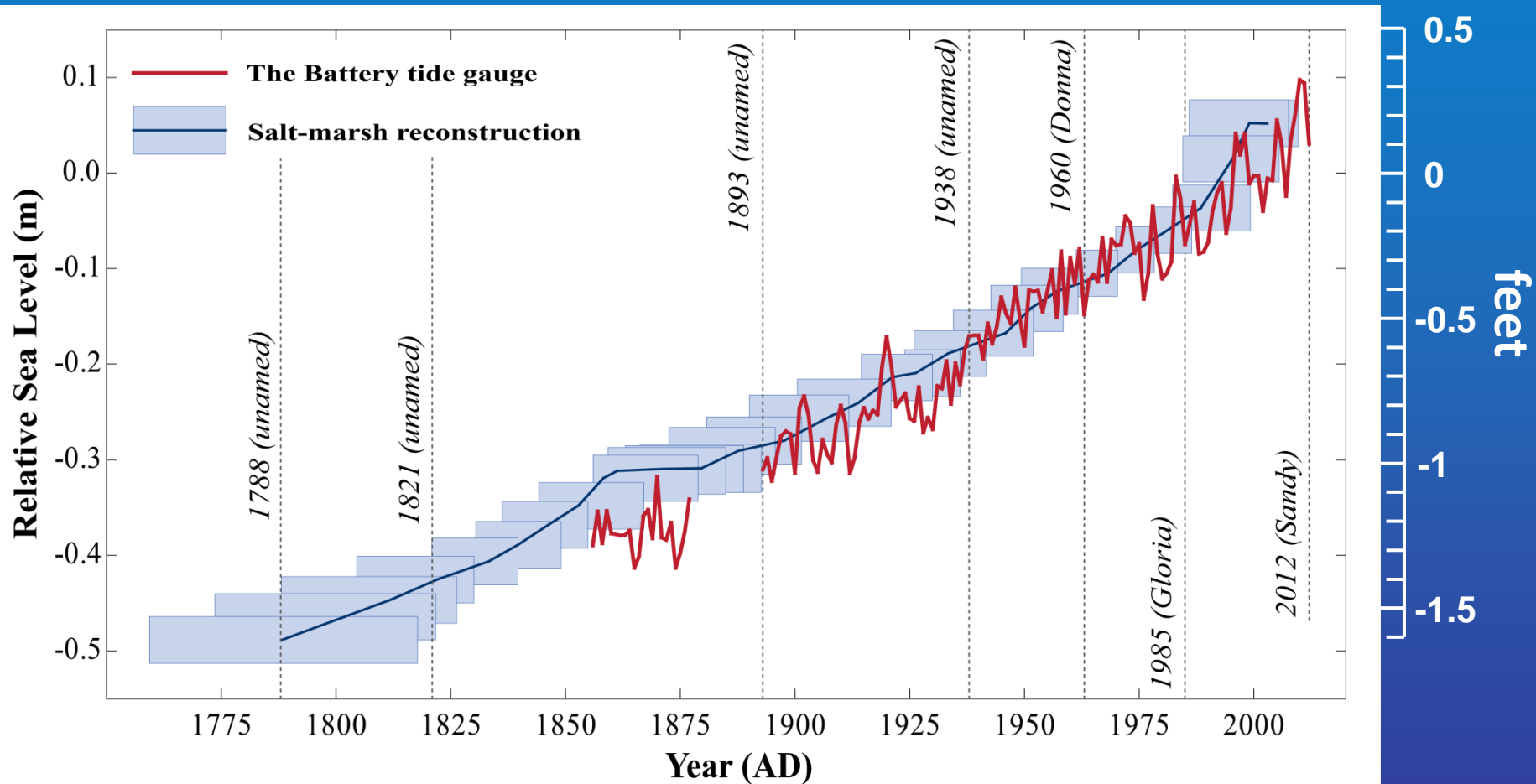
1900-2013 US Hurricane Damage in 2005 USD



Damage accounting for increased wealth and population



Sea-Level Rise



From Kemp and Horton, 2013 *Journal of Quaternary Science*

Hurricane Records from Blue Holes



Hurricane Records from Blue Holes



Record from South Andros Bahamas



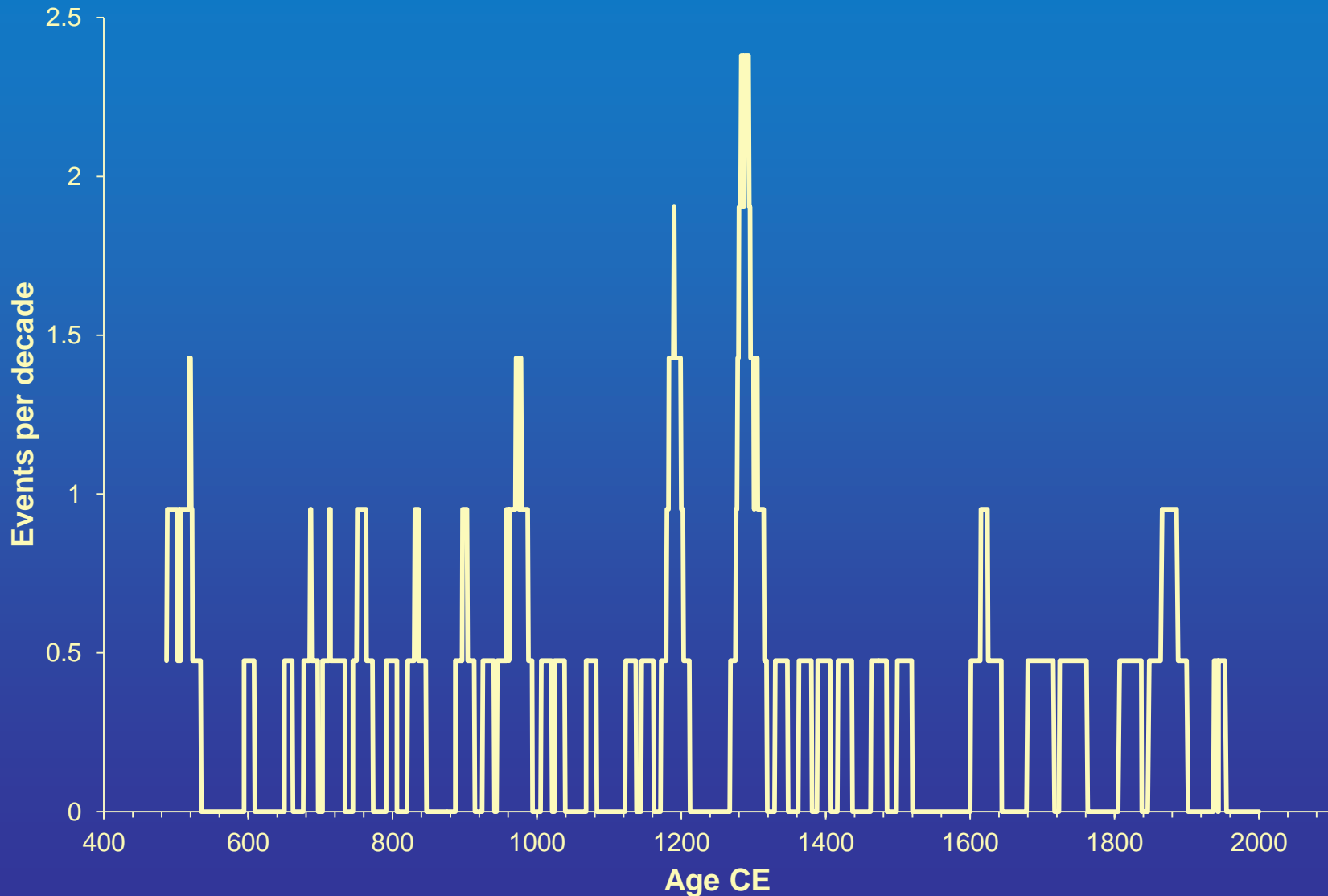
Hurricane Event Bed



Record from South Andros Bahamas



South Andros, Bahamas - Event Frequency (>6%)



What we don't know



What we don't know



- What are the drivers of changes in hurricane activity?
What climatic conditions combined to yield intervals of hurricane hyperactivity in the past?

What we don't know



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What climatic conditions combined to yield intervals of hurricane hyperactivity in the past?
- Will our future climate also yield similar climate states?

What we don't know



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- Does the maximum intensity of hurricanes change with climate change?

What we don't know



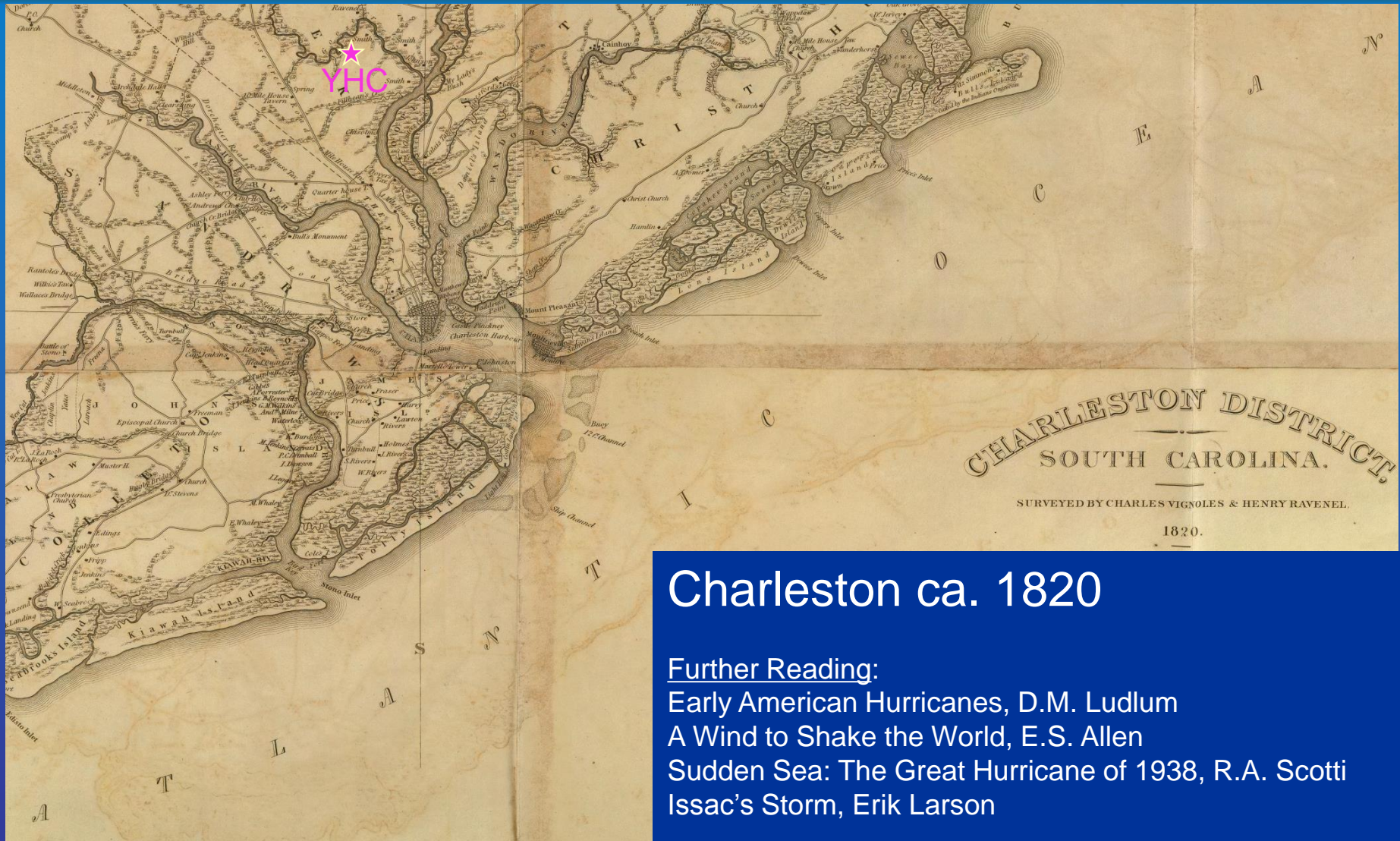
- What are the drivers of changes in hurricane activity?
What climatic conditions combined to yield intervals of hurricane hyperactivity in the past?
- Will our future climate also yield similar climate states?
- Does the maximum intensity of hurricanes change with climate change?
- What are the implications of changes in hurricane activity for coastal landforms, ecosystems, and humanity?

The negative 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.

The negative 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.

The good news is we have many tools to mitigate the impacts of hurricanes. And they no longer take us by surprise because of our excellent forecasting and monitoring abilities and capacity for communication.

Thank you!



Charleston ca. 1820

Further Reading:

Early American Hurricanes, D.M. Ludlum

A Wind to Shake the World, E.S. Allen

Sudden Sea: The Great Hurricane of 1938, R.A. Scotti

Issac's Storm, Erik Larson

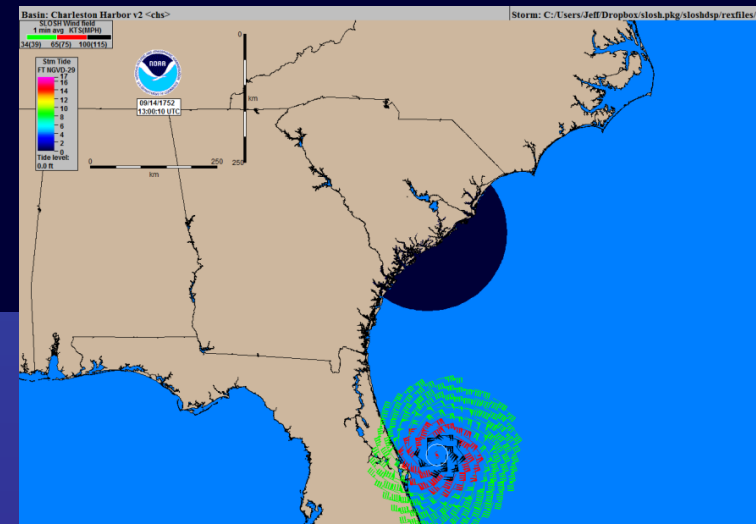
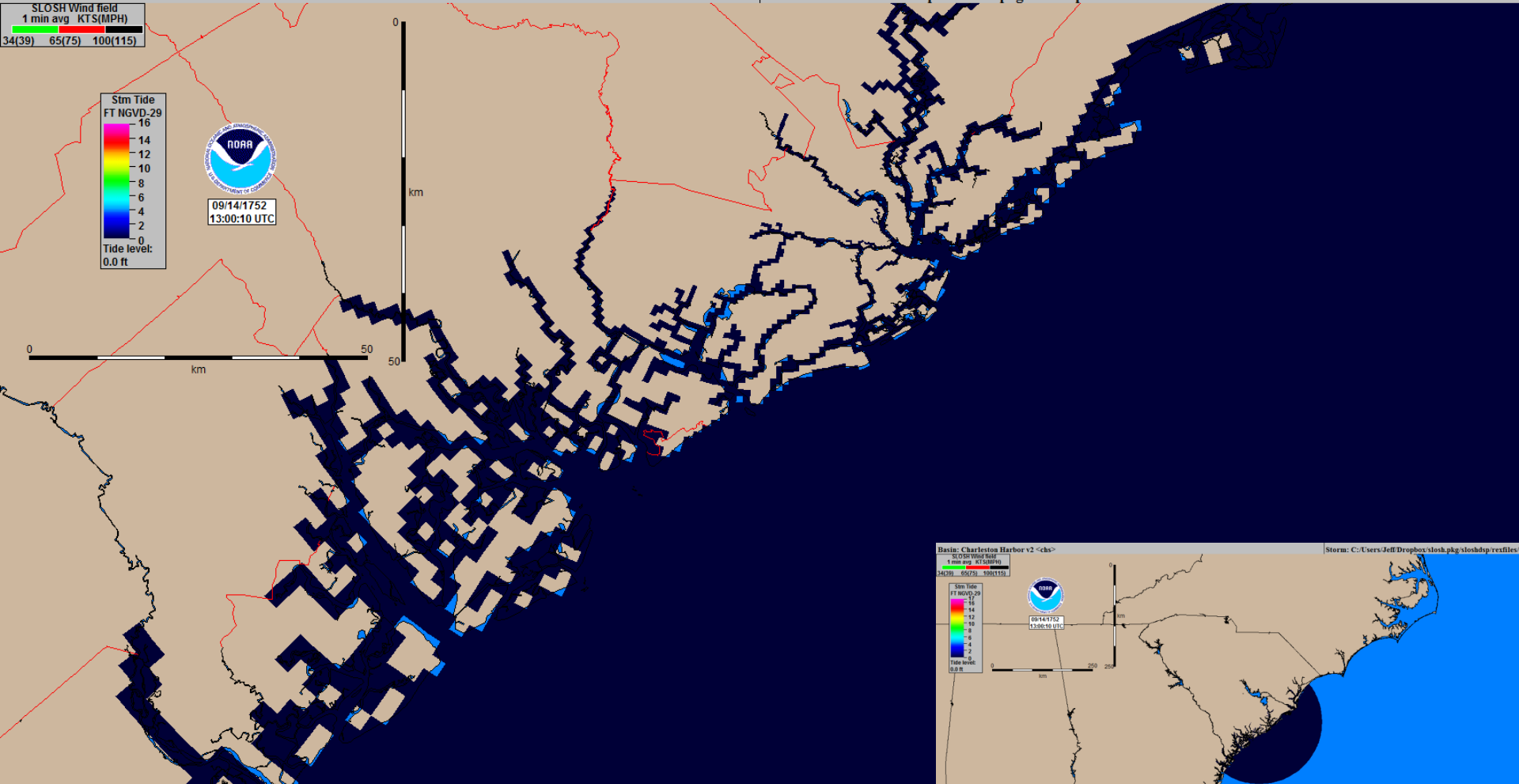
Also checkout episode 2 of *Years of Living Dangerously* on National Geographic Channel, NOVA in summer 2017, and www.whoi.edu/science/GG/coastal

1752 Charleston Hurricane Hindcast



Basin: Charleston Harbor v2 <chs>

Storm: C:/Users/Jeff/Dropbox/slosh.pkg/sloshdsp/rexfiles/1752k.rex

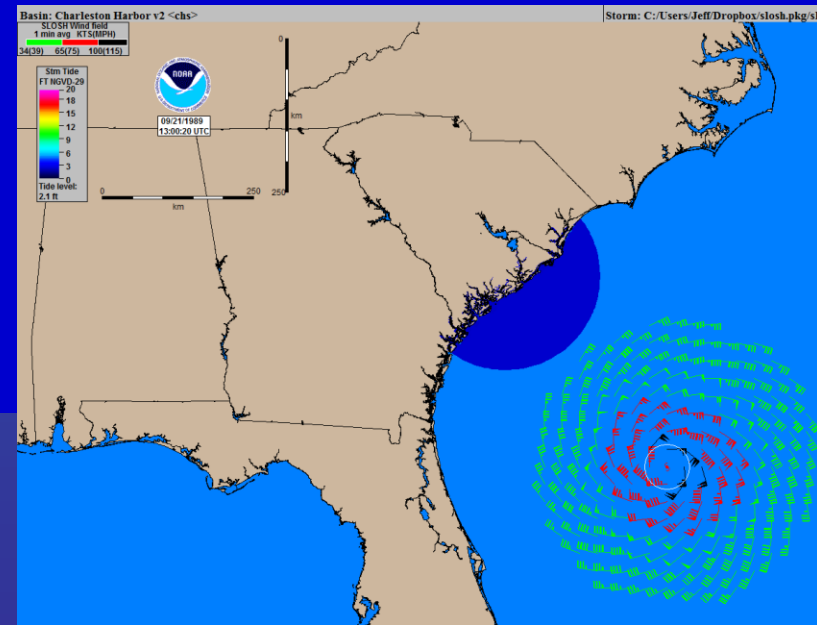
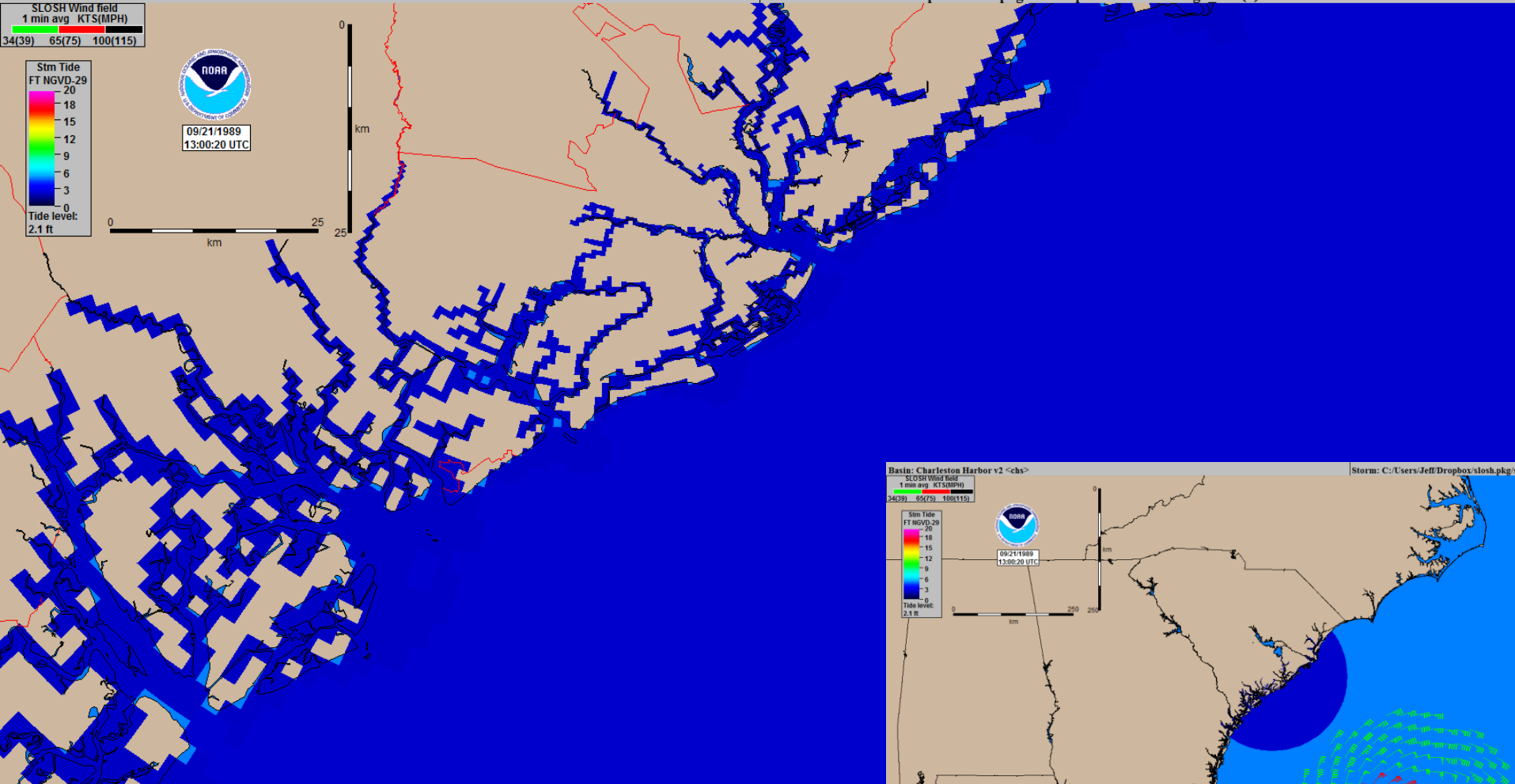


Hurricane Hugo



Basin: Charleston Harbor v2 <chs>

Storm: C:/Users/Jeff/Dropbox/slosh.pkg/sloshdsp/rexfiles/1989Hugo_chs (2).rex

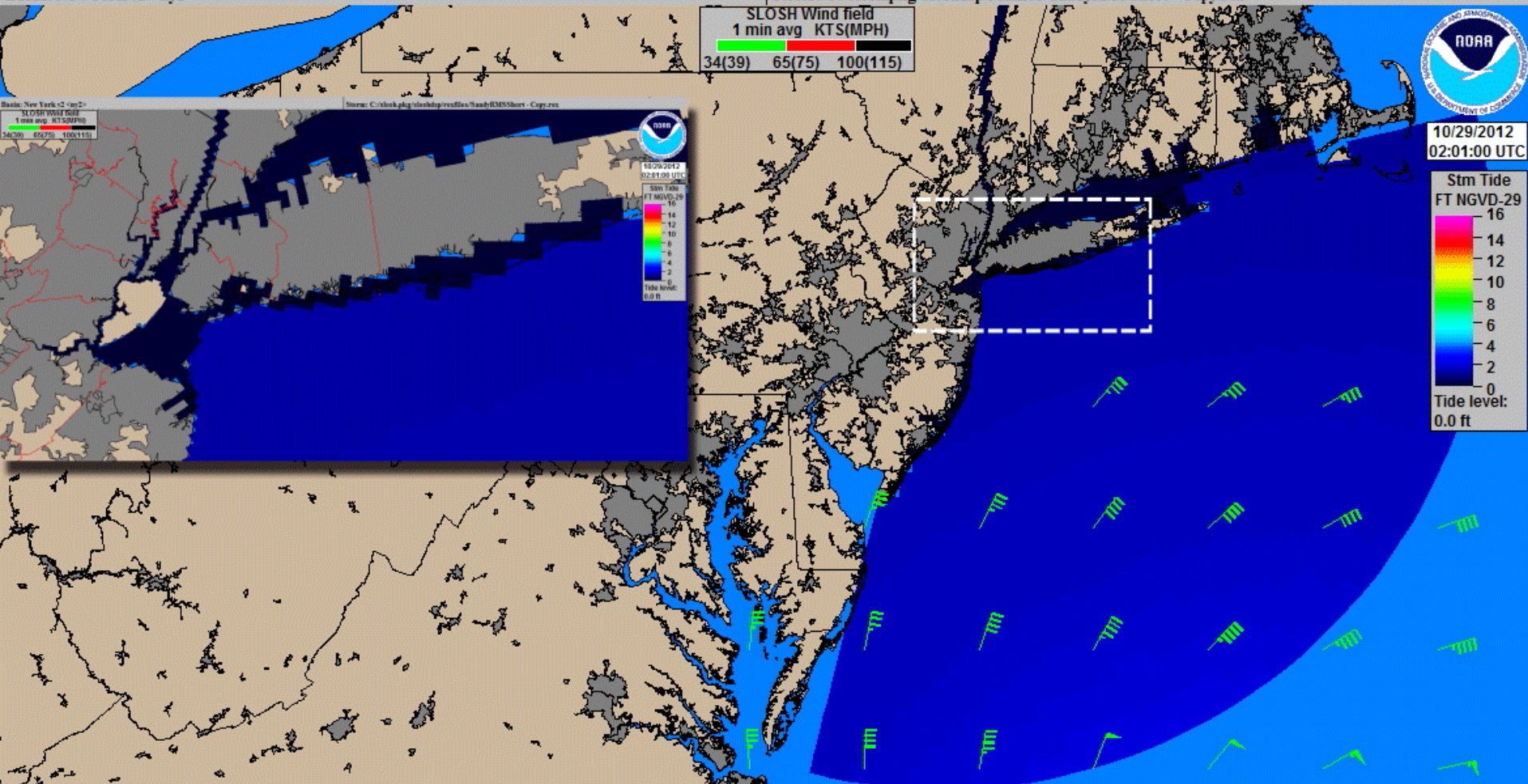


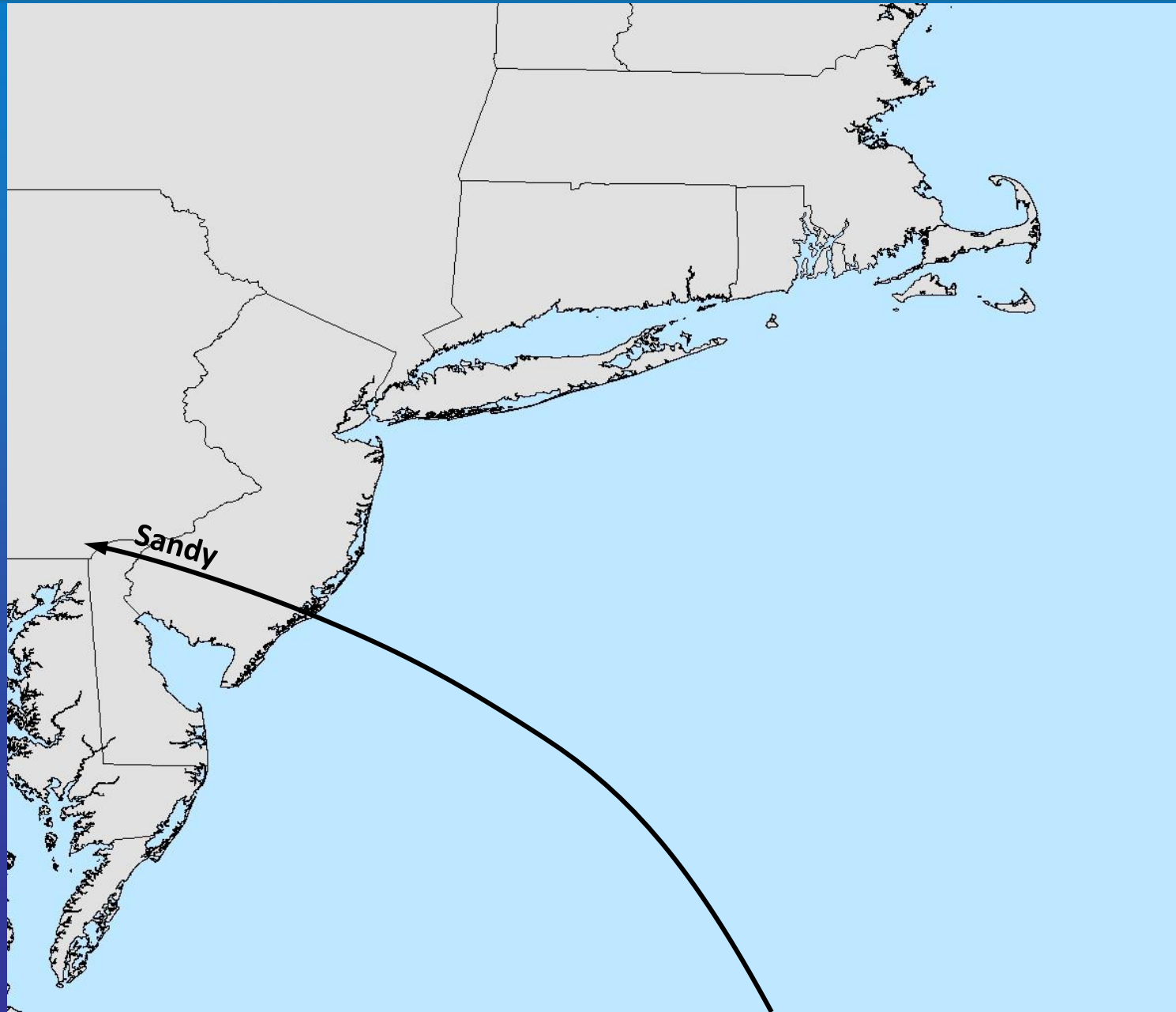
Hurricane Sandy SLOSH Simulation



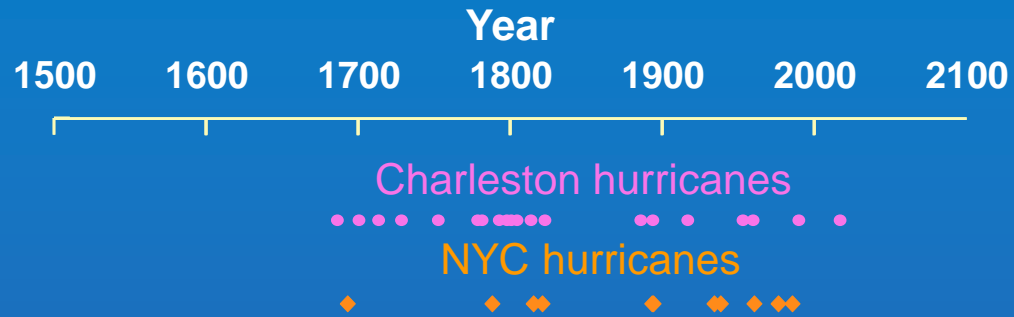
Basin: New York v2 <ny2>

Storm: C:/slosh.pkg/sloshdsp/rexfiles/SandyRMSShort - Copy.rex

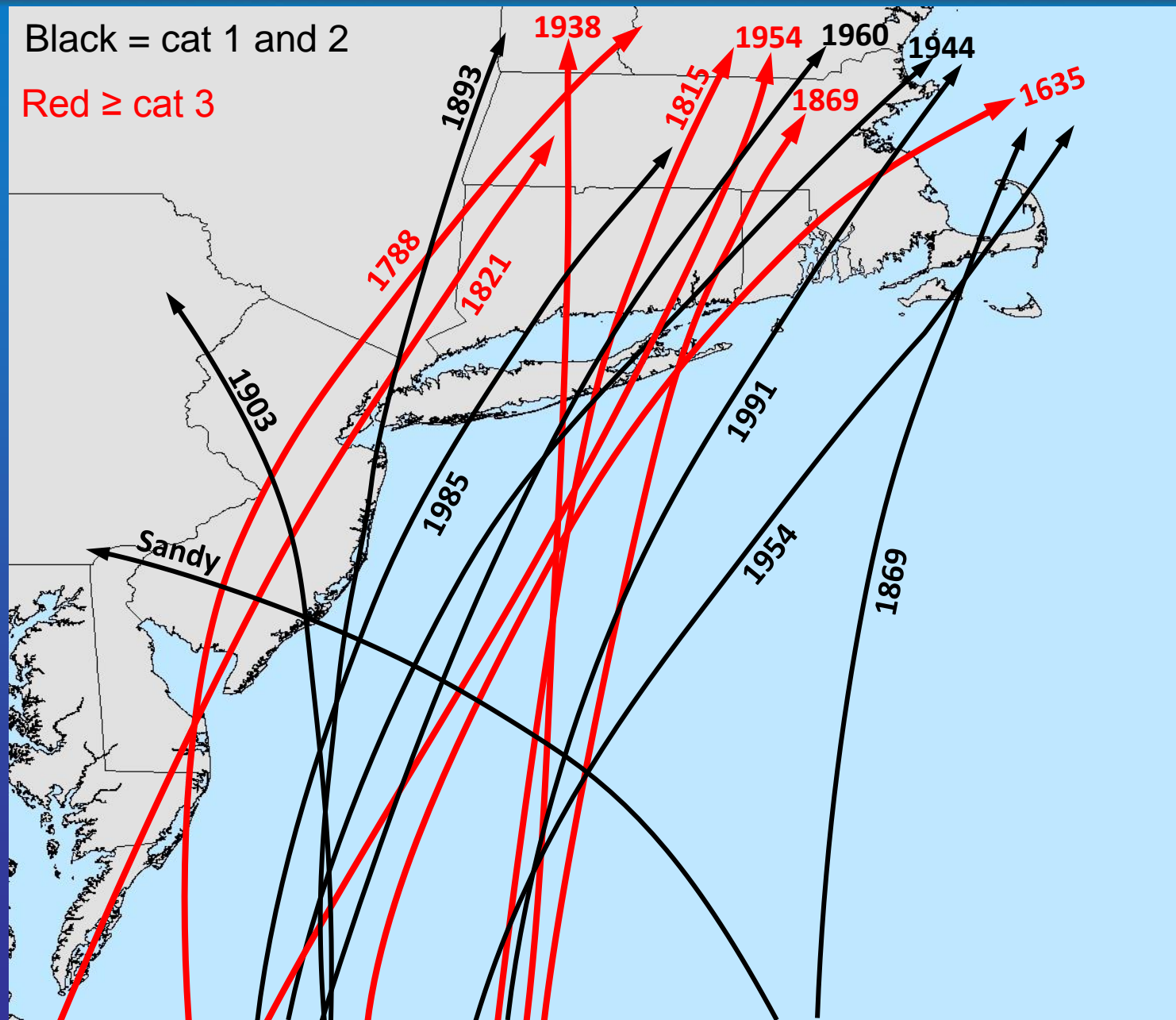




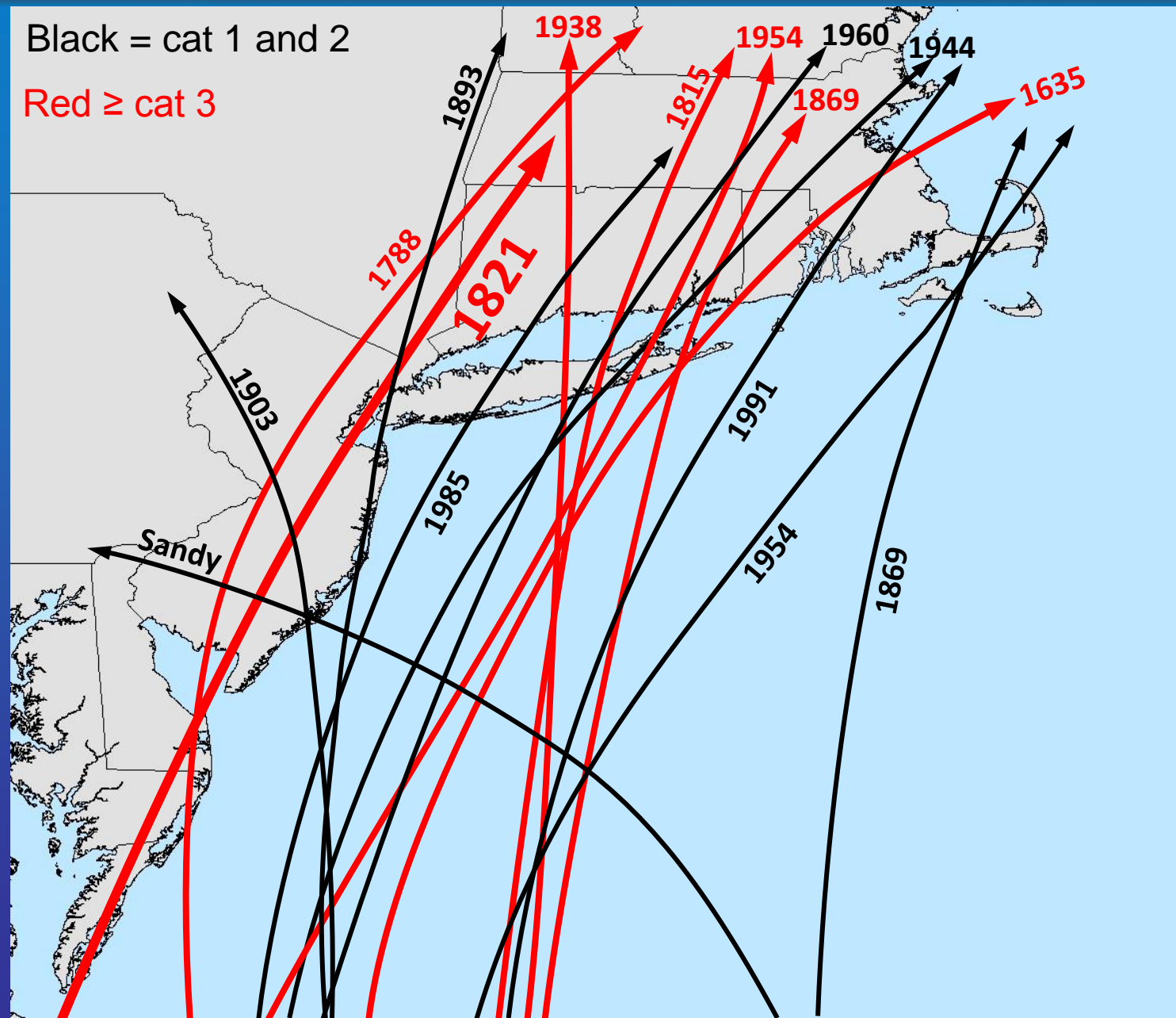
Historical Hurricanes



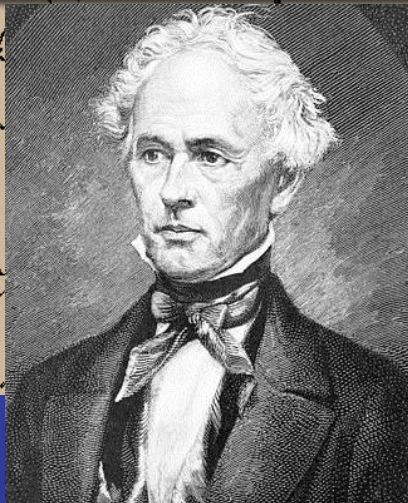
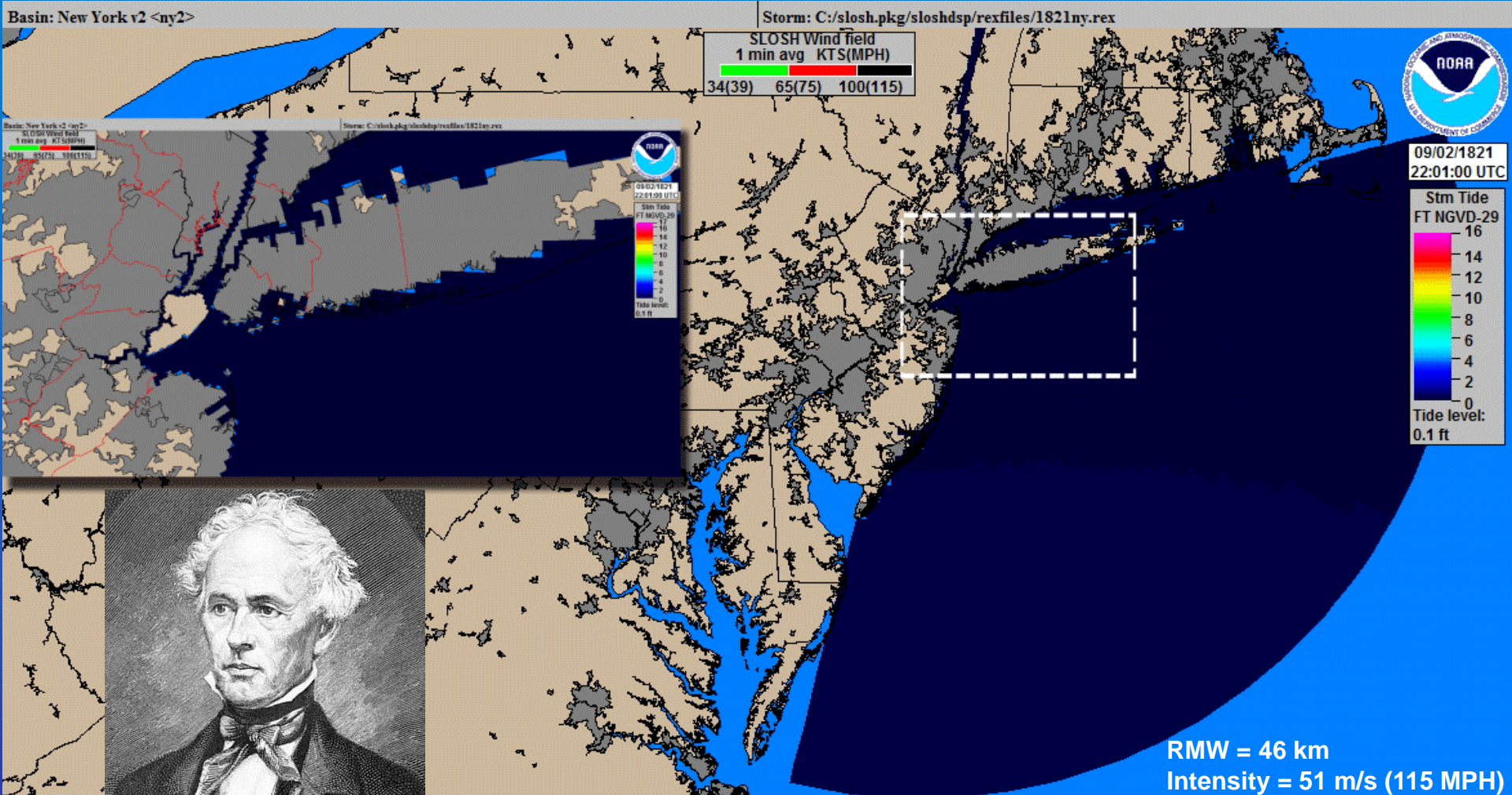
Historical Northeast US Hurricanes



Historical Northeast US Hurricanes



1821 Hurricane SLOSH Simulation



William C. Redfield
1789-1857

SLOSH input

Track: ~known

Translation speed: ~known (~65 km/hr (40 MPH))

Radius of maximum winds: ?

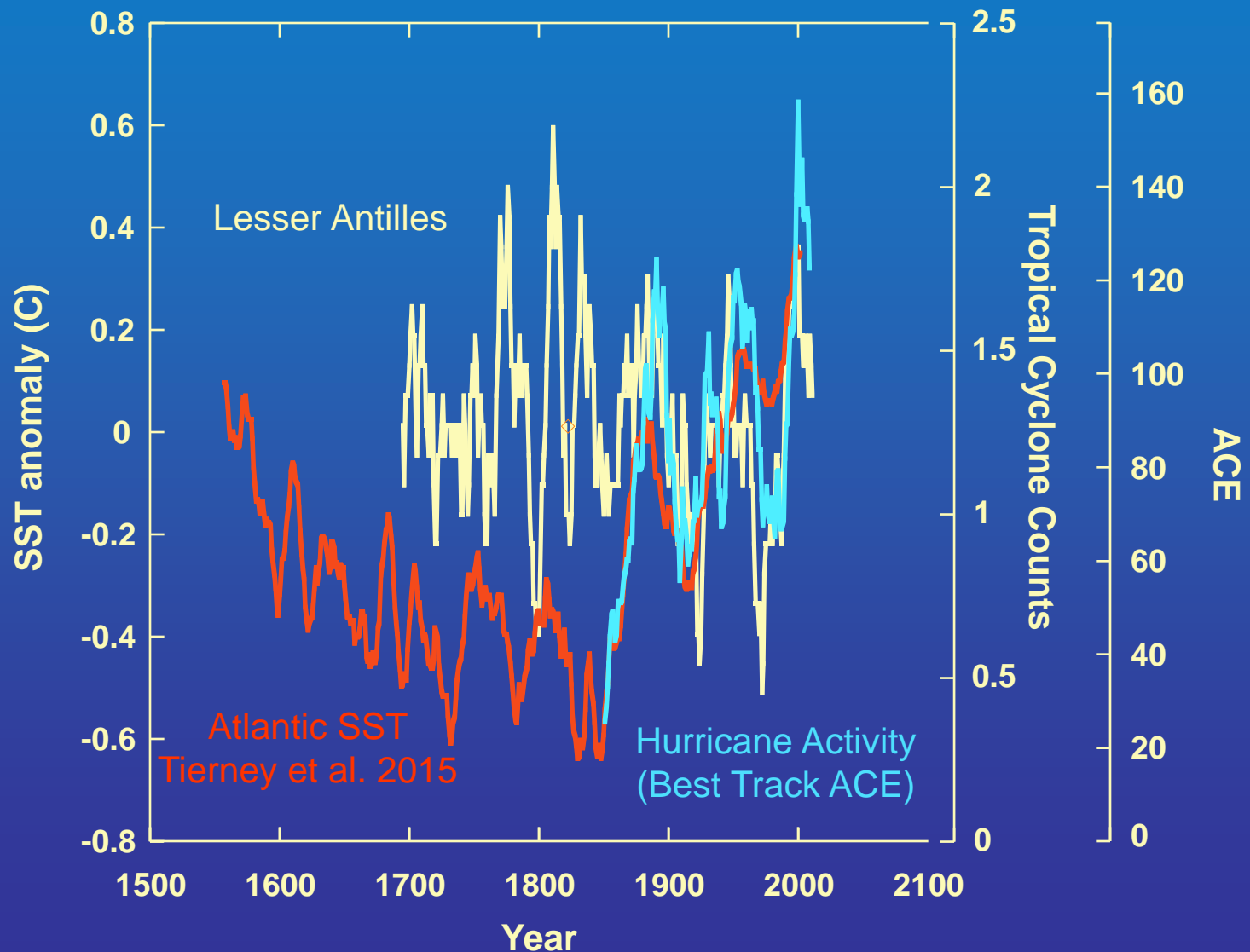
Intensity: ?

} Though some inferences
can be drawn from damage

Historical Hurricanes and Sea Surface Temp



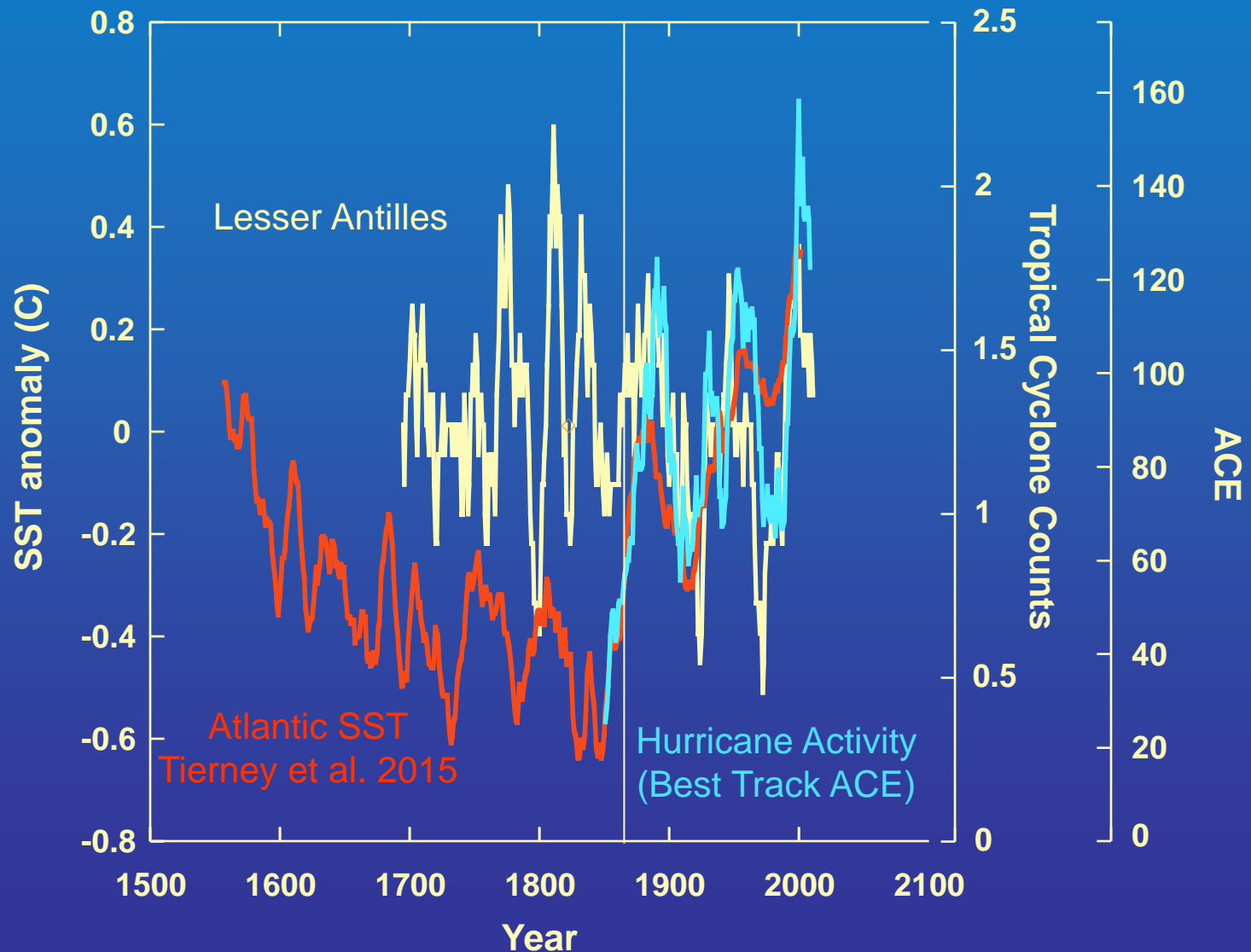
Is there other evidence for elevated LIA activity?



Historical Hurricanes and Sea Surface Temp



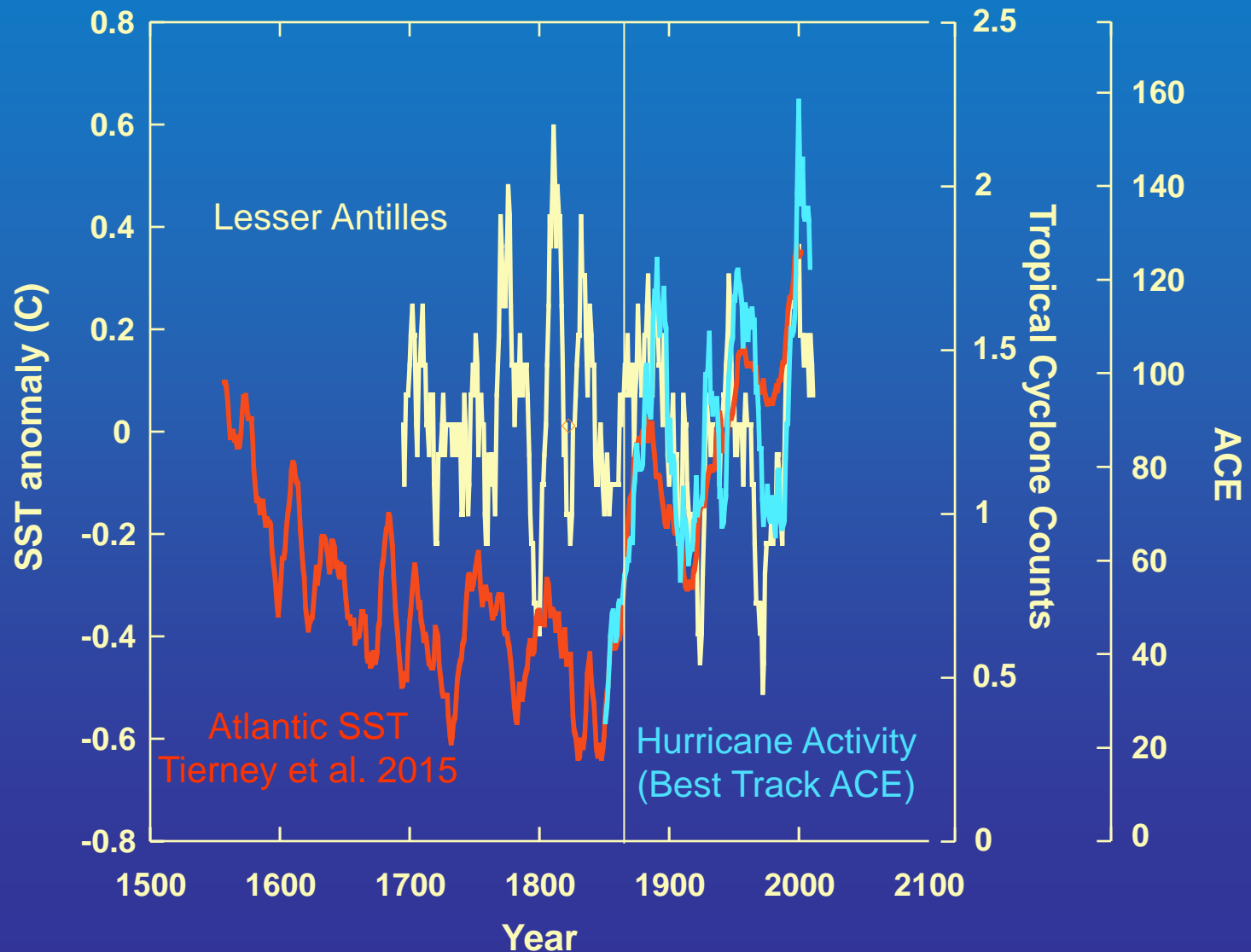
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Historical Hurricanes and Sea Surface Temp



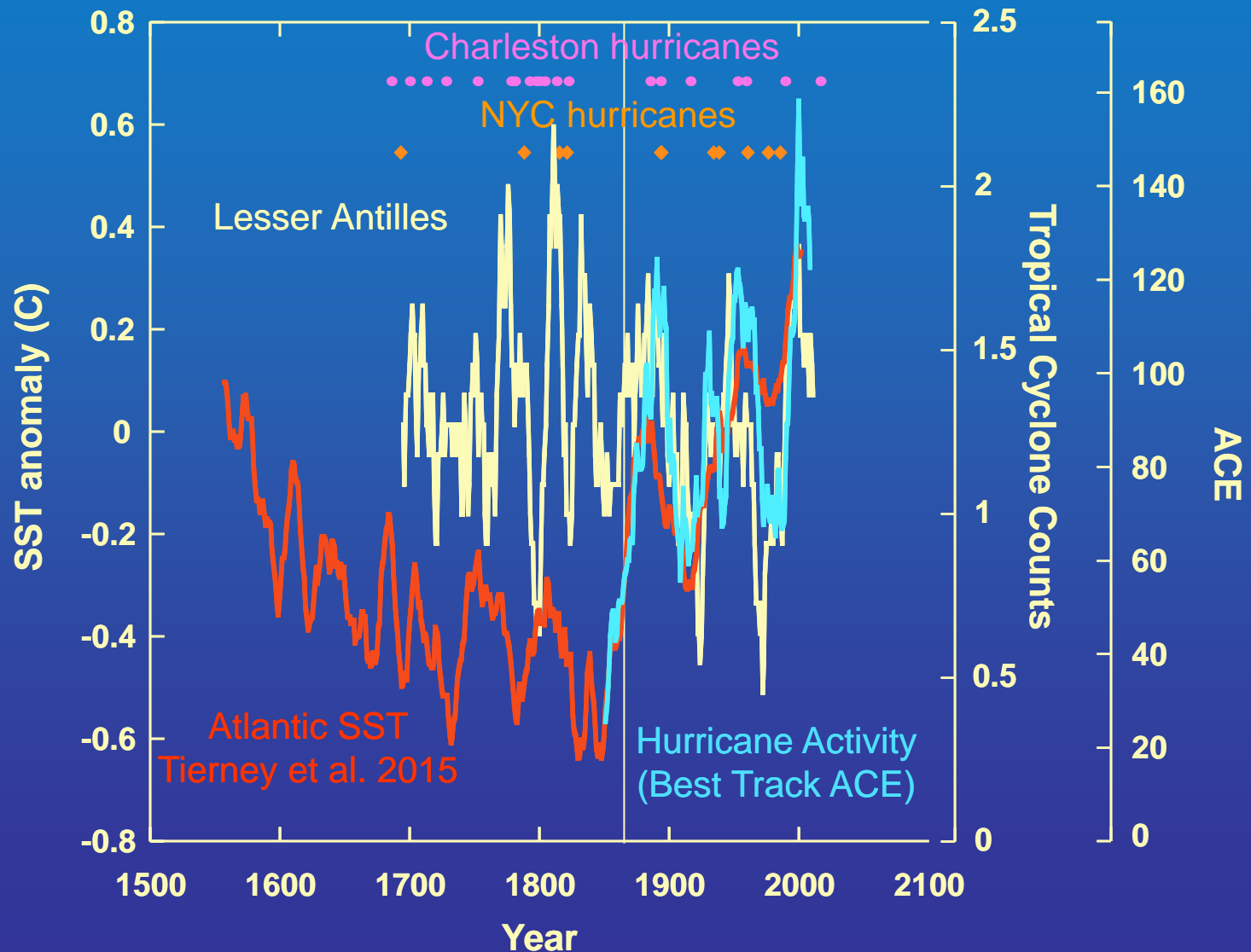
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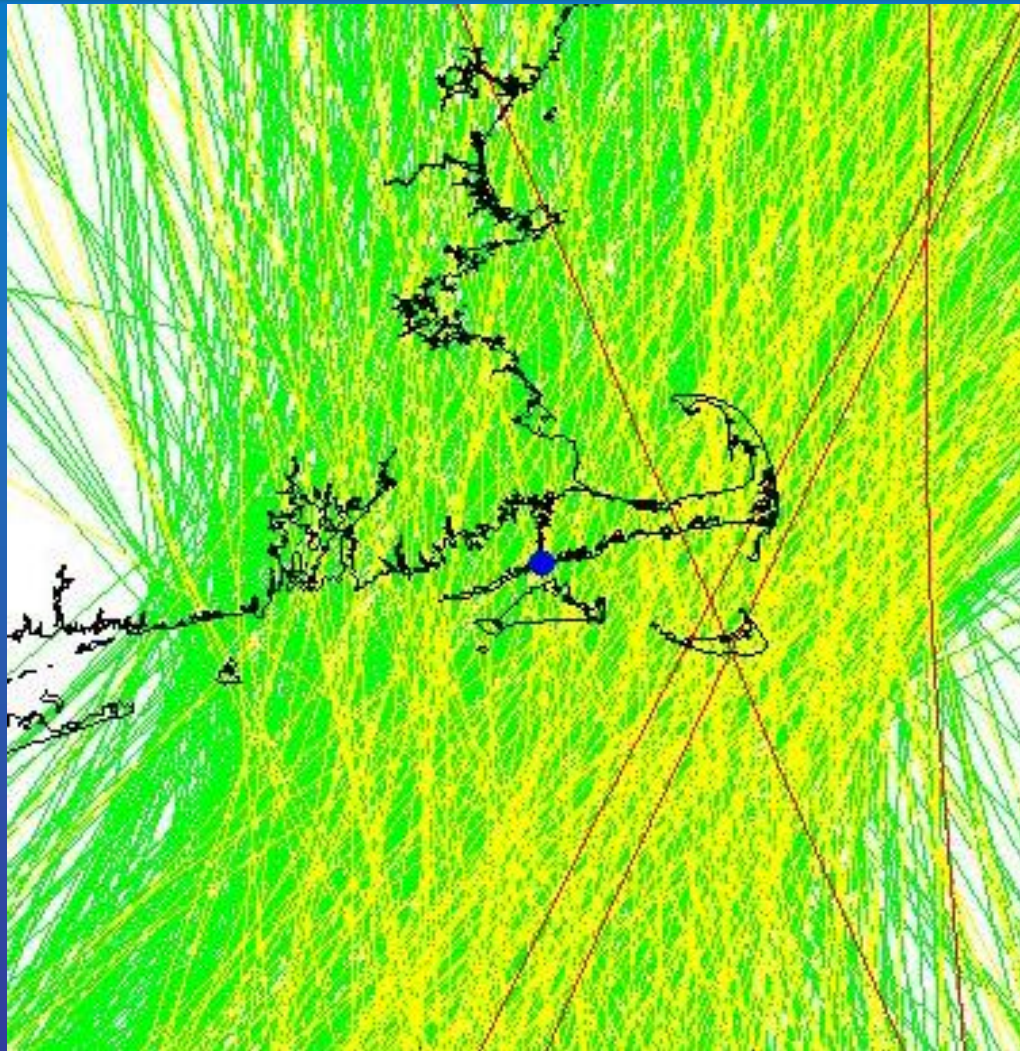
Historical Hurricanes and Sea Surface Temp



Is there other evidence for elevated LIA activity?

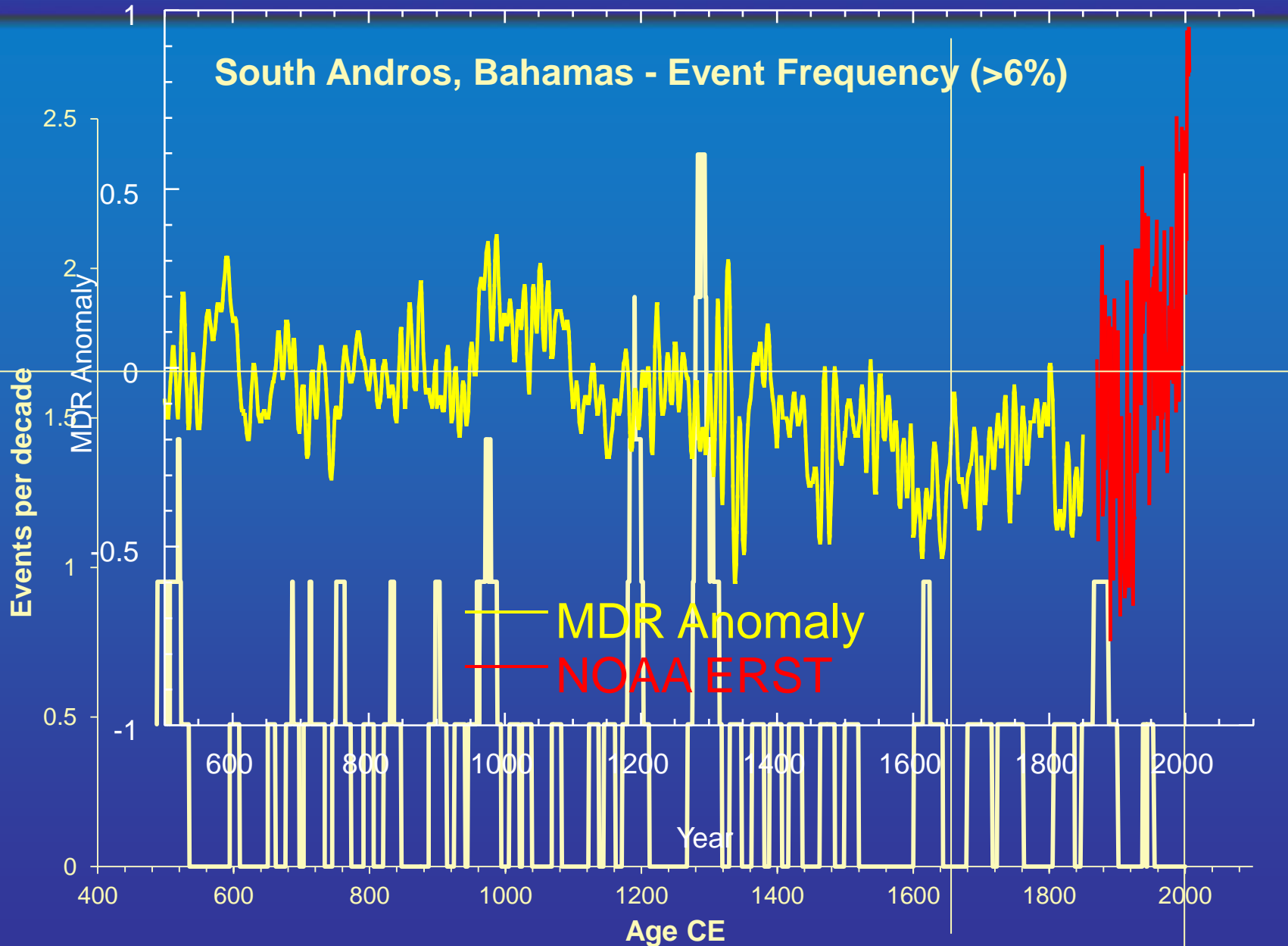


Modeling Hurricanes

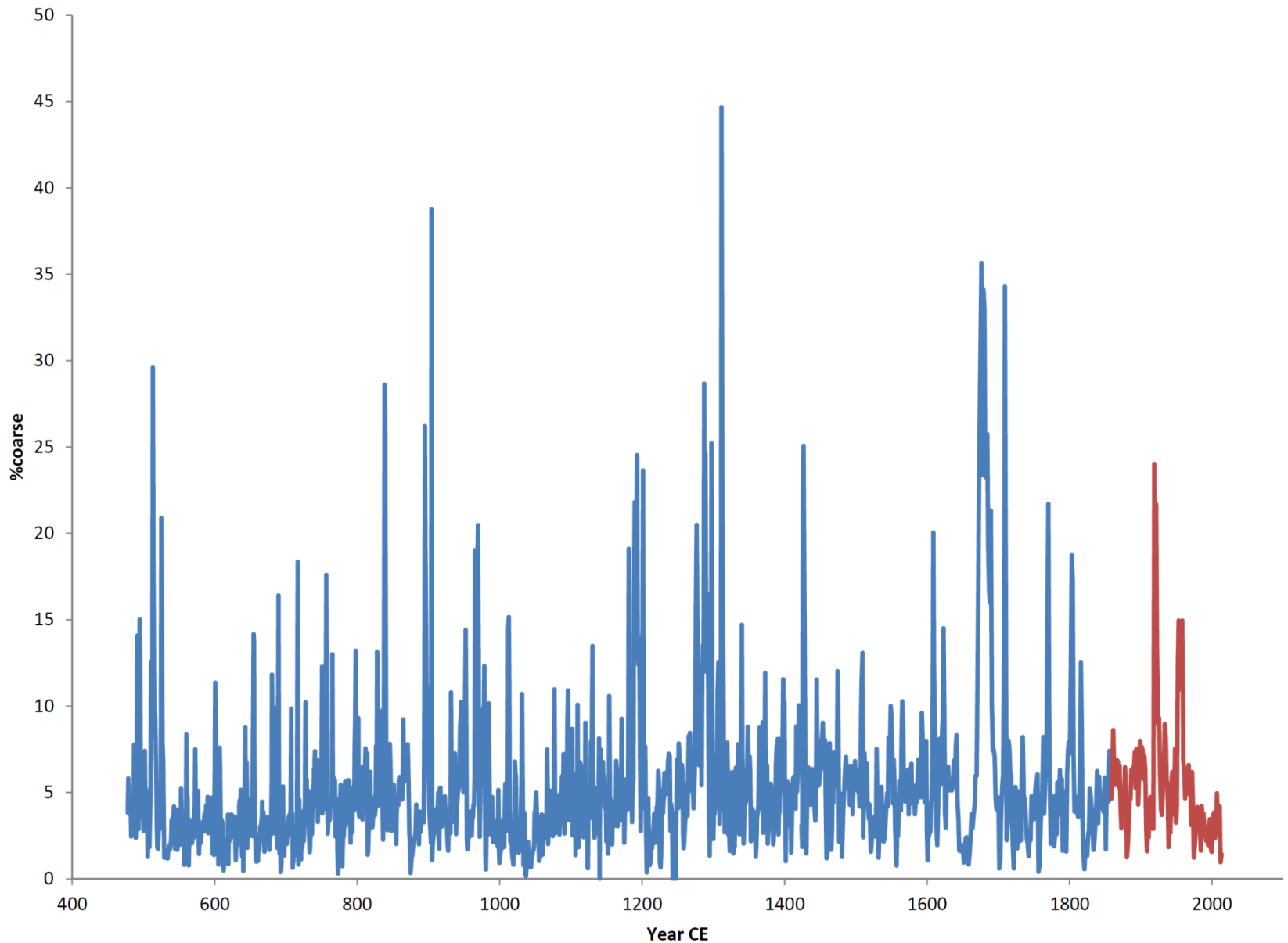


8000 years worth of hurricane tracks (\geq Cat 2 intensity) from the Emanuel (2006) model passing within 60 miles of the Woods Hole (17,354 total storms).
1049 Cat 2 storms (green), 242 Cat 3 storms (yellow) and four Cat 4 storms (red).
No Cat 5 storms were simulated.

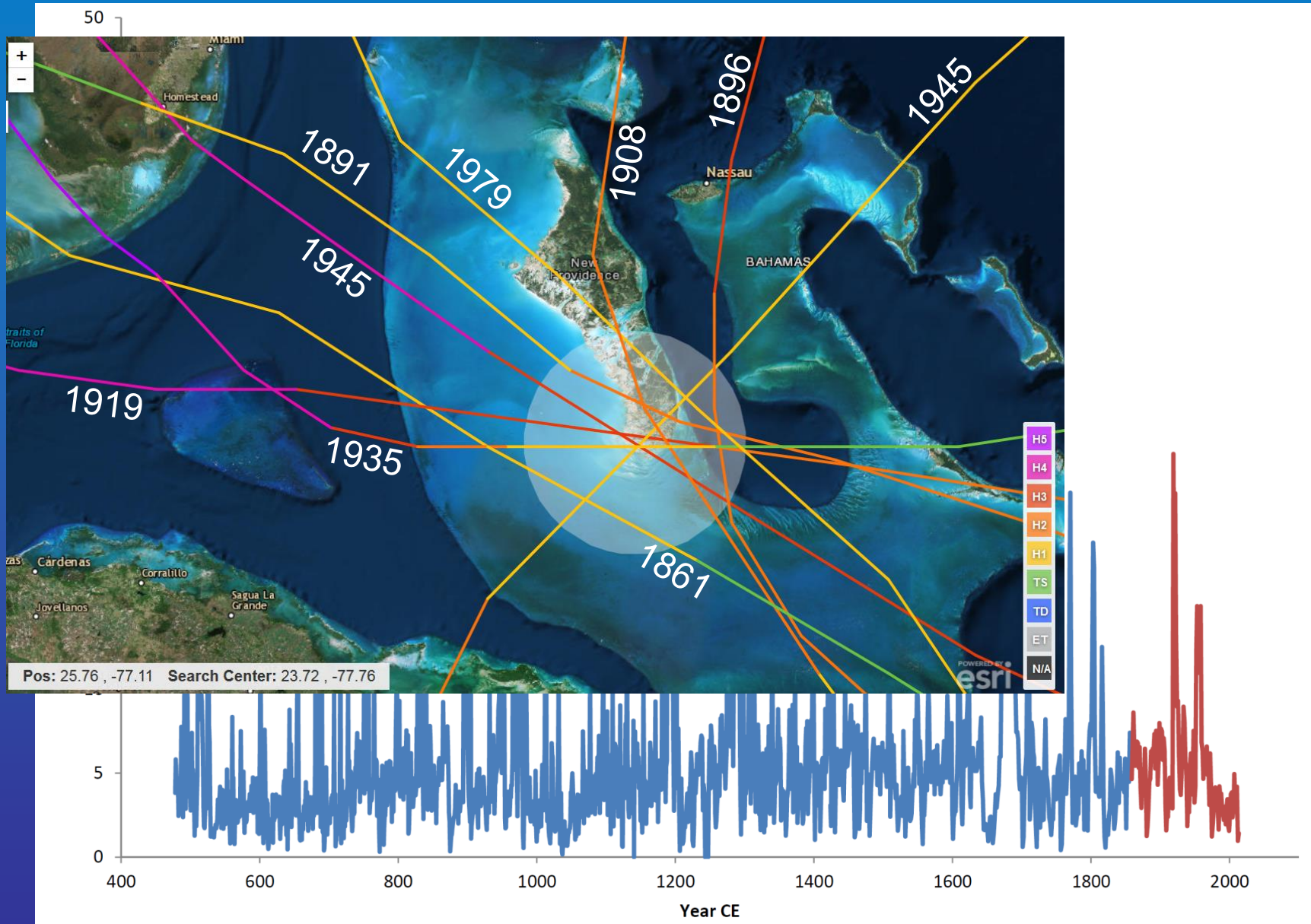
Mann et al. 2009 Main Development Region SST



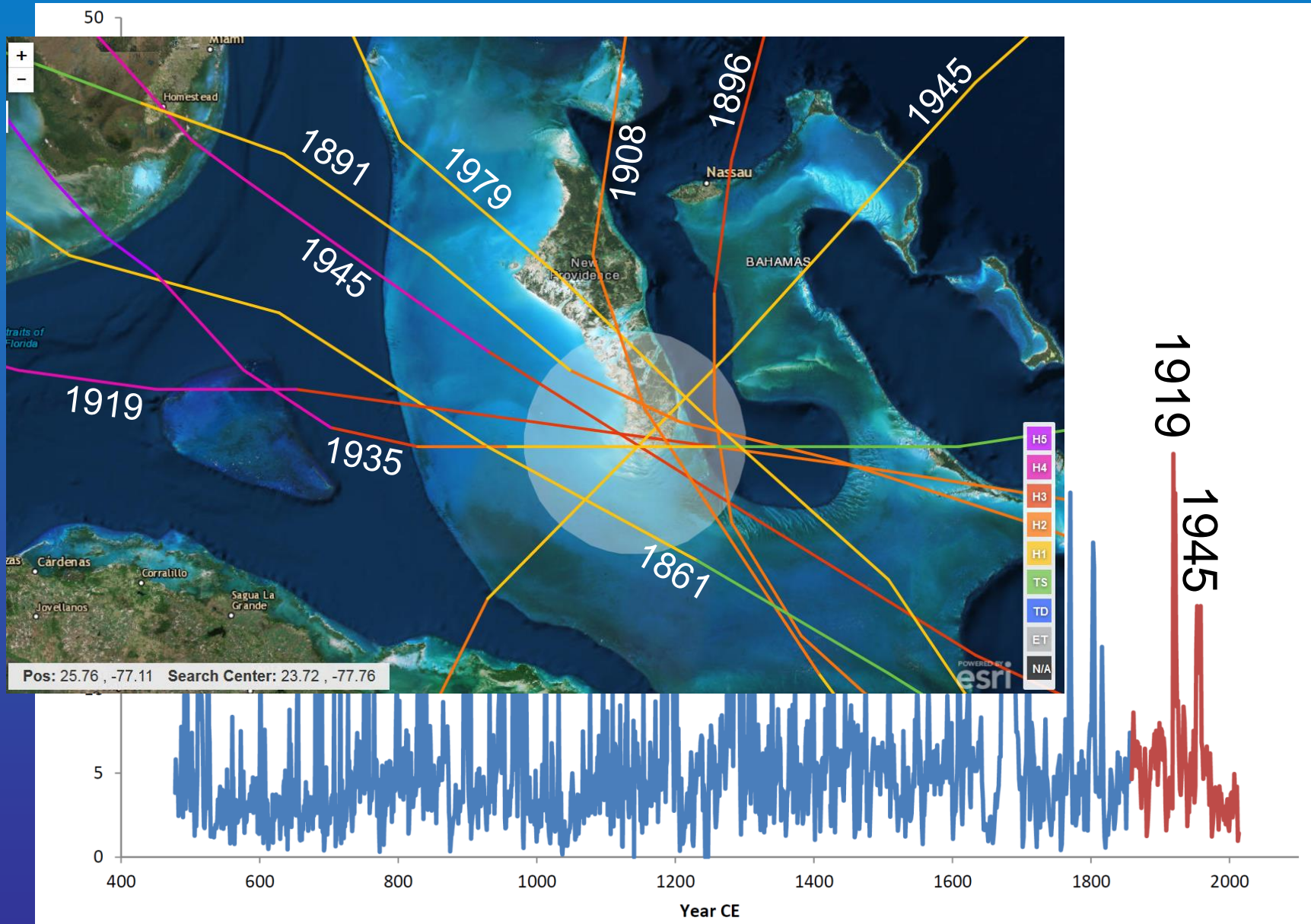
Record from South Andros Bahamas



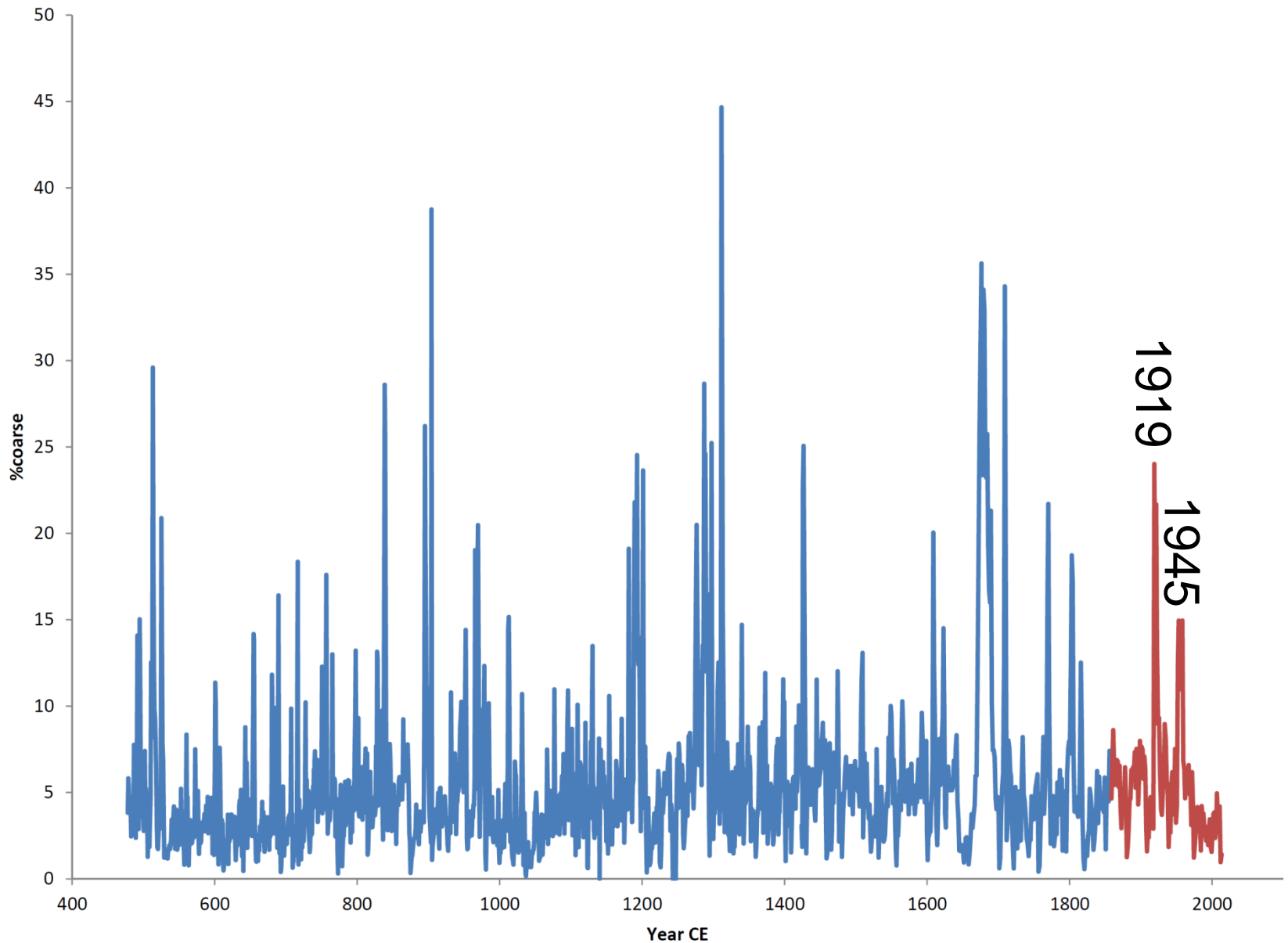
Record from South Andros Bahamas



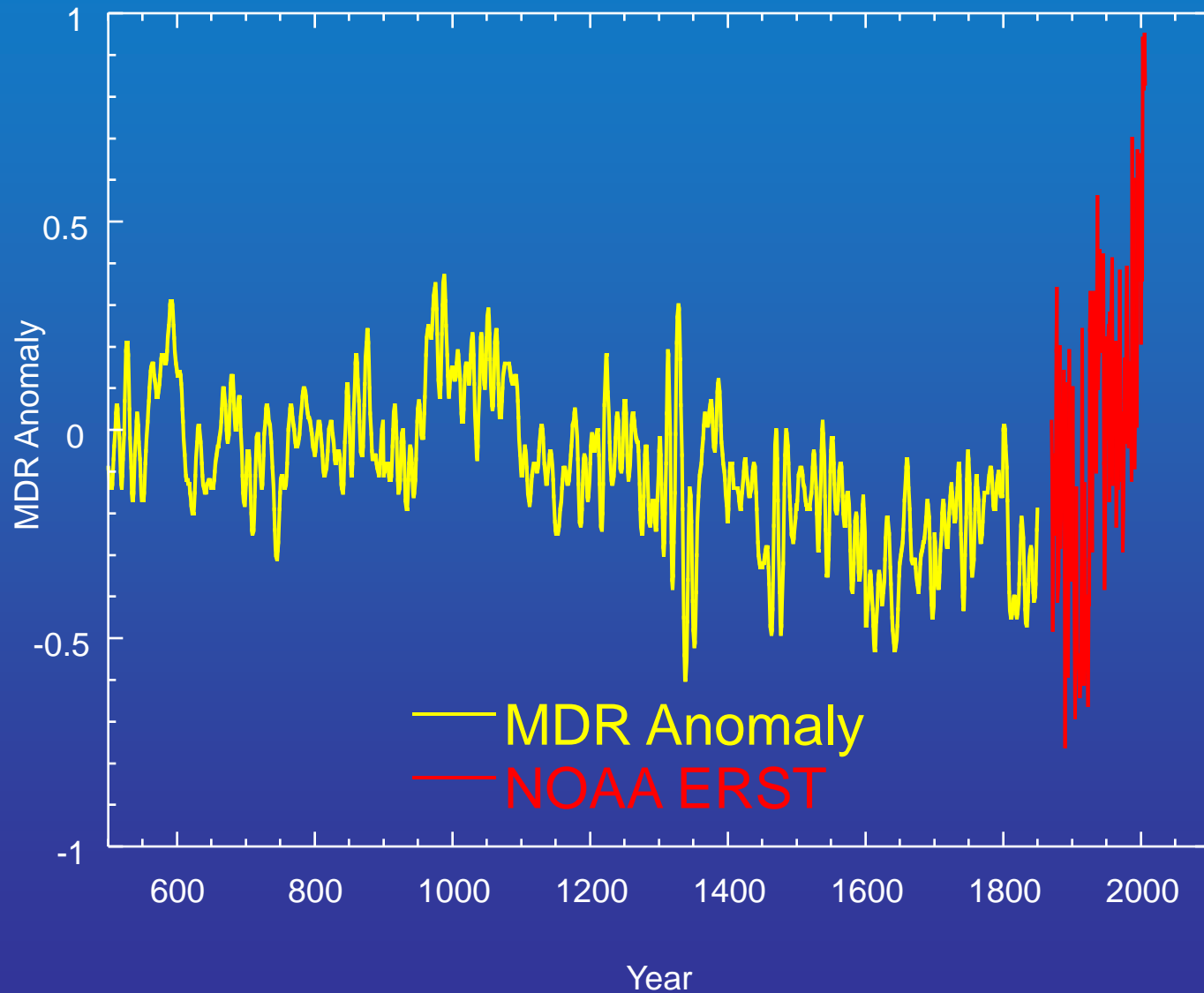
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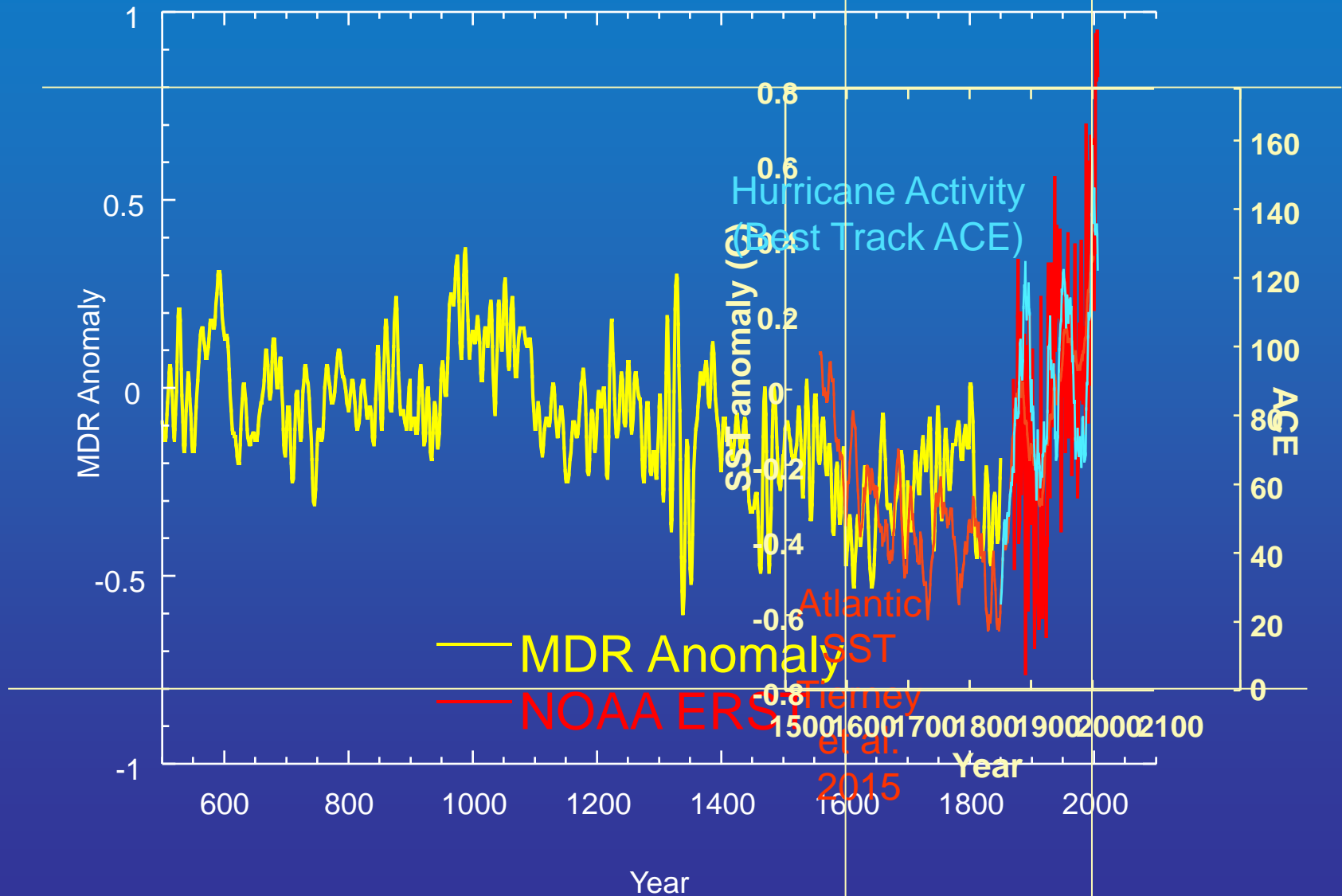
Record from South Andros Bahamas



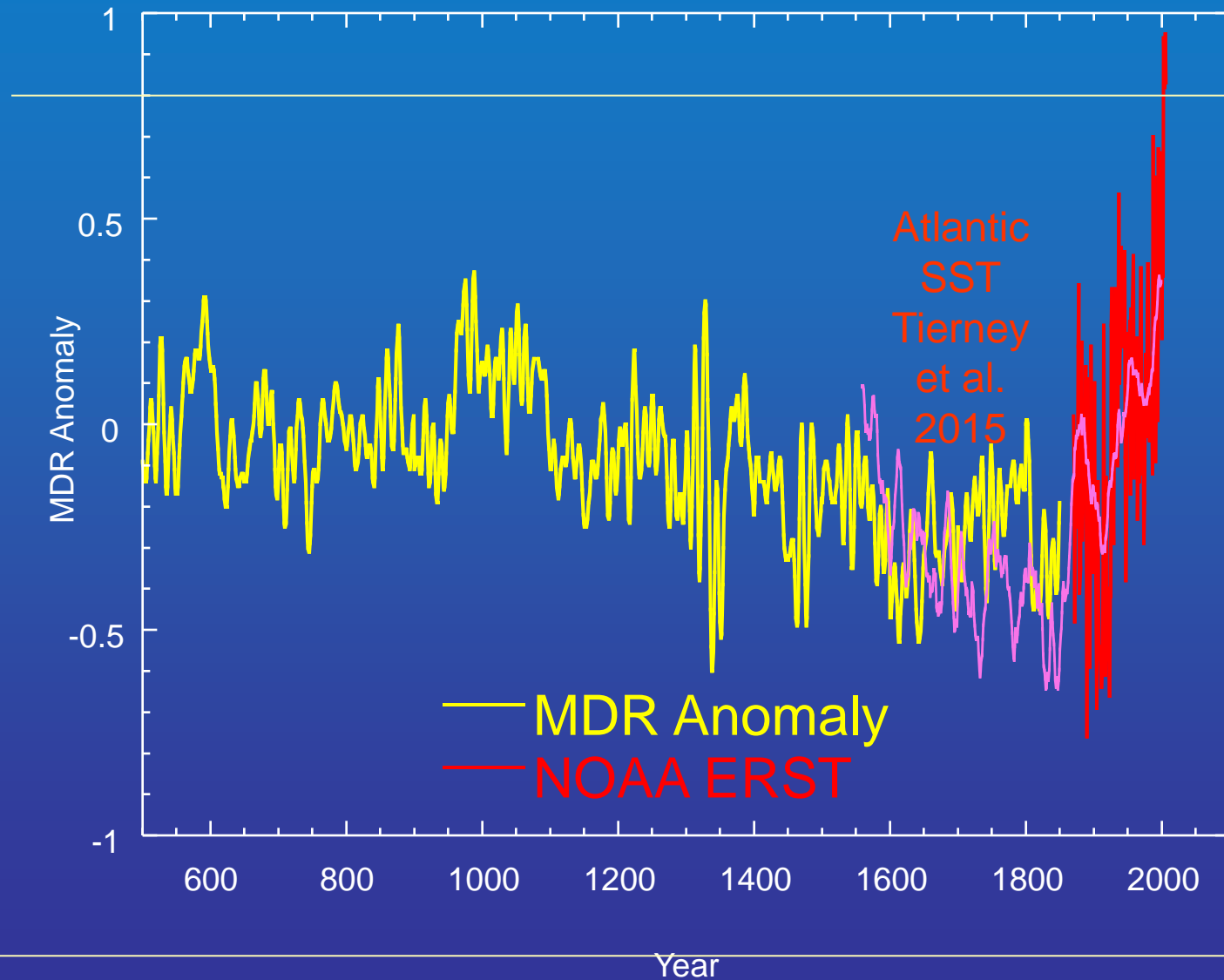
Mann et al. 2009 Main Development Region SST



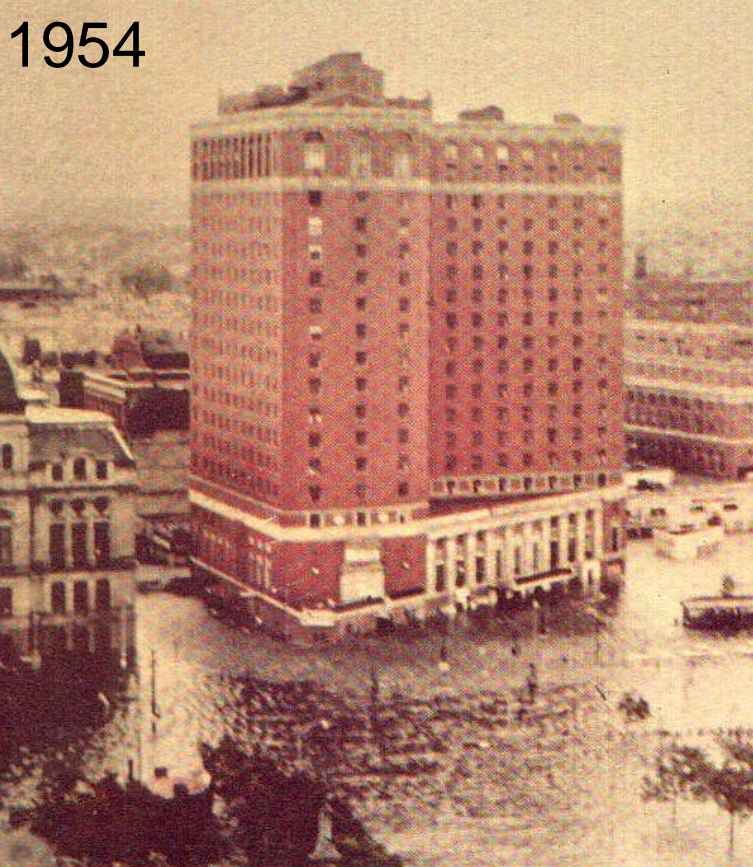
Mann et al. 2009 Main Development Region SST



Mann et al. 2009 Main Development Region SST



1954



1938



1815



Thank you!

Further Reading:

Early American Hurricanes, D.M. Ludlum

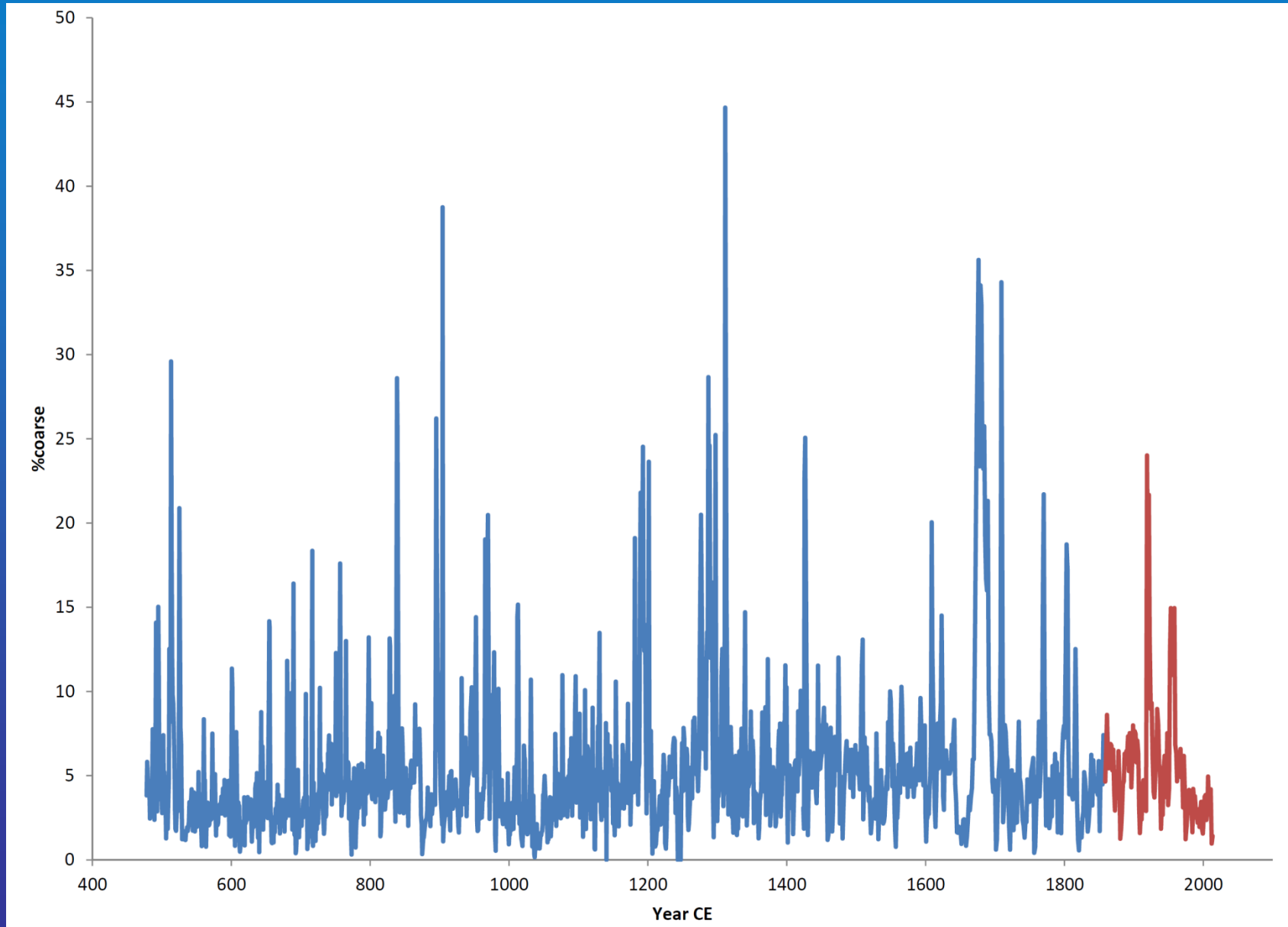
A Wind to Shake the World, E.S. Allen

Sudden Sea: The Great Hurricane of 1938, R.A. Scotti

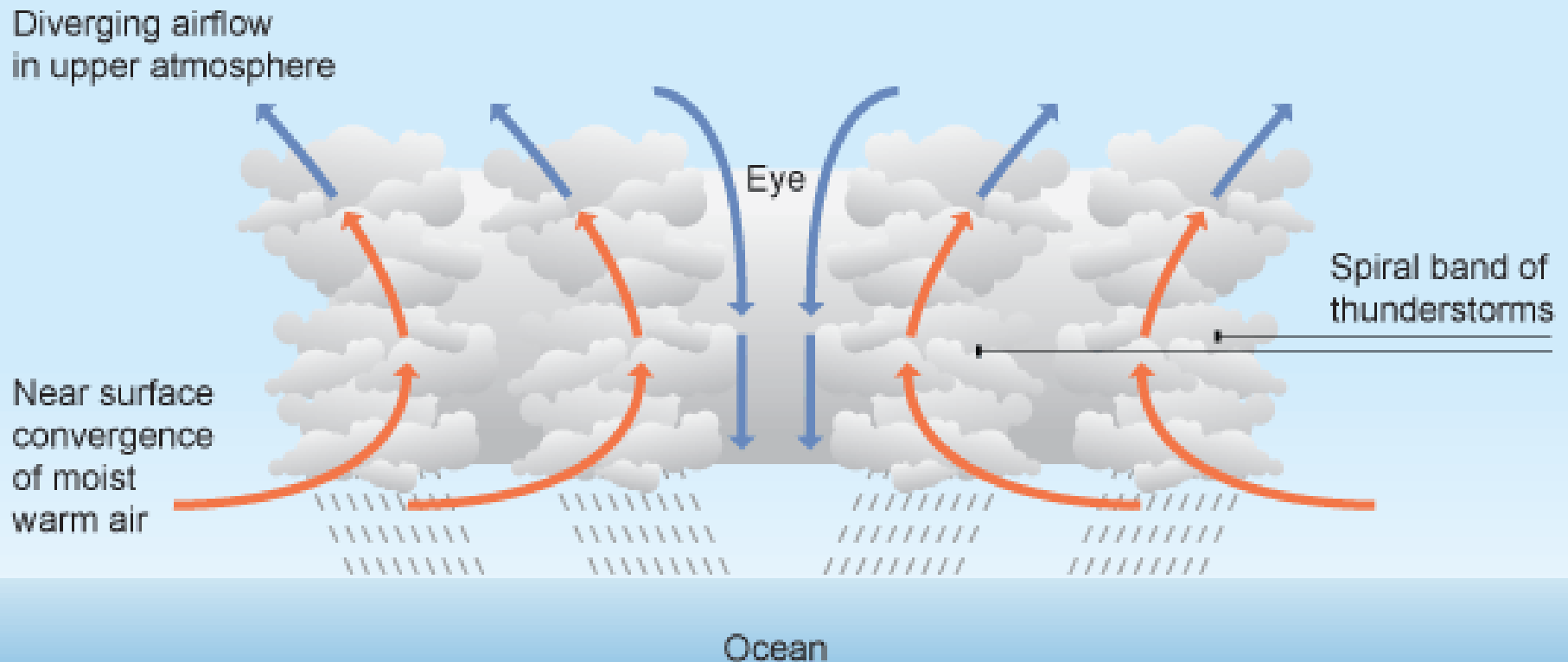
Issac's Storm, Erik Larson

Also checkout episode 2 of *Years of Living Dangerously*
on National Geographic Channel and NOVA in 2017
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Hurricane Records from Blueholes



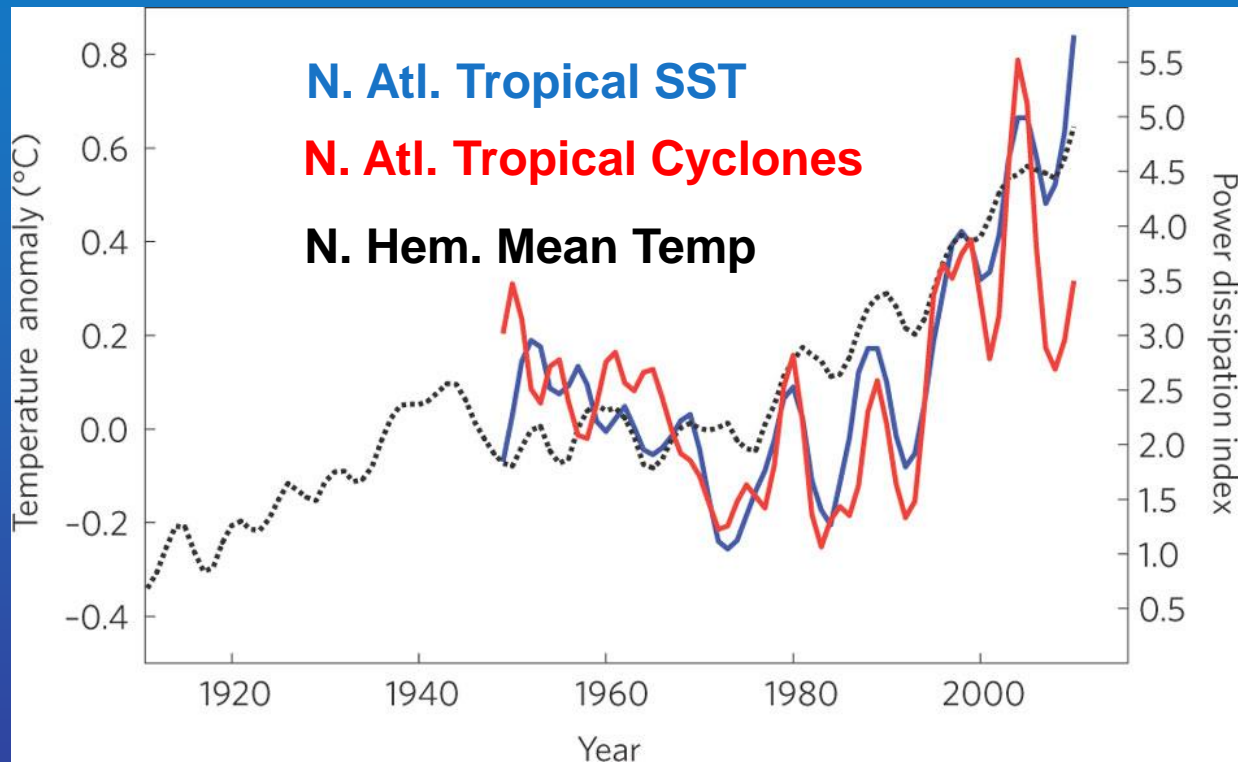
What is a tropical cyclone?



Conditions for genesis

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

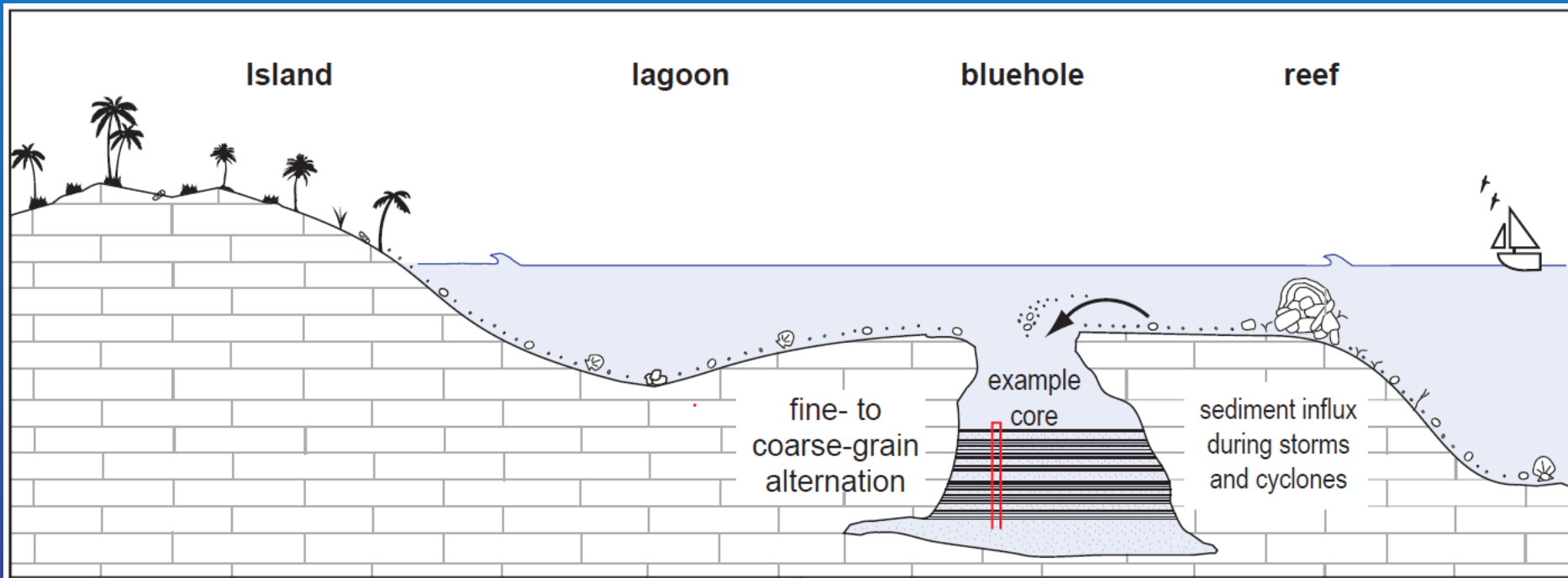
What Might the Future Hold?



From
Coumou and Rahmstorf, 2012
Nature Climate Change

Hurricane Records from Blueholes

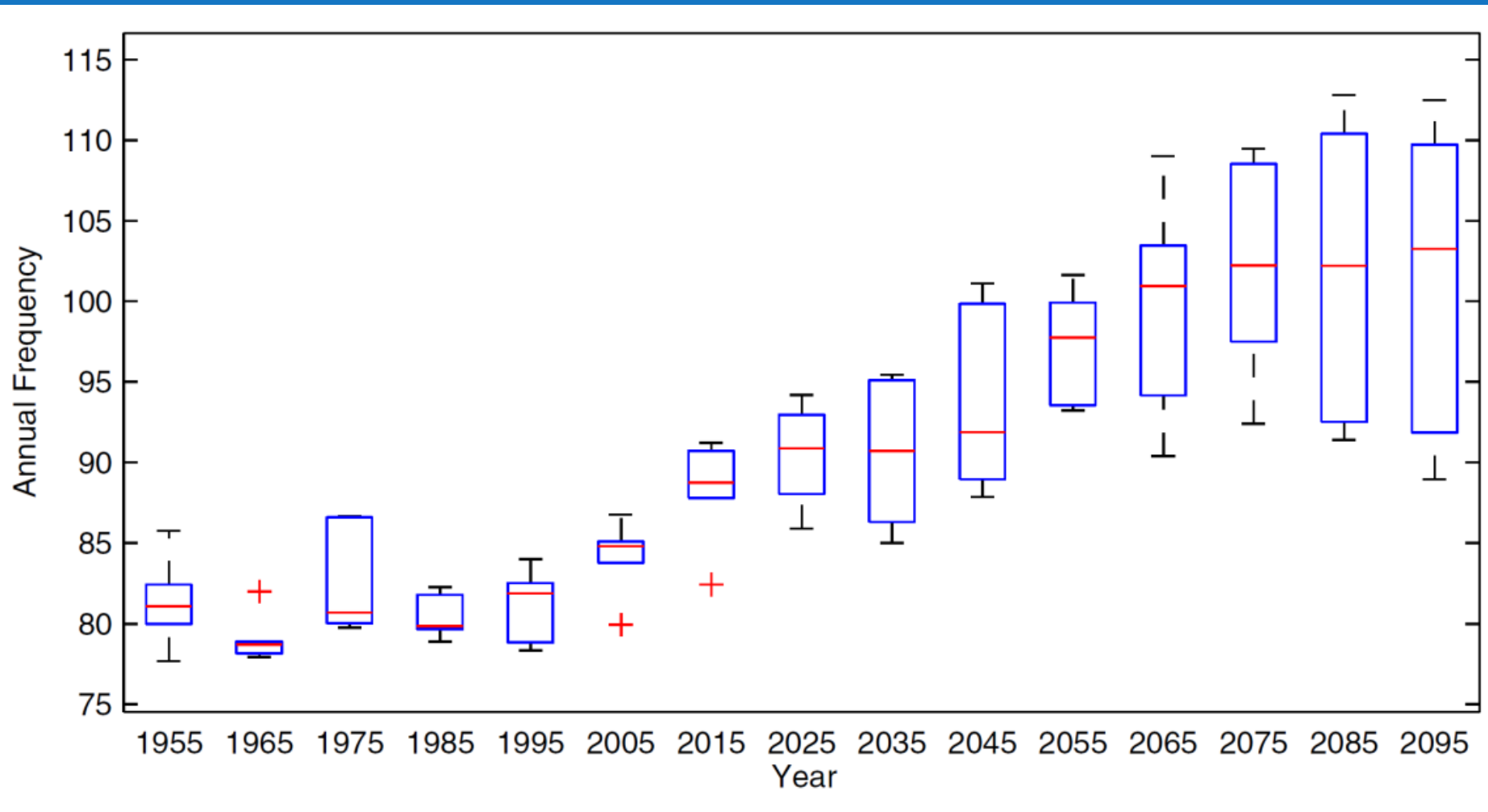
Sedimentary archives in blueholes provide the means to reconstruct regional patterns



Hurricanes



Frequency of hurricanes may increase (particularly intense storms)



Record from South Andros Bahamas

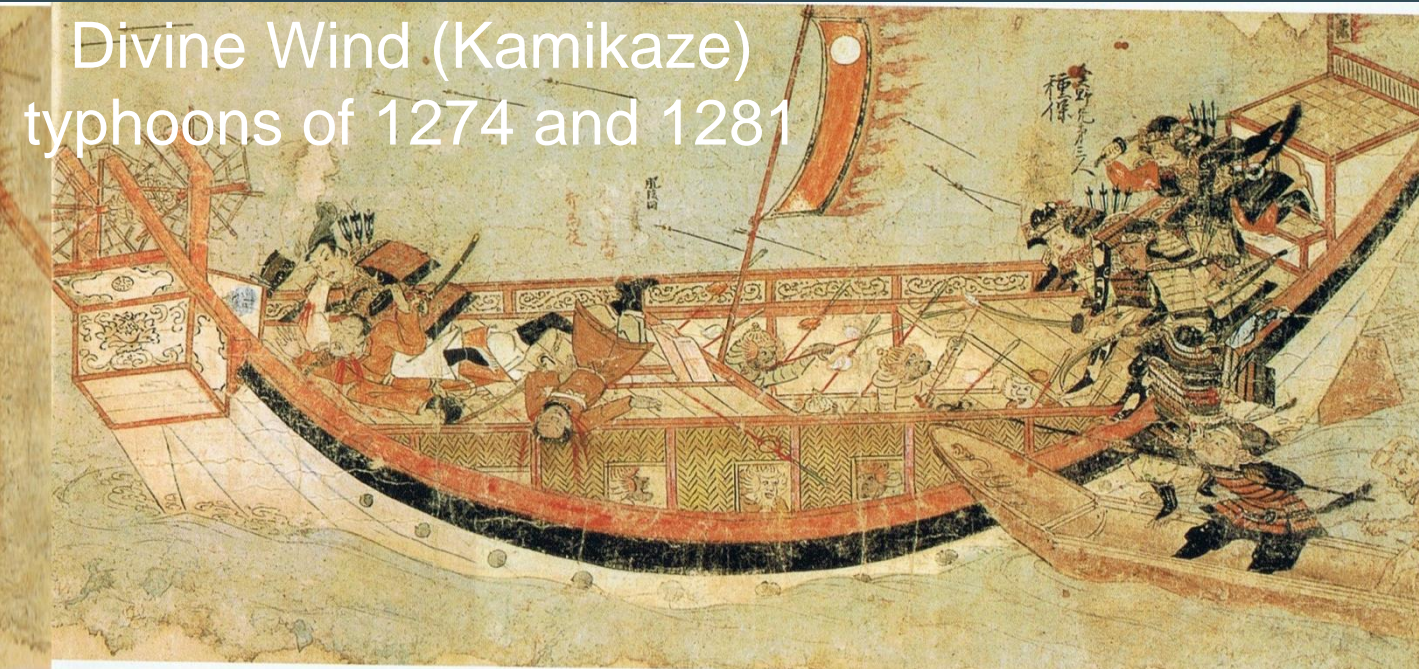


Hurricane Event Bed



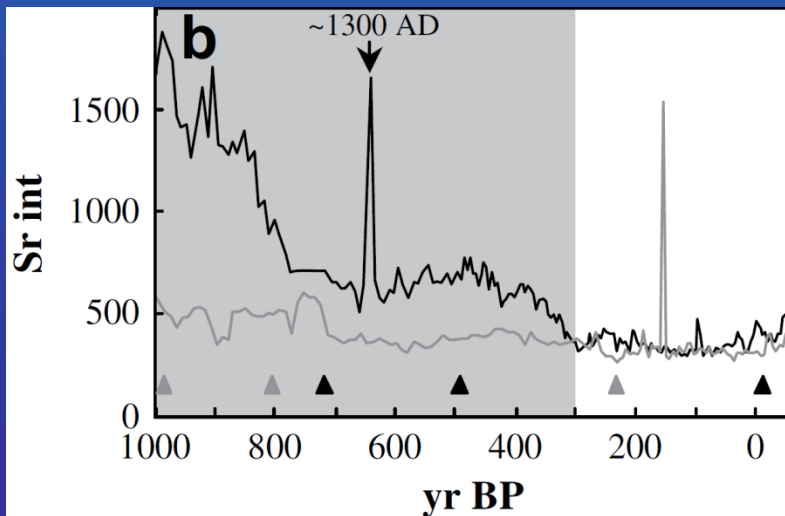
Historical Impacts of Tropical Cyclones

Divine Wind (Kamikaze)
typhoons of 1274 and 1281



Kublai Khan

Woodruff et al., 2009 QSR



Bay of Bengal Cyclone Tragedies



1737 - 300,000-350,000 fatalities

1876 - 100,000 fatalities

1897 - 175,000 fatalities

1942 - 40,000 fatalities

1963 - 22,000 fatalities

1965 - 60,000 fatalities

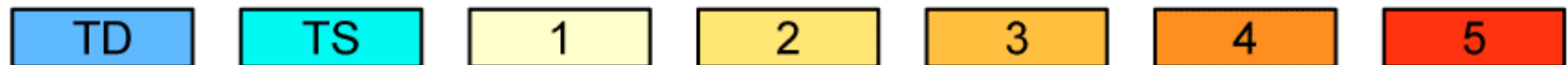
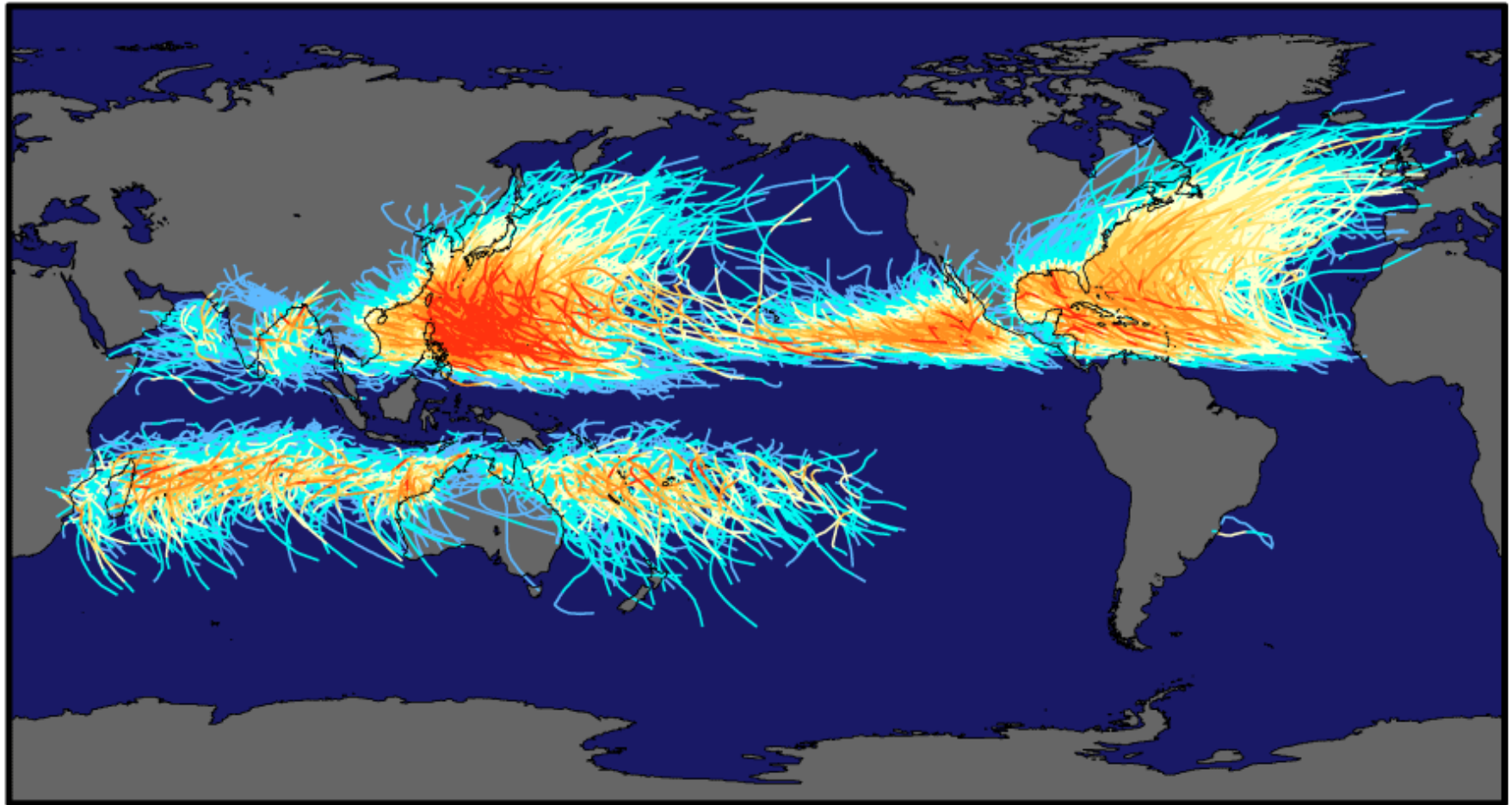
1970 - 300,000-500,000 fatalities
(contributed to civil war and eventually Bangladesh independence)

1991 - 138,000 fatalities



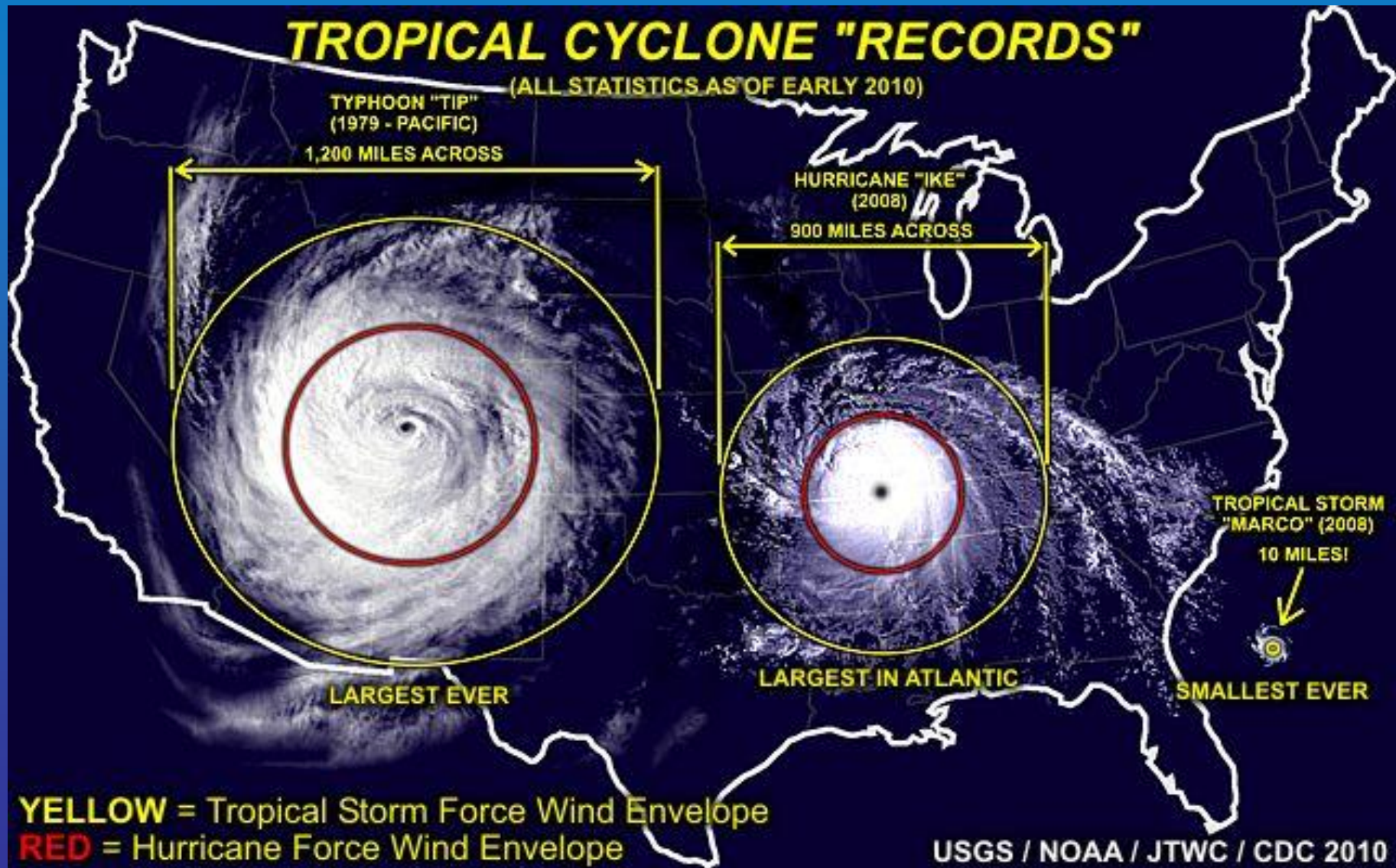
Where do they occur?

Tracks and Intensity of All Tropical Storms



Saffir-Simpson Hurricane Intensity Scale

Tropical cyclones come in different sizes



Historical Impacts of Hurricanes



A French Florida?

French assault on St. Augustine Florida thwarted by Hurricane in 1565 CE.
The French are expelled from FL by the Spanish.



Fort Caroline (Jacksonville), FL

Questions



- Why so much damage from Sandy?
- What is the relationship with SST and Atlantic hurricane activity during the historic period?
- How has hurricane activity varied prehistorically?
- Is there a relationship between changes prehistoric hurricane activity and SST
- How well does climate modeling capture historical and prehistoric hurricane activity? Should we trust them to predict the future?

Outline



- Background on hurricanes and climate
- Putting Hurricane Sandy in context
- What the long term (prehistoric) record tells us

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

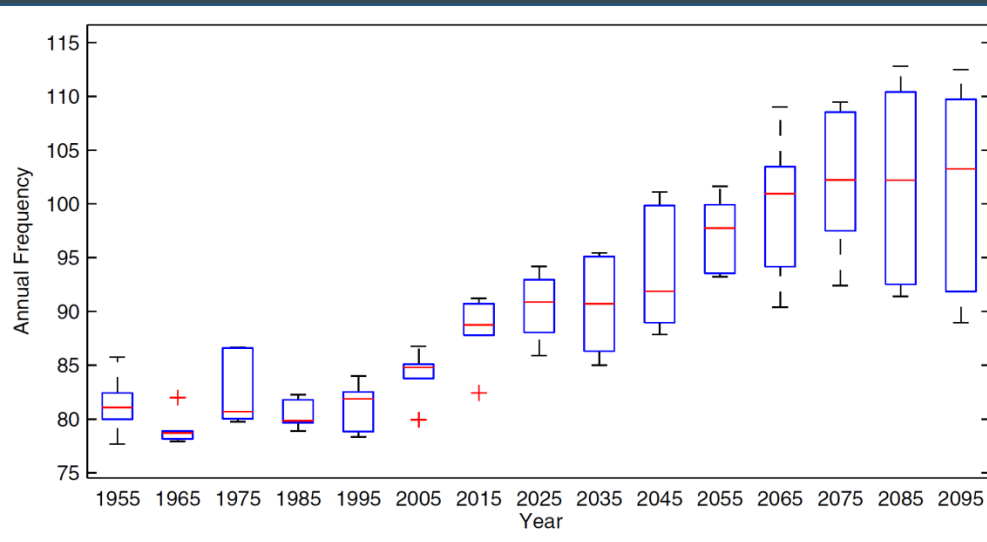
0.5m Sea Level Rise

1.0m Sea Level Rise

1.5m Sea Level Rise

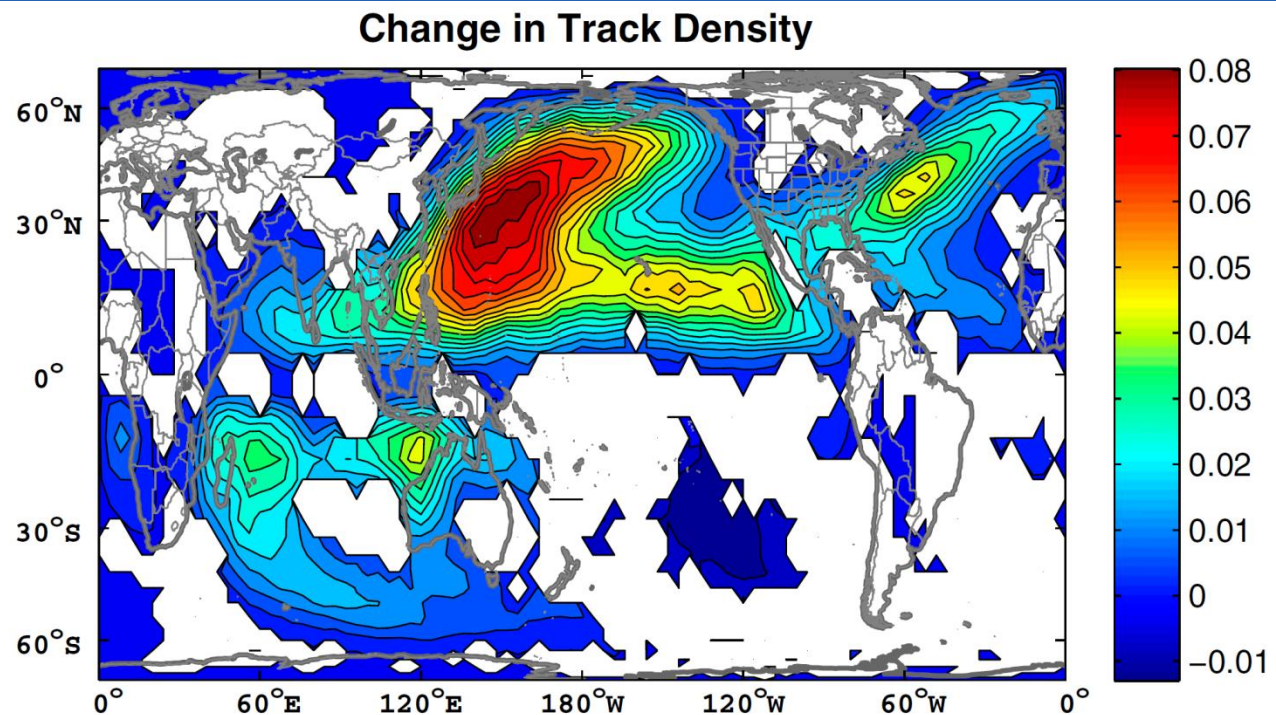
Falmouth

What Might the Future Hold?

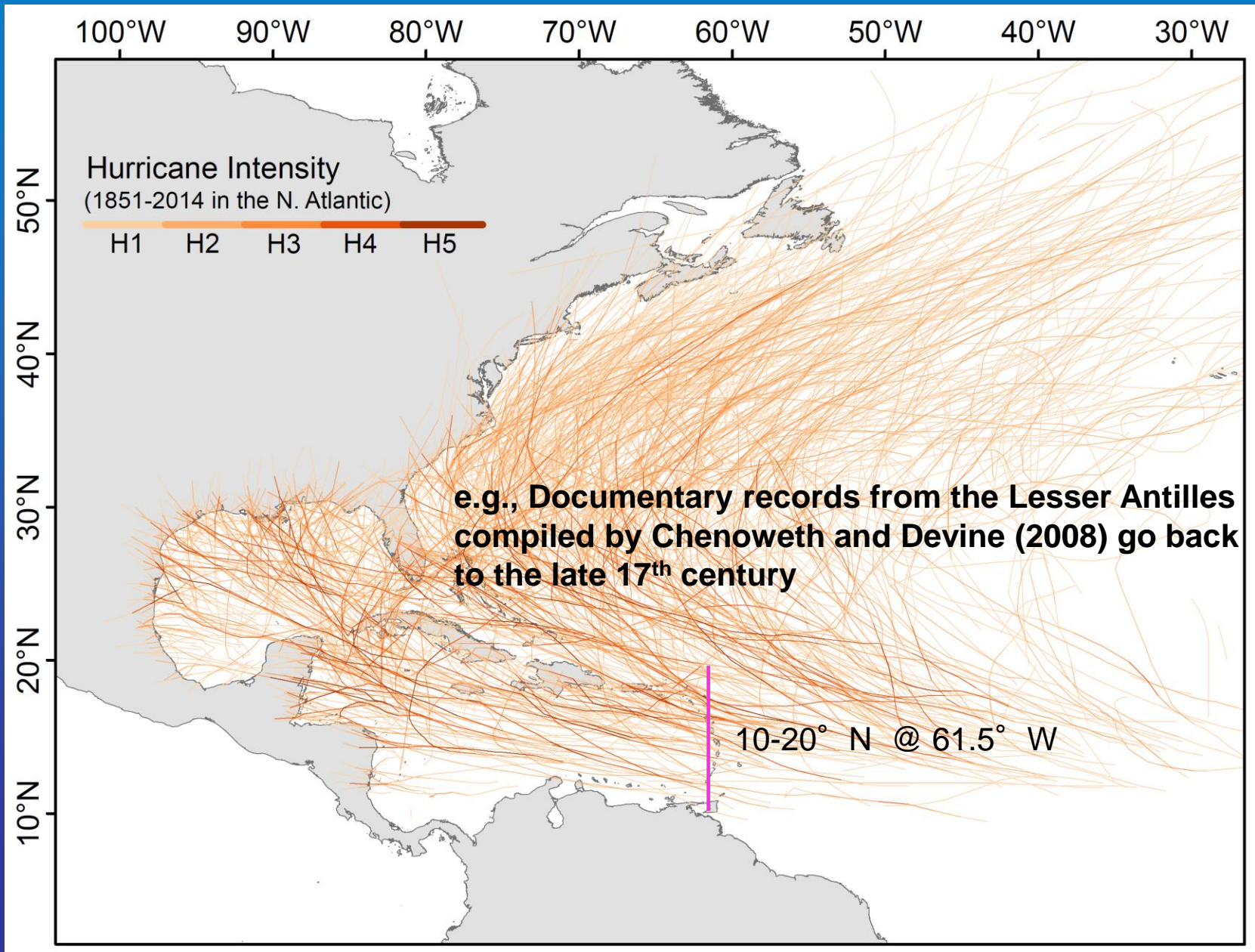


Frequency of
hurricanes
may increase
(particularly
intense storms)

From Emanuel, 2013 PNAS
Using IPCC AR5 models

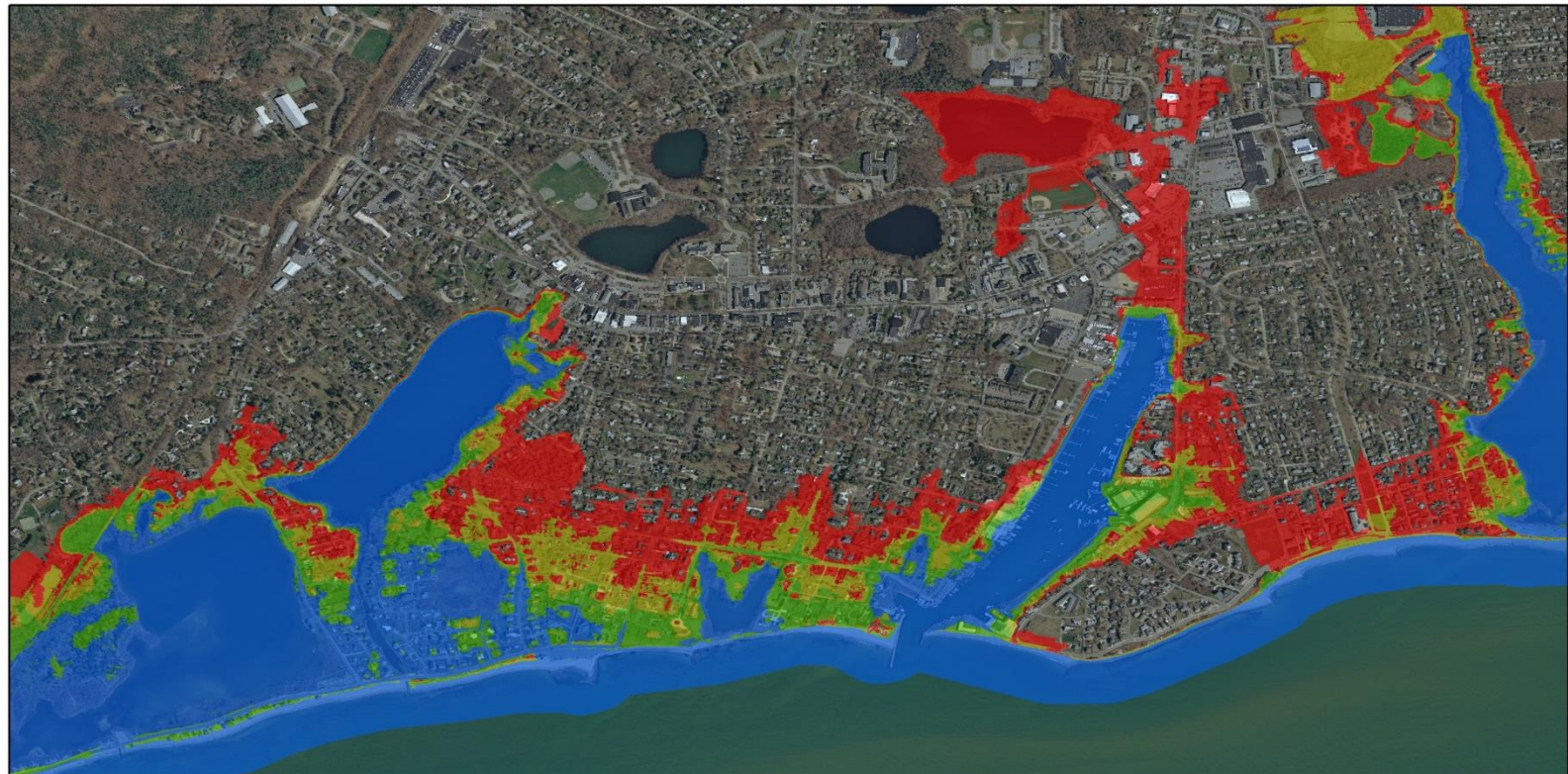


Regional historical compilations can extend the record back further



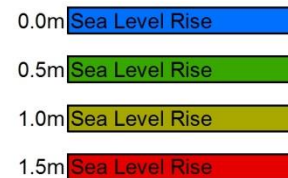
What if Hurricane Bob Struck Again?

Hurricane Bob - 1991



0 0.5 1 1.5 Kilometers

Maximum Surge Heights Under Different Sea Levels

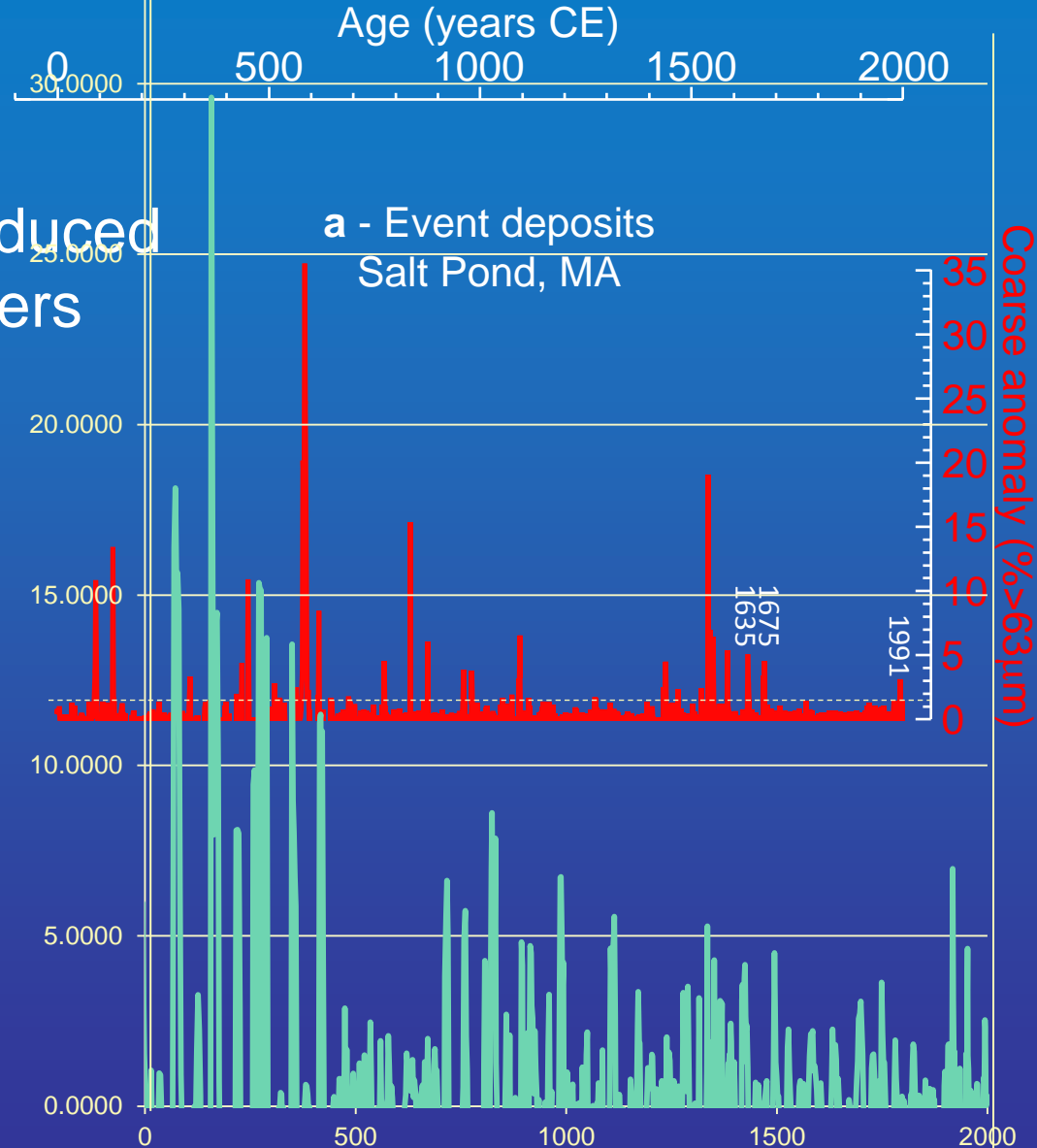


Falmouth

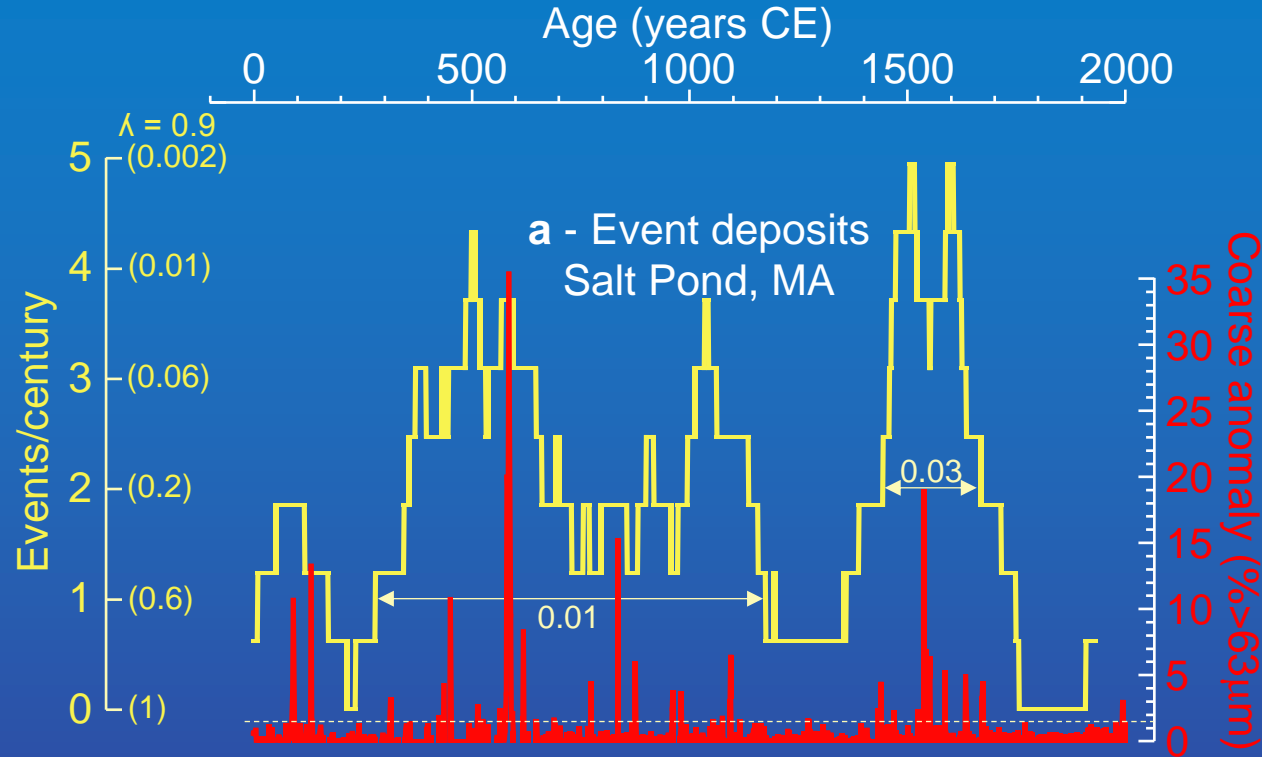
Prehistoric Hurricanes and Climate



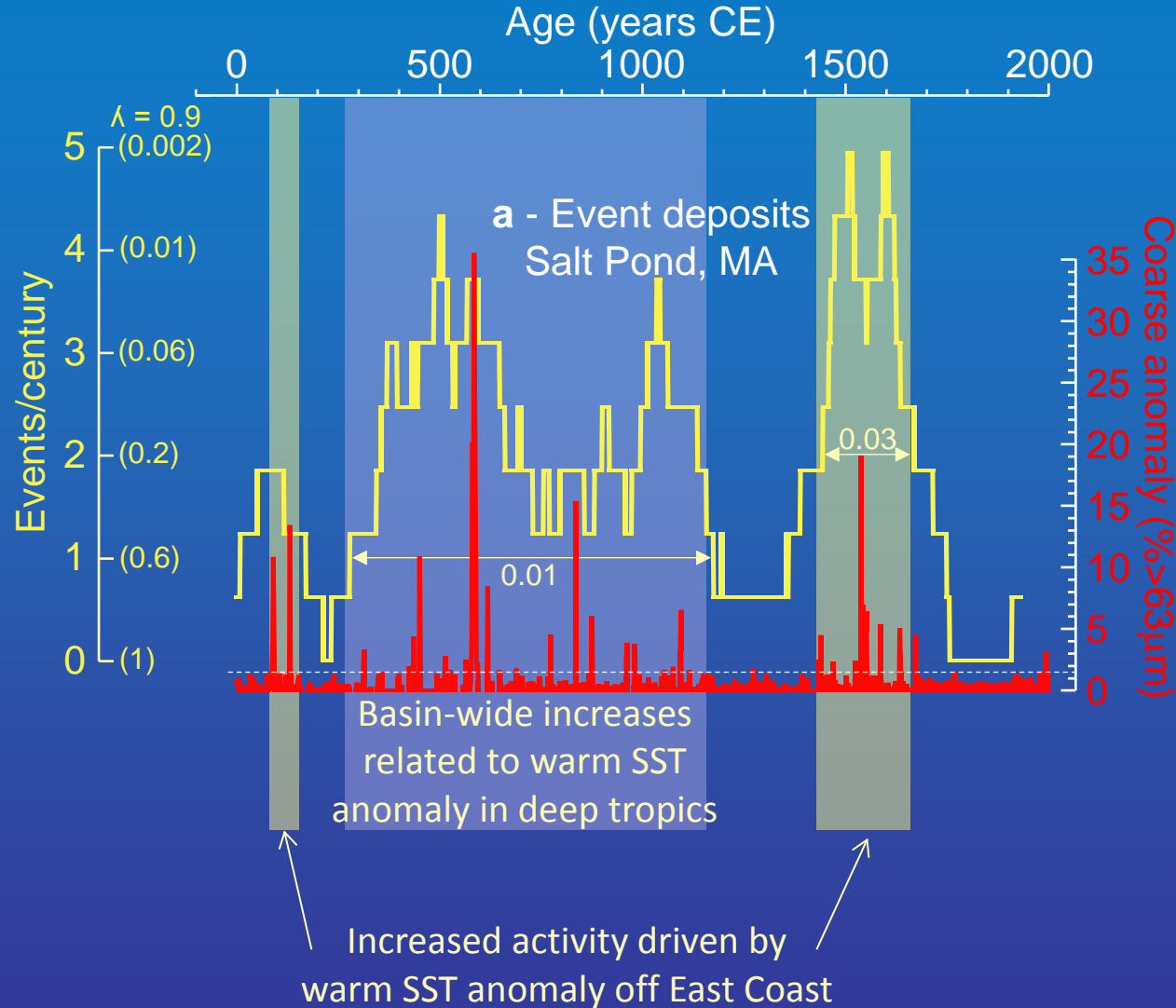
Hurricane-induced Sand Layers



Prehistoric Hurricanes and Climate



Prehistoric Hurricanes and Climate



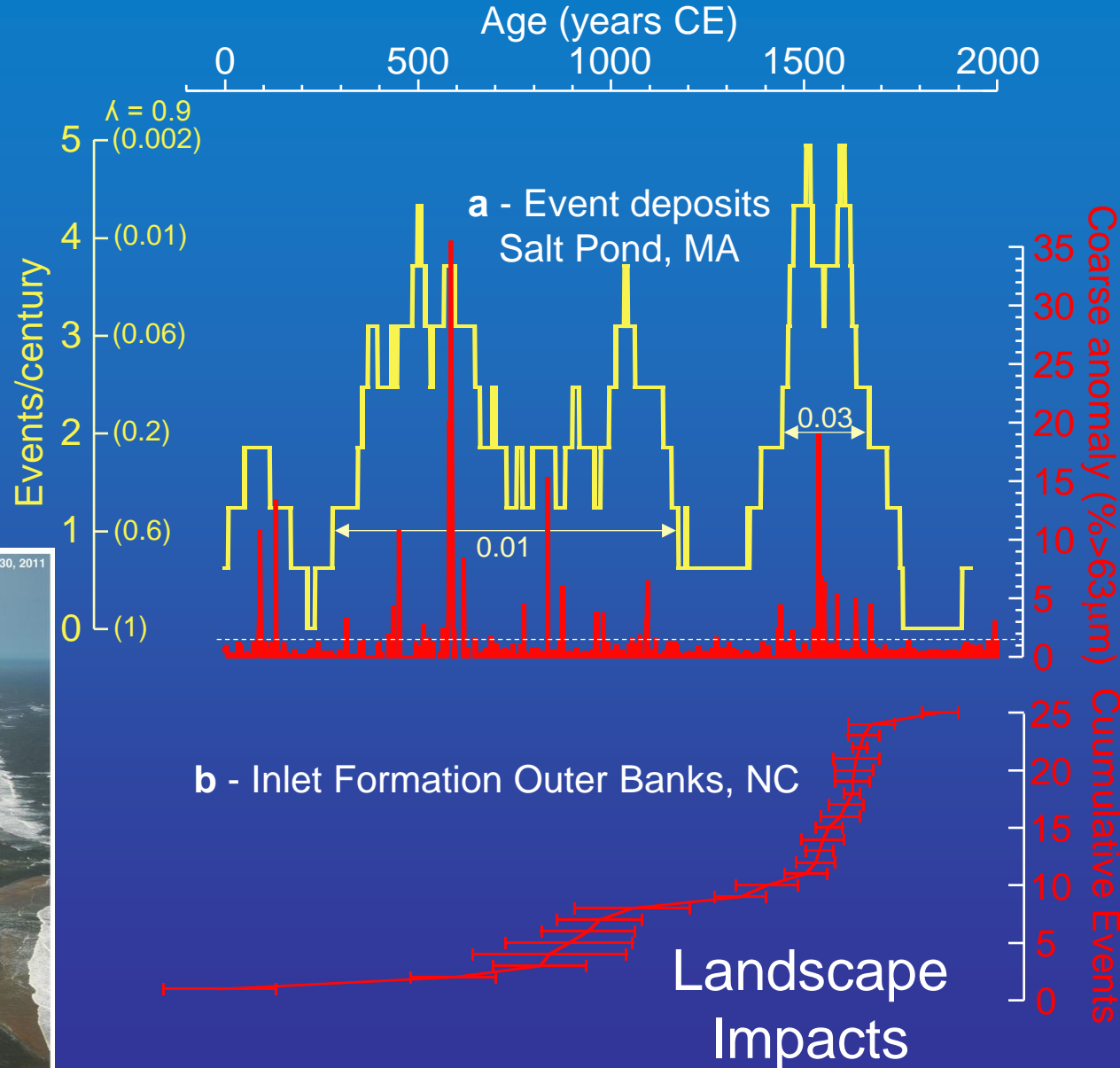
Intensity



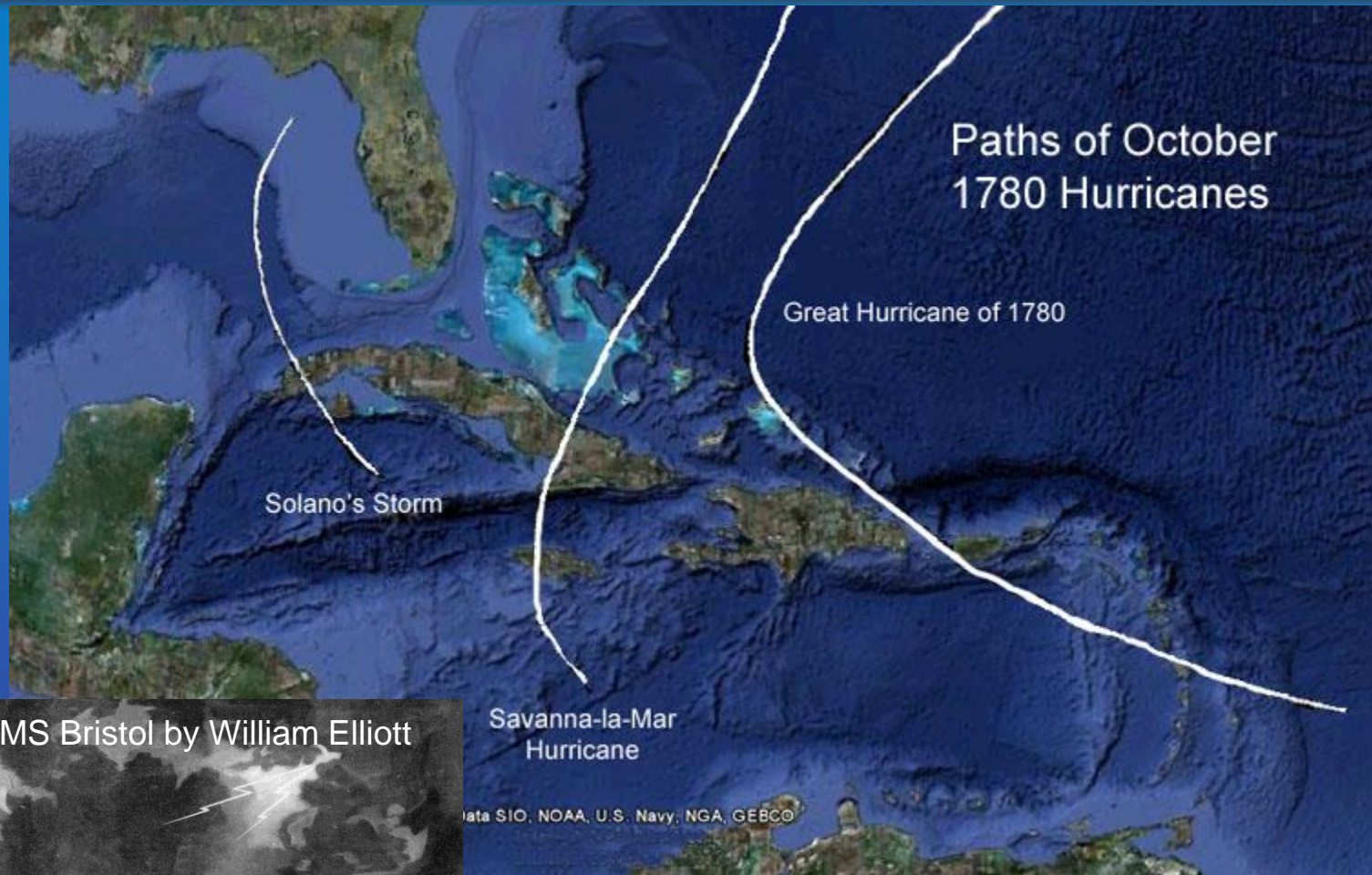
Saffir-Simpson Scale for Hurricane Classification

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		

Prehistoric Hurricanes and Climate



Infamous Atlantic Hurricanes



HMS Hector and HMS Bristol by William Elliott



More than 23,000 fatalities
in Great Hurricane of 1780

Infamous Atlantic Hurricanes



1900 Galveston, TX Hurricane

Category 4 at landfall

5,000-12,000 fatalities

No warning – weather service predicted track along eastern seaboard



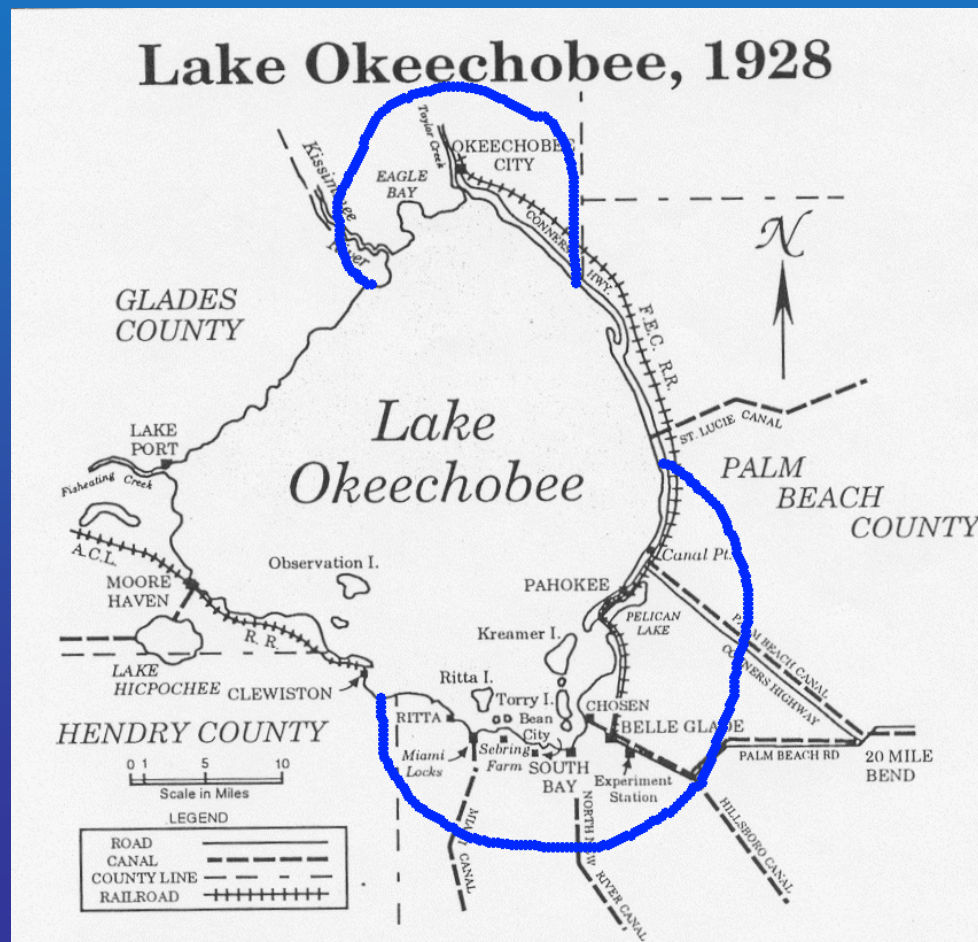
Infamous Atlantic Hurricanes



1928 San Felipe II or Okeechobee Hurricane

Category 5 in Puerto Rico/Category 4 at FL landfall

Over 4,000 fatalities total
2,500 at Lake Okeechobee



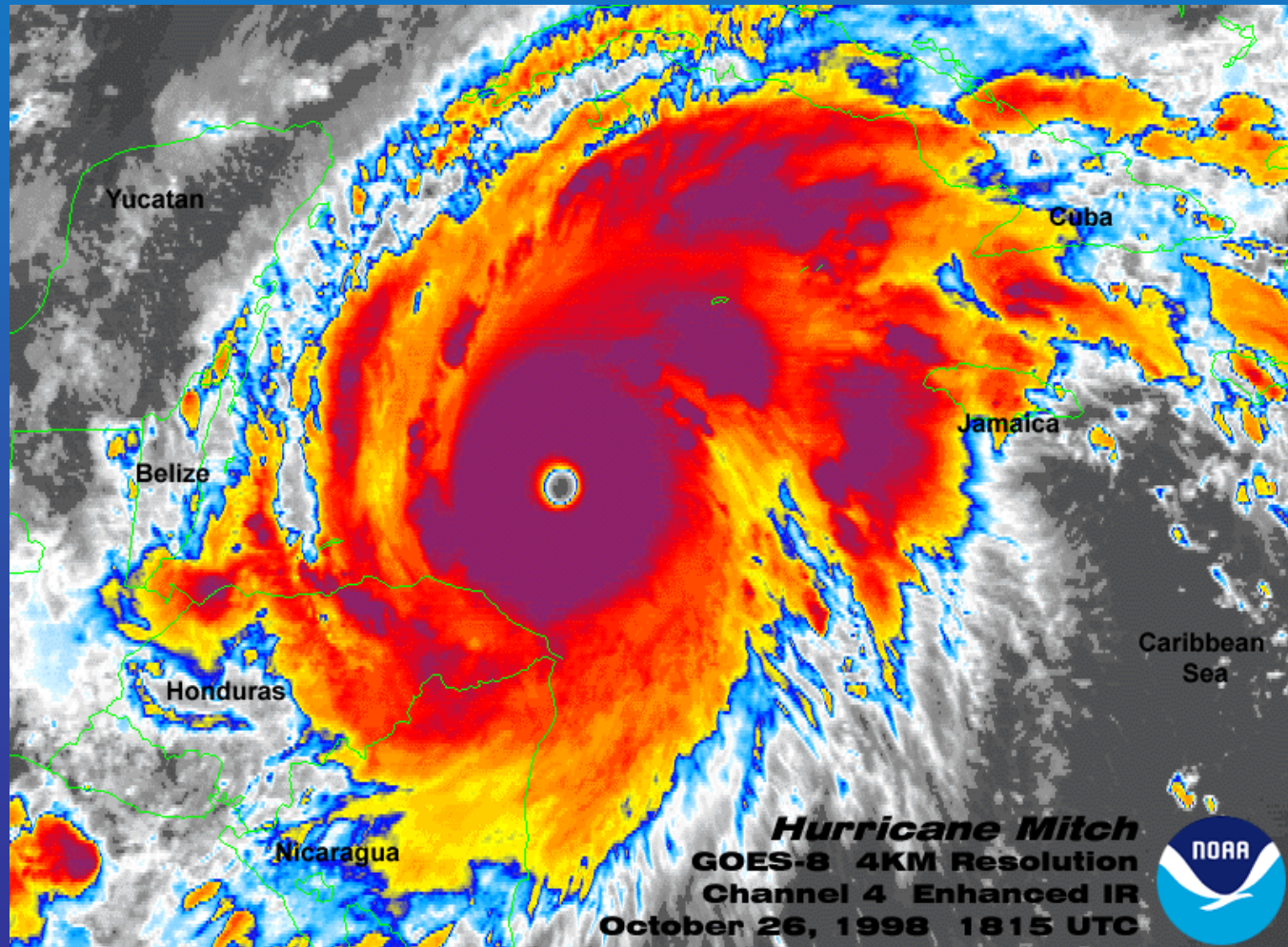
Infamous Atlantic Hurricanes



Hurricane Mitch in 1998

20,000 fatalities (mostly in Honduras)

Made landfall as a cat 1 but dumped nearly a meter of rain



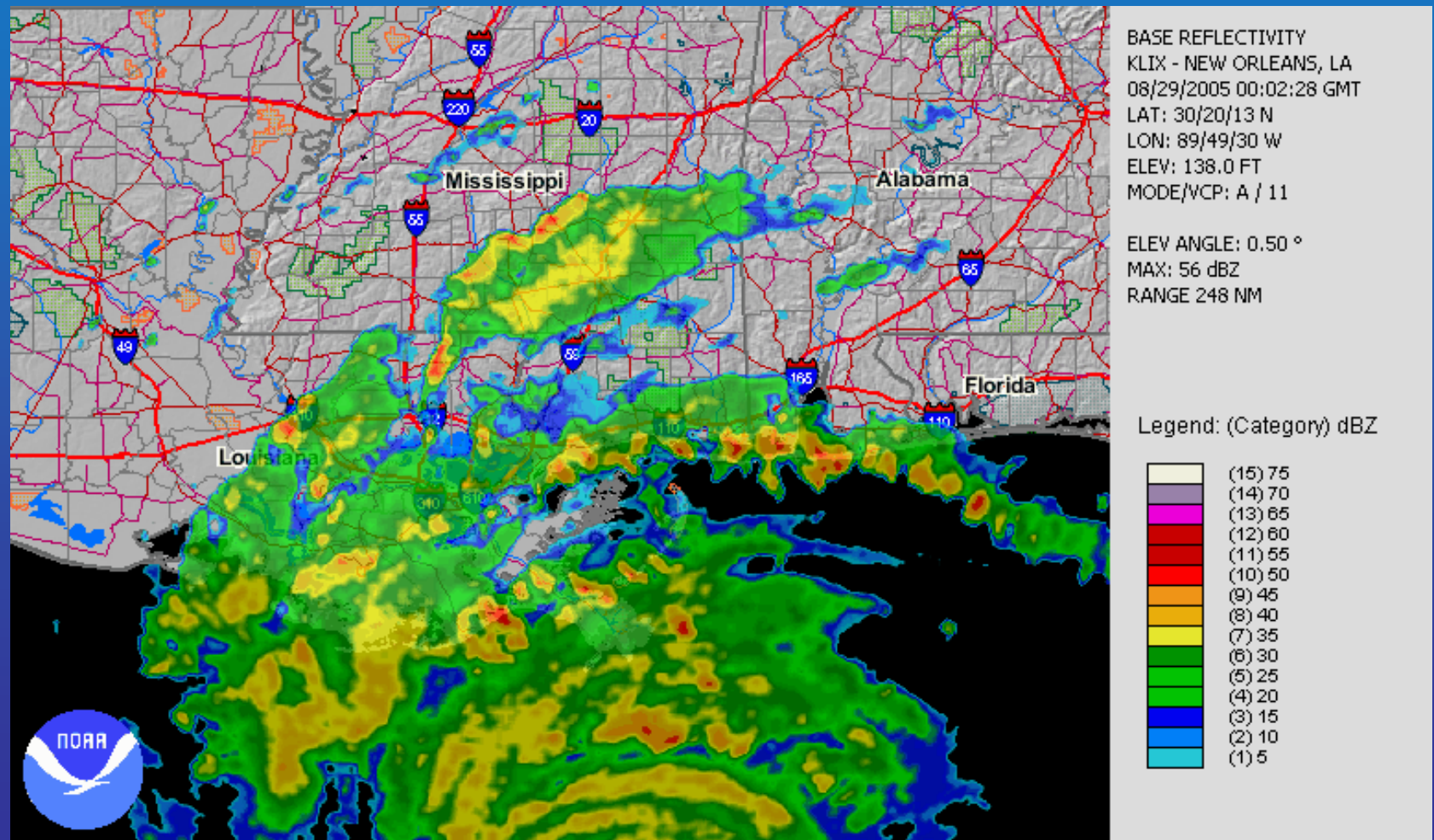
Infamous Atlantic Hurricanes



Hurricane Katrina 2005

1833 fatalities

81 billion dollars of damage



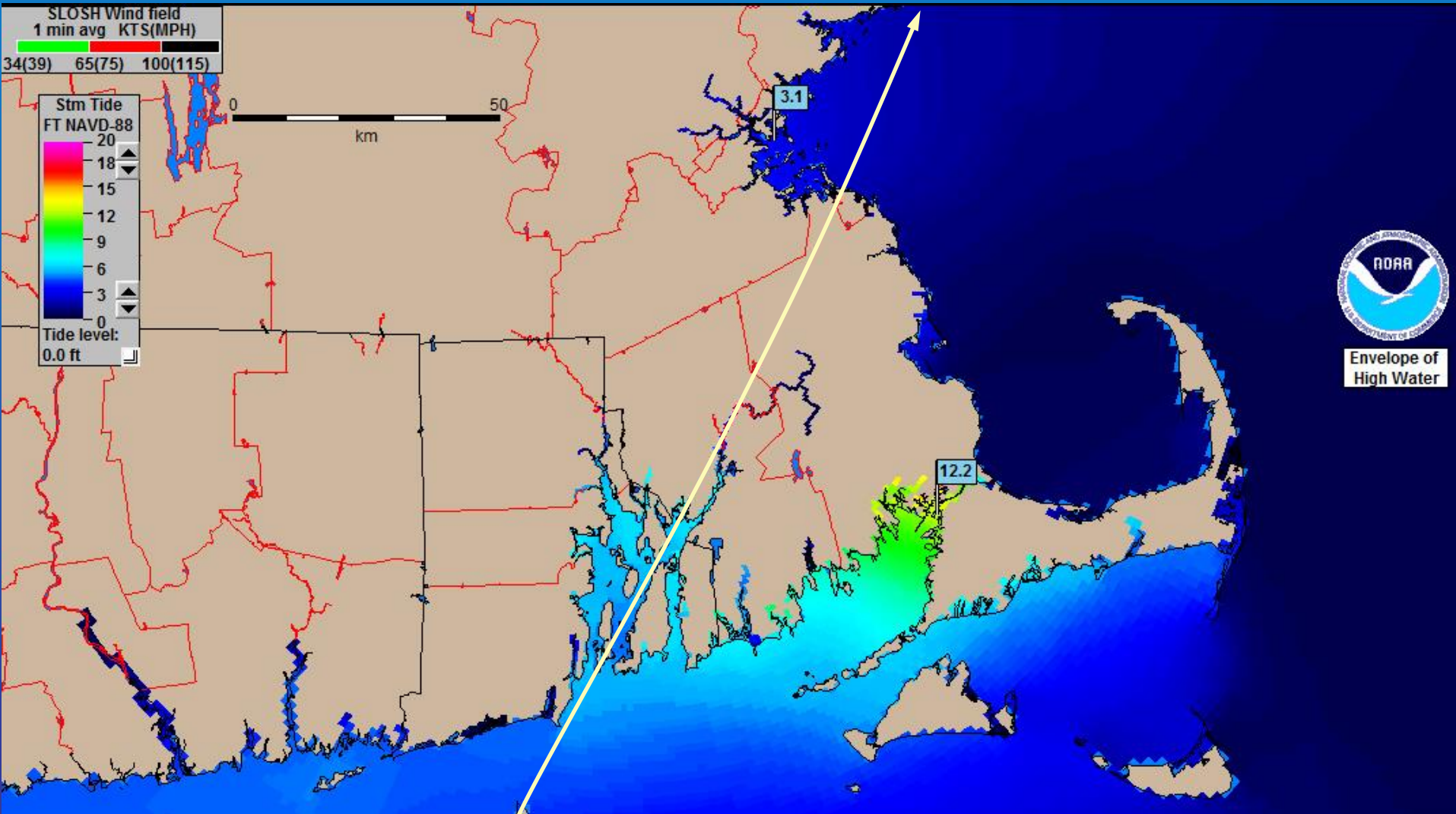
Hurricane Records from Blueholes

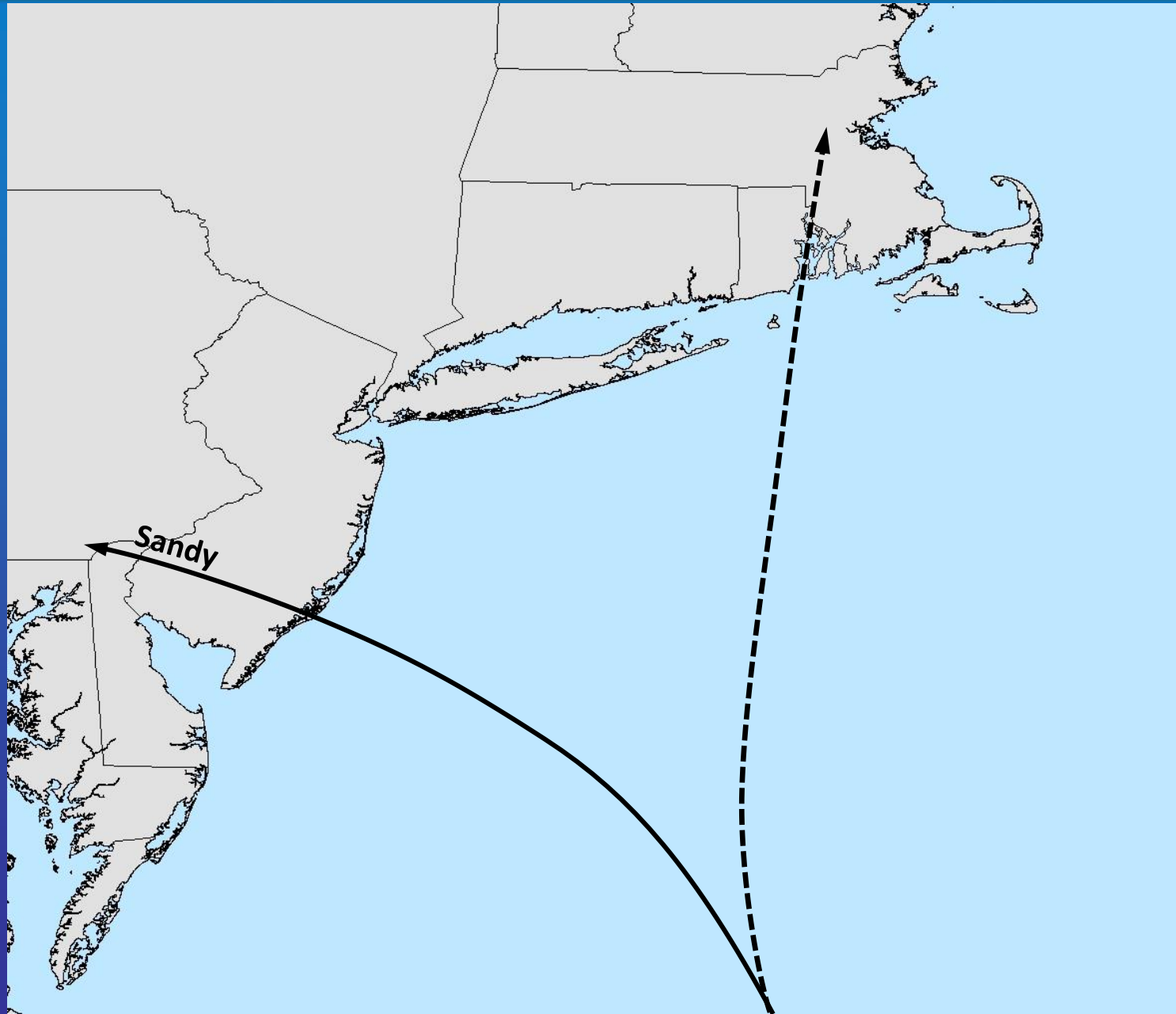


What about eastern MA?

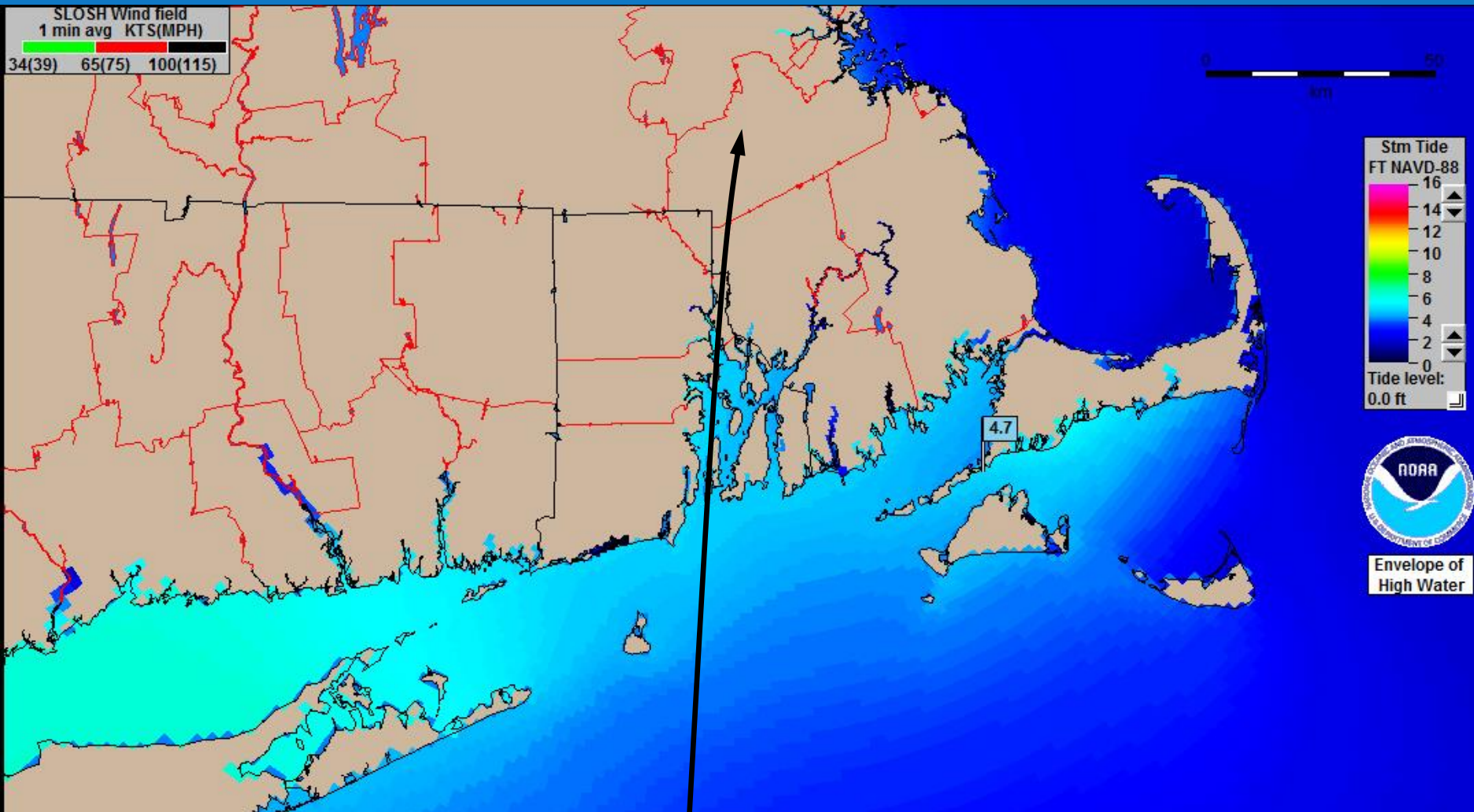


Hurricane Bob (1991) Storm Surge

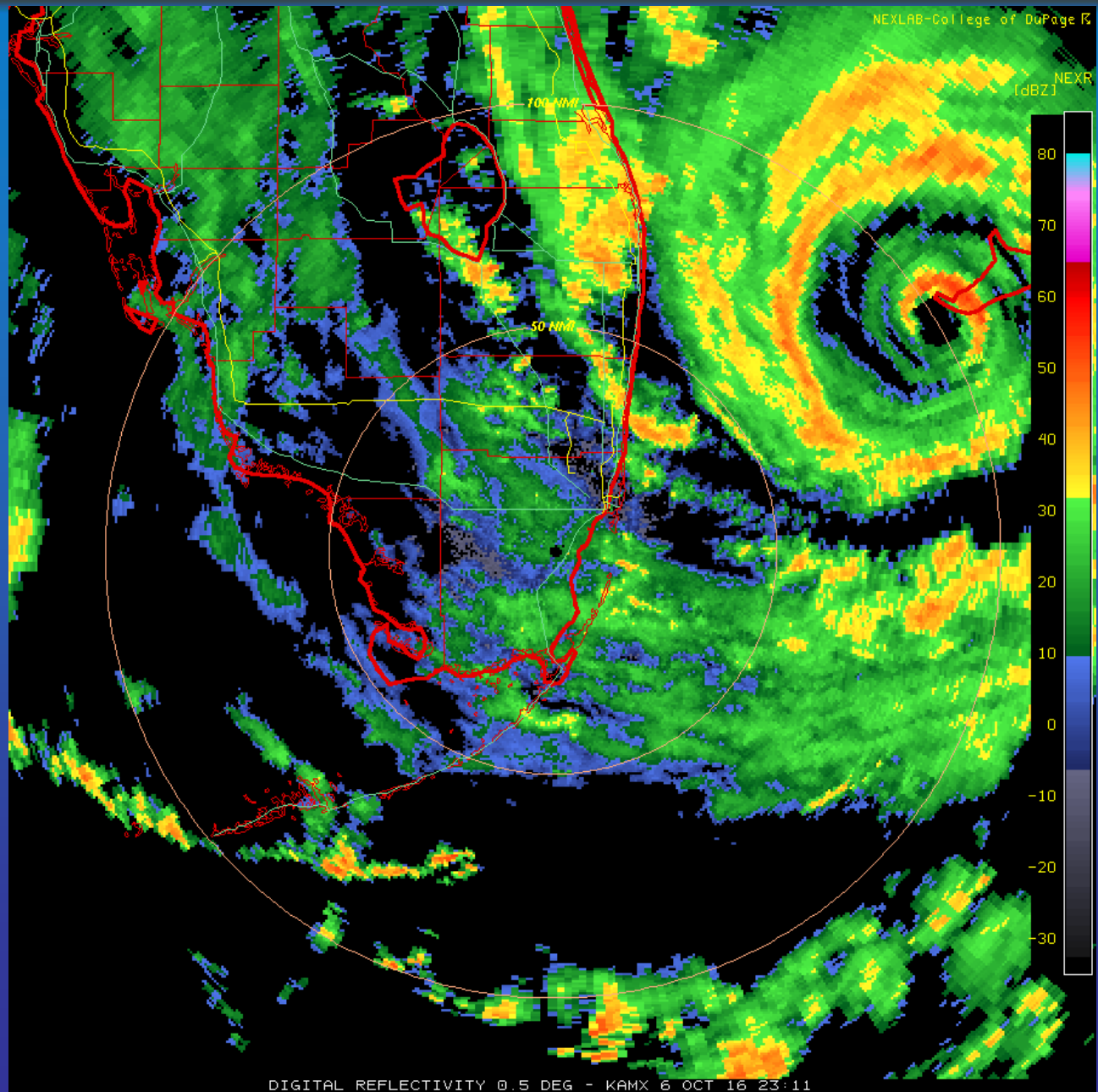




What if Sandy hit SE New England?



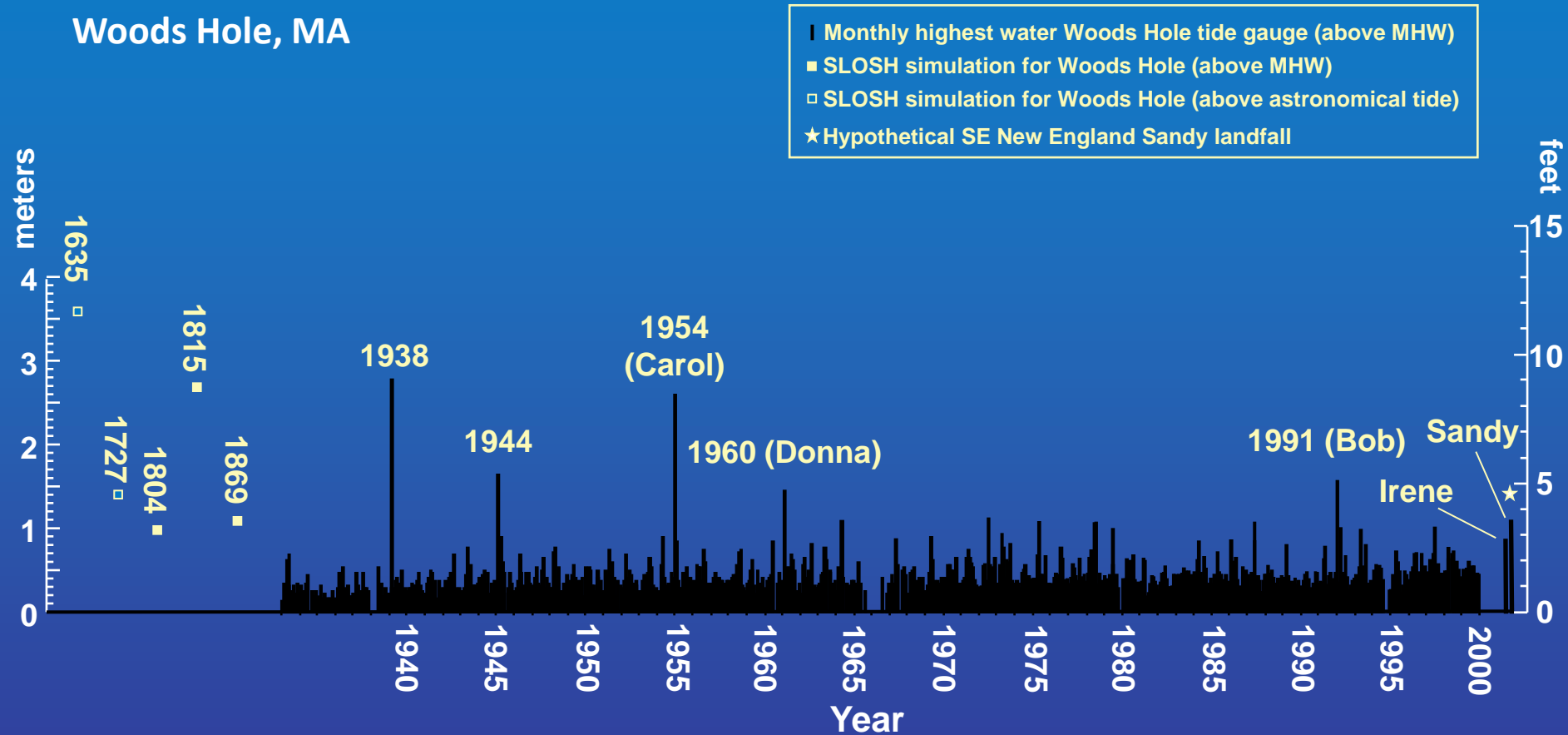
~1.4 m of surge at Woods Hole



What if Sandy hit SE New England?



Woods Hole, MA



Sedimentary Records of Hurricane Strikes



Overwash sand layer

Overwash sand layer

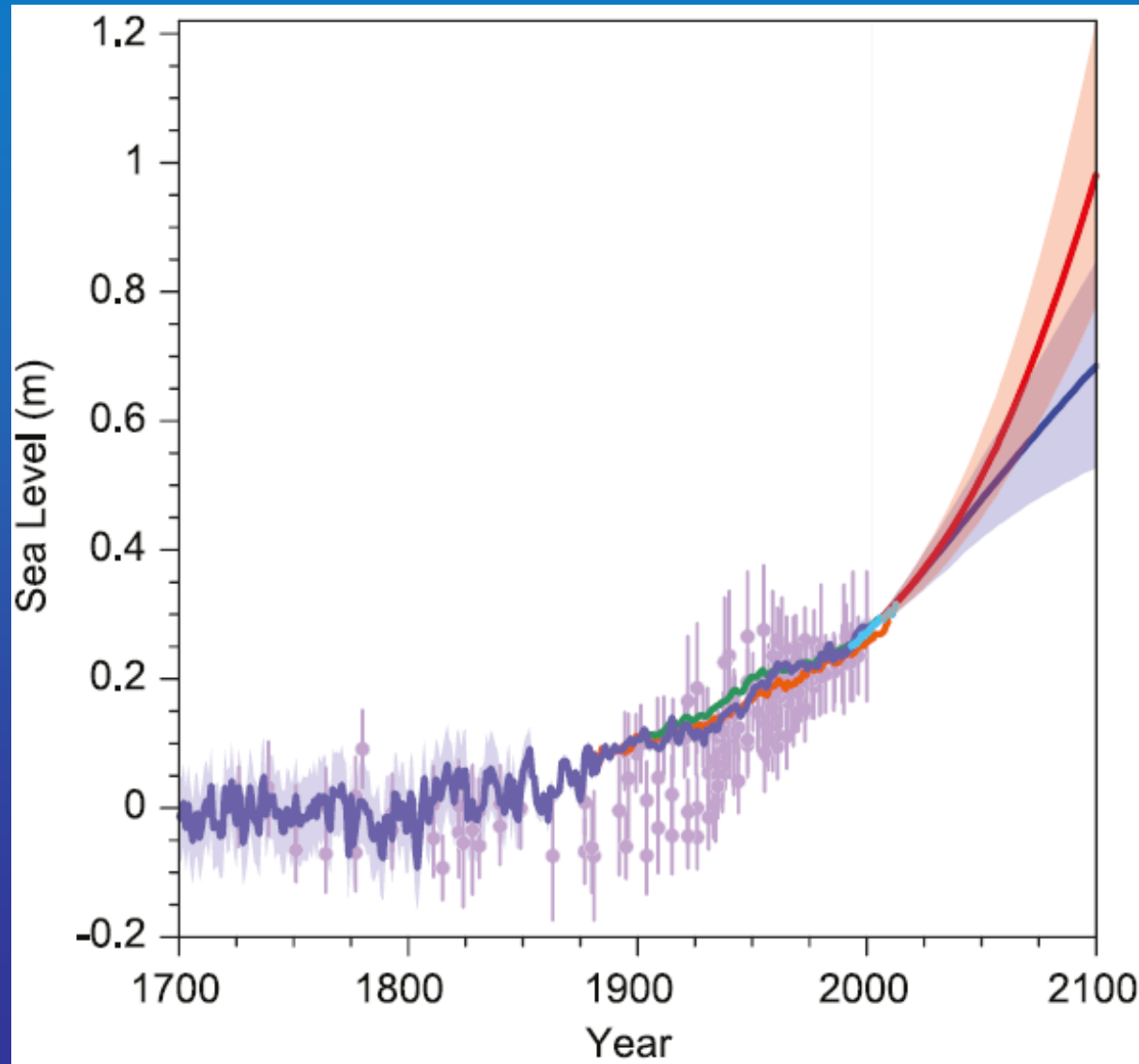
1 foot

Overwash sand layer
Overwash sand layer

What Might the Future Hold?



Rate of sea-level rise will continue to accelerate

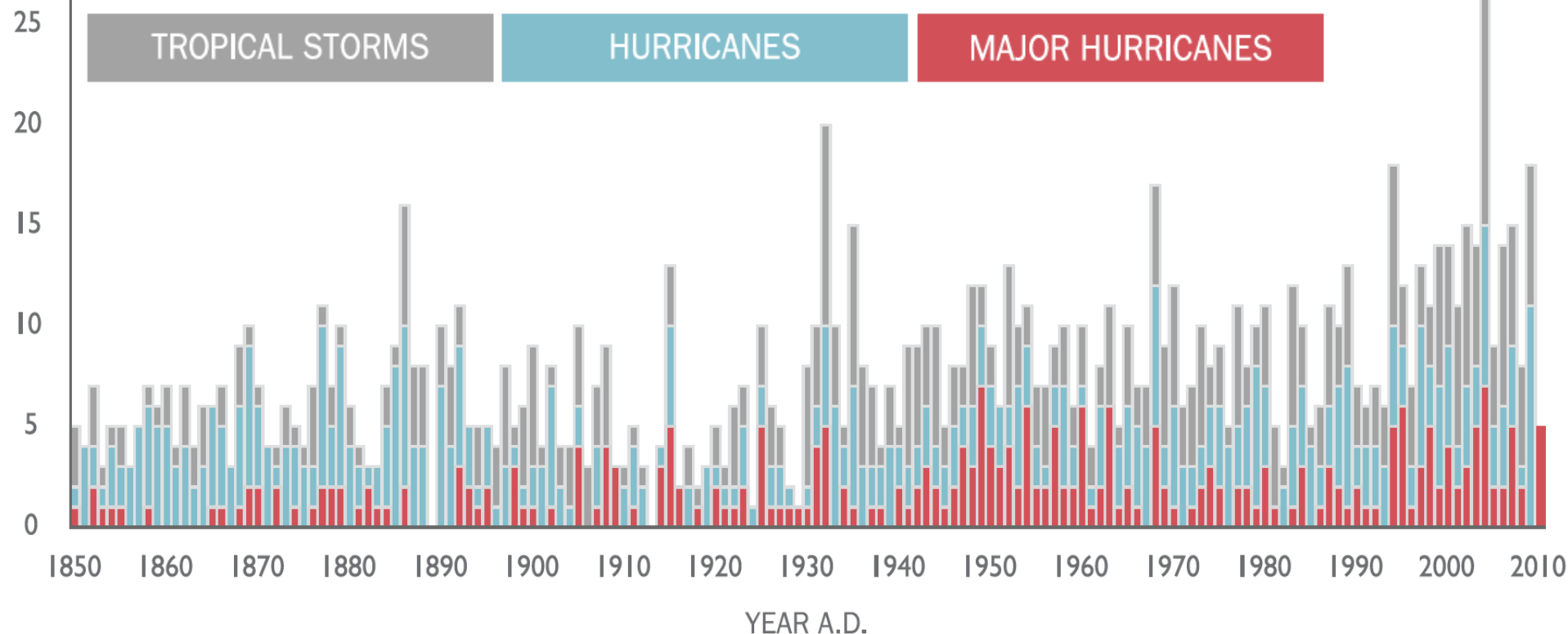


IPCC AR5

Recent Hurricane Trends



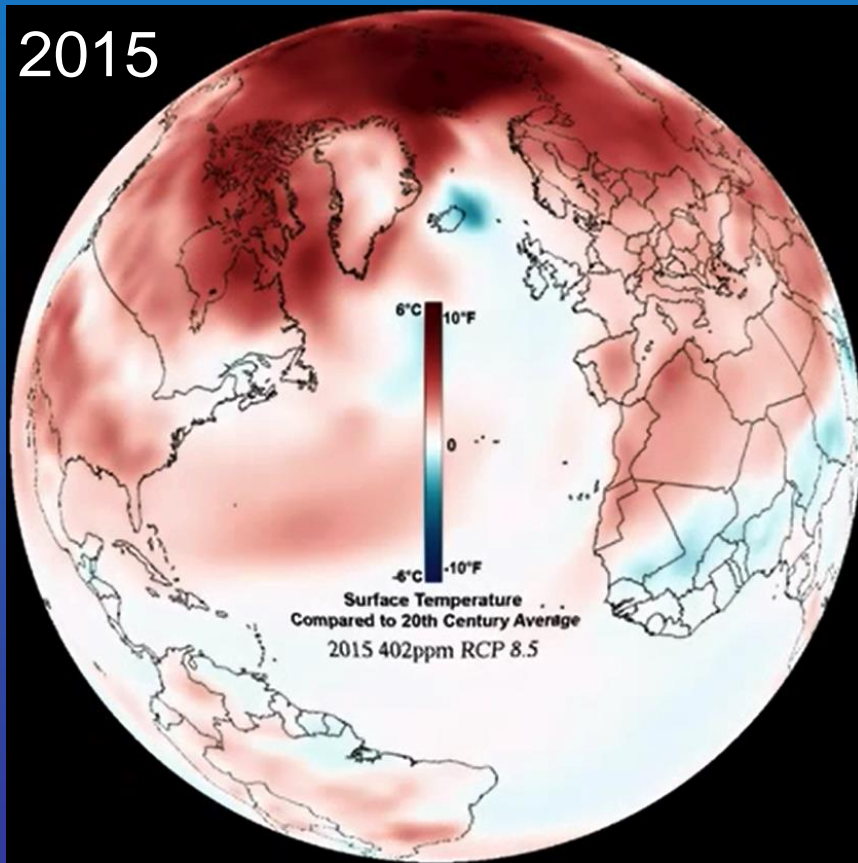
ANNUAL FREQUENCY OF NORTH ATLANTIC TROPICAL CYCLONES



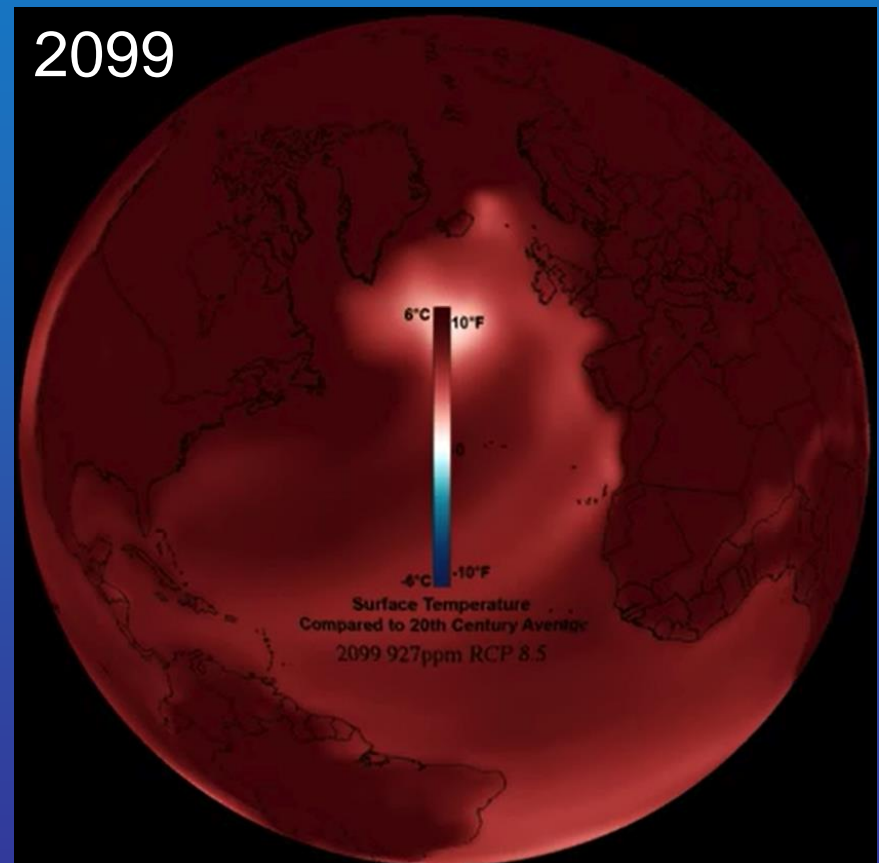
What Might the Future Hold?

Temperatures will continue to warm

2015



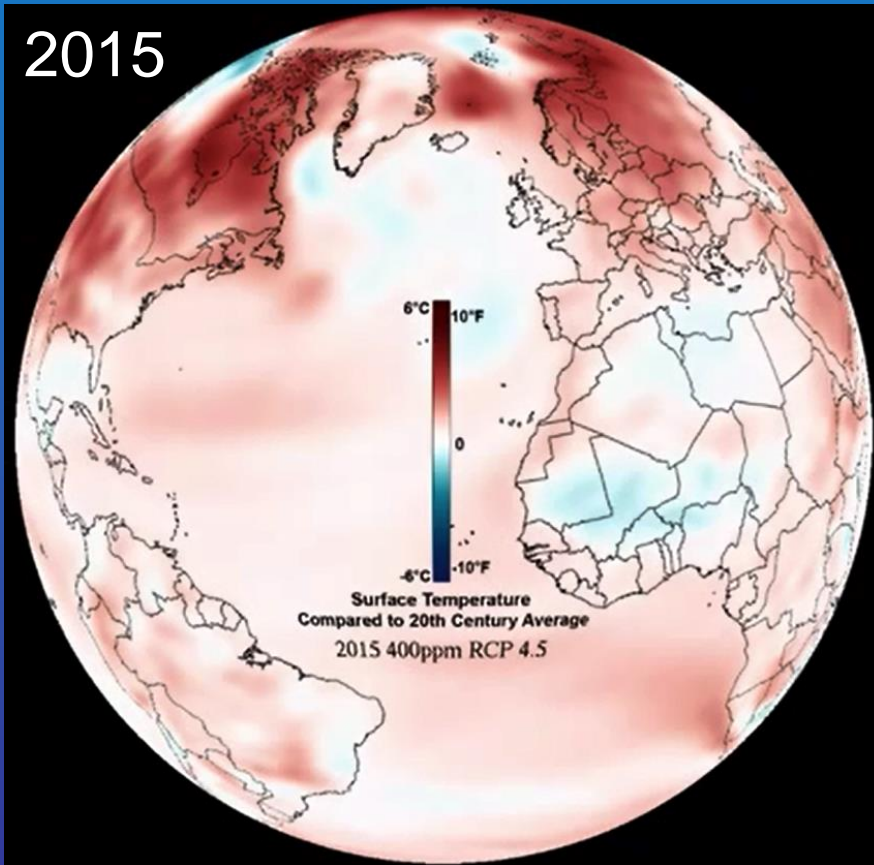
2099



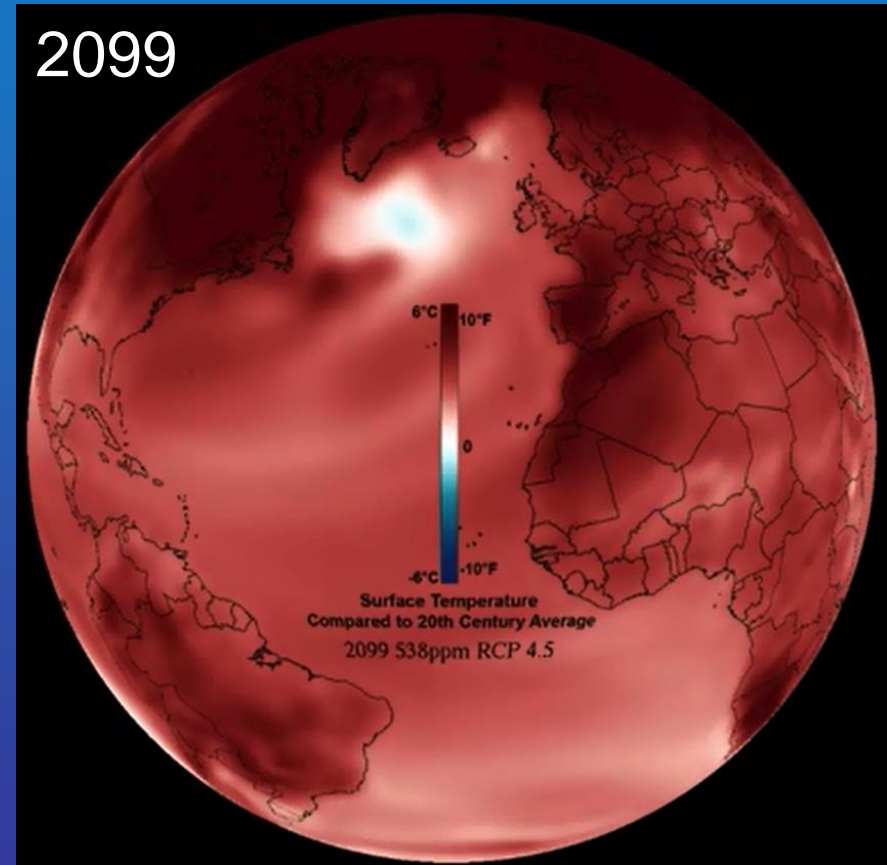
What Might the Future Hold?

Temperatures will continue to warm

2015

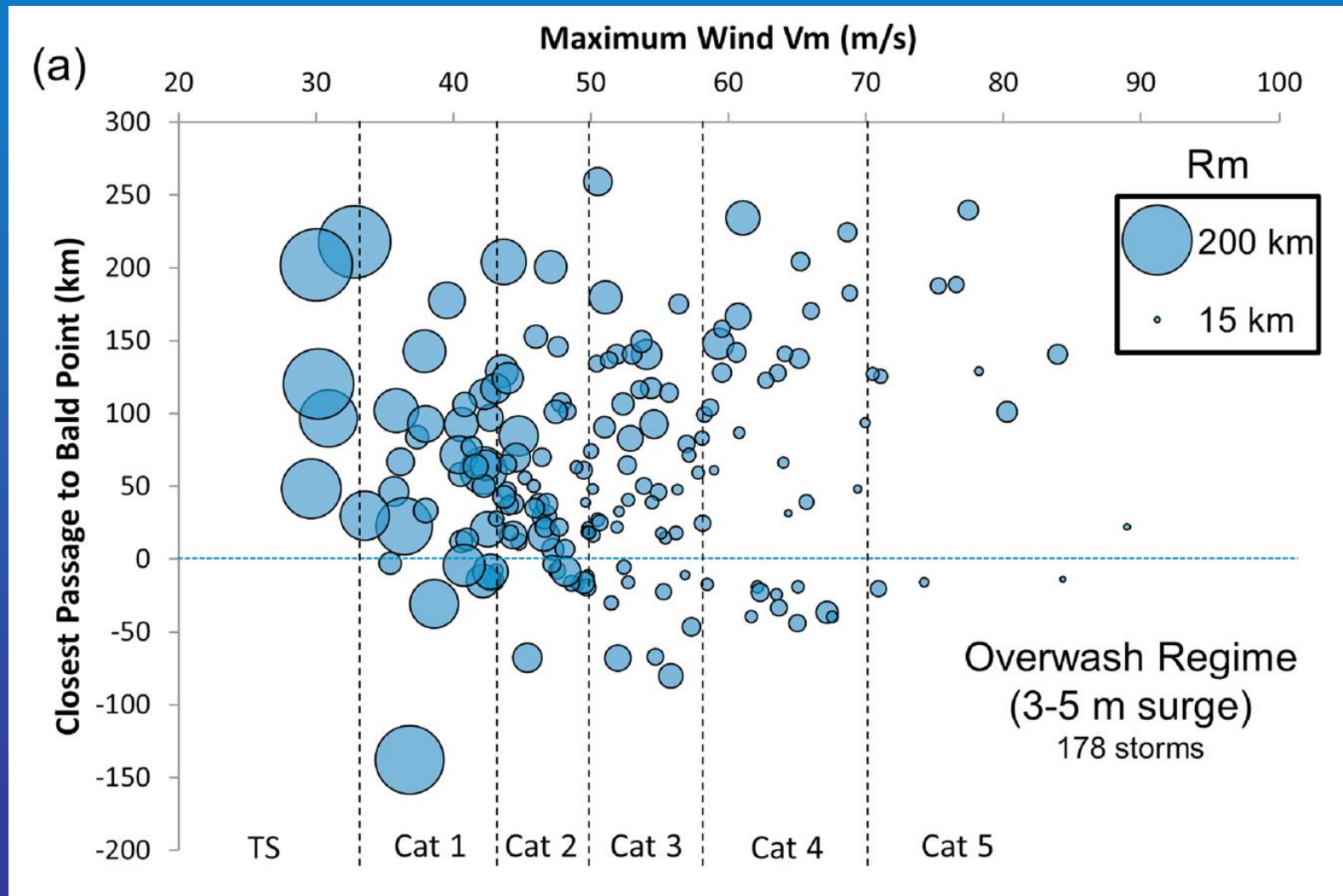


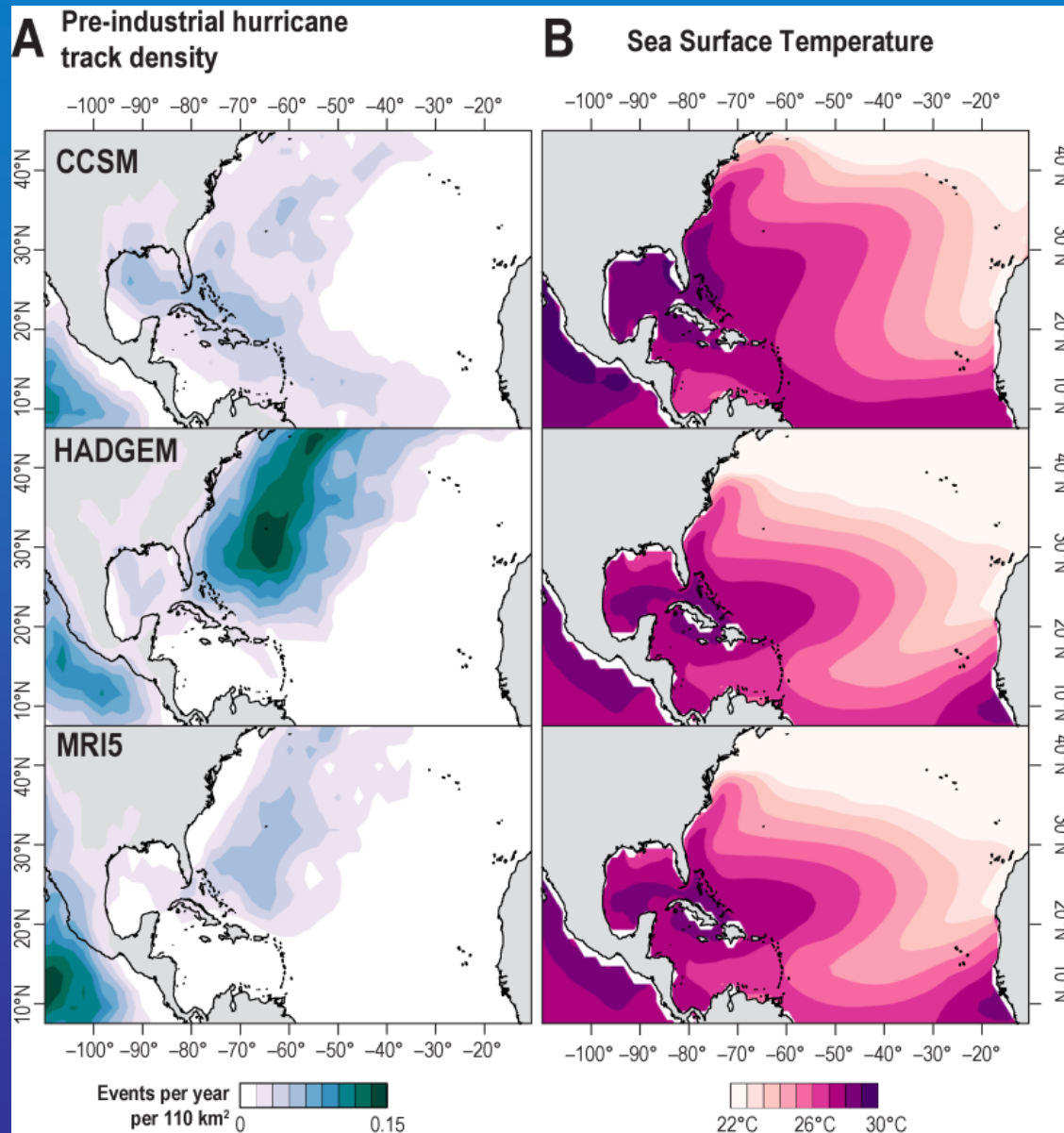
2099



Similar to COP 21

Record from Florida Panhandle (Mullet Pond)

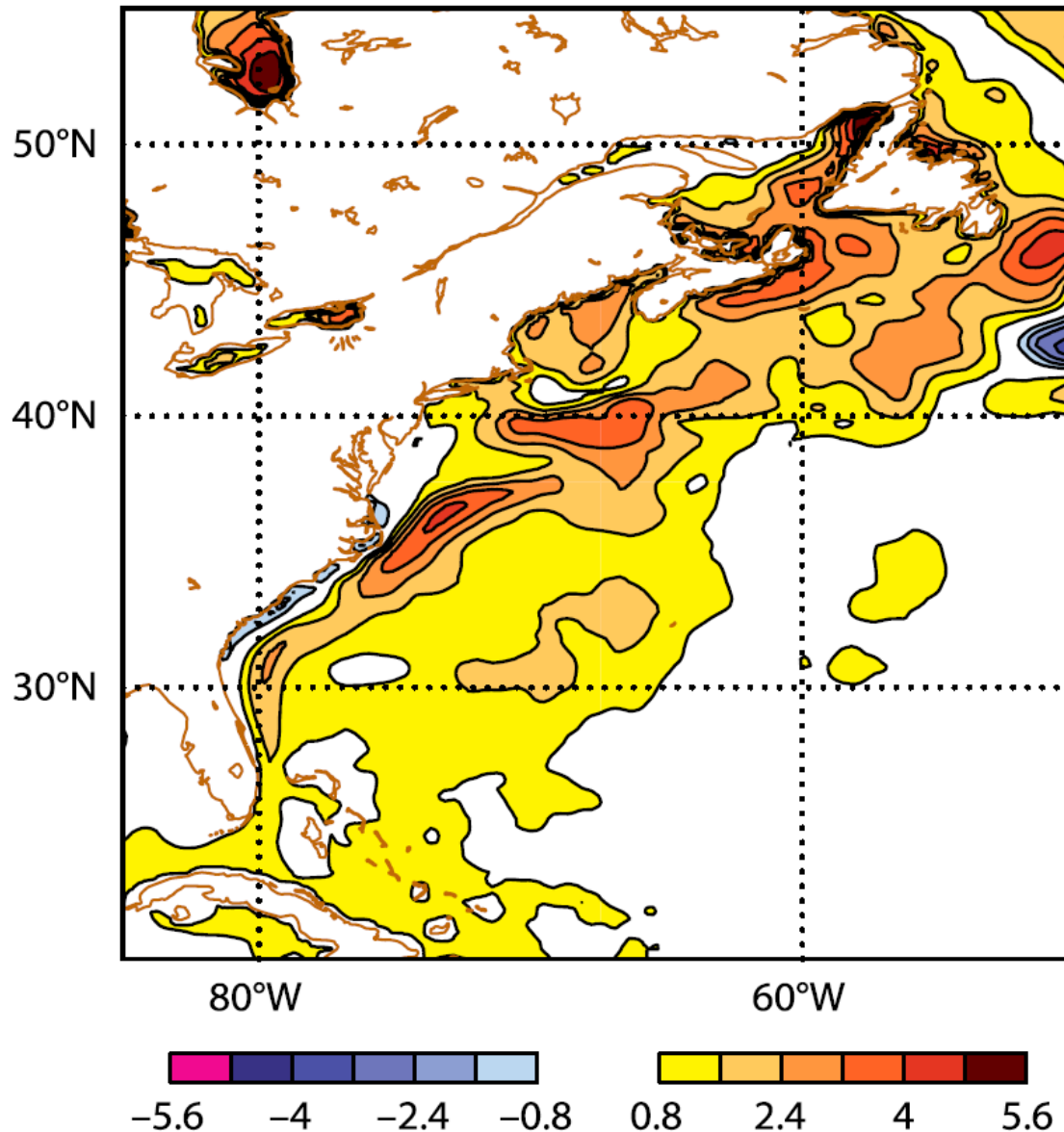




Influence of warm SSTs on Sandy



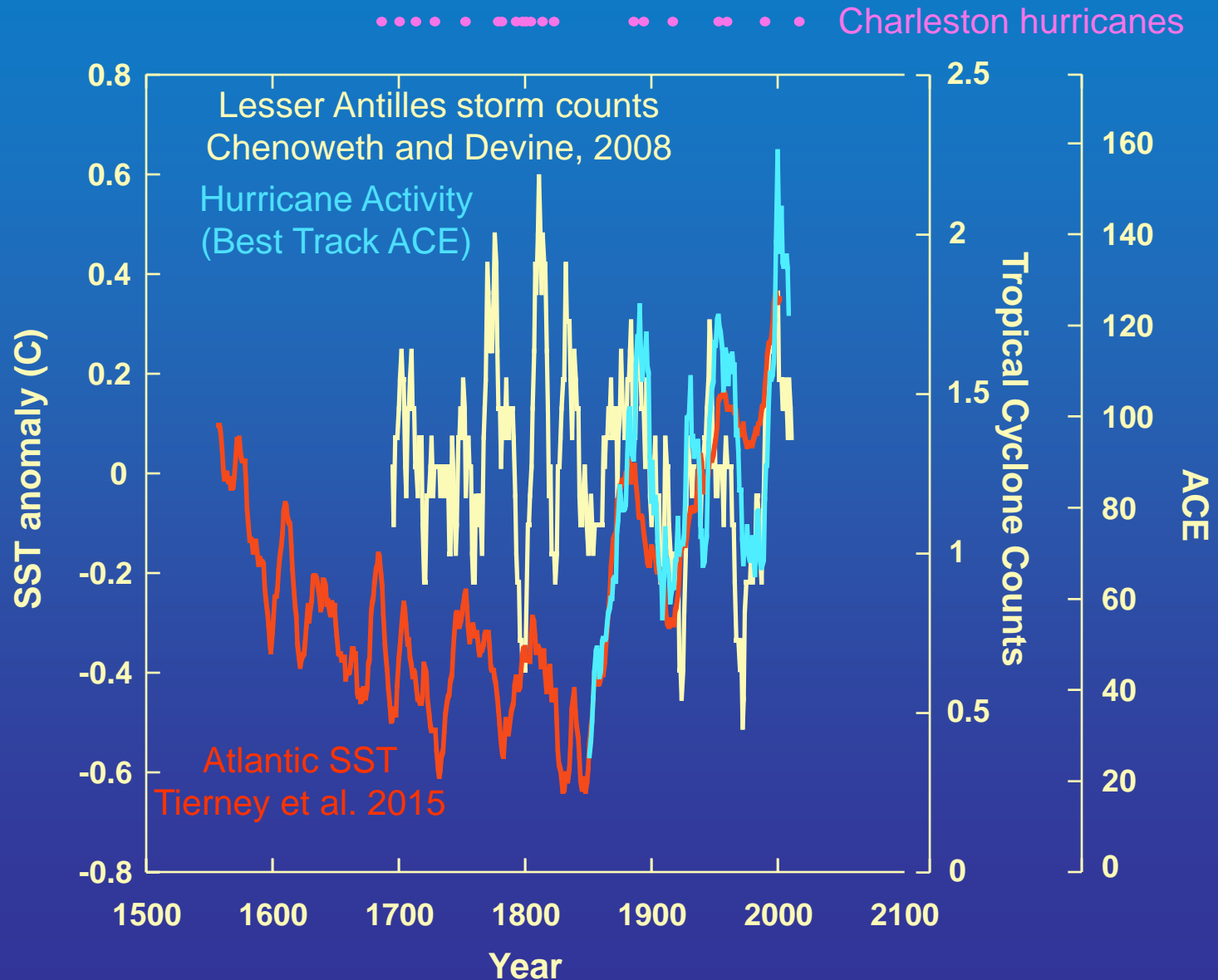
c) SST difference



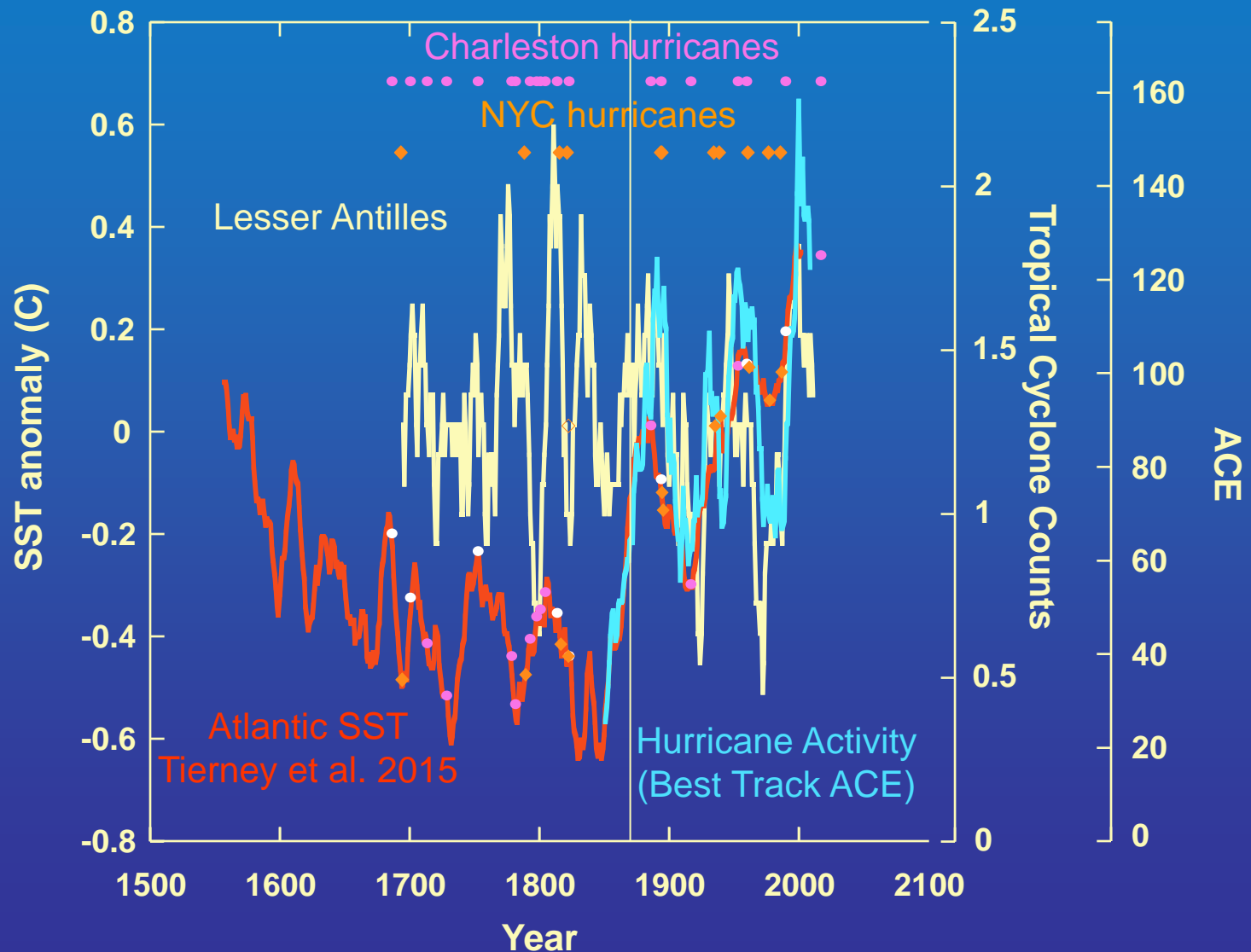
The average depth of the storm was increased by 7.6 hPa, the wind speeds were increased by 3.6 m s⁻¹ and the precipitation increased by 35%.

Magnussen et al. 2014
Monthly Weather Review

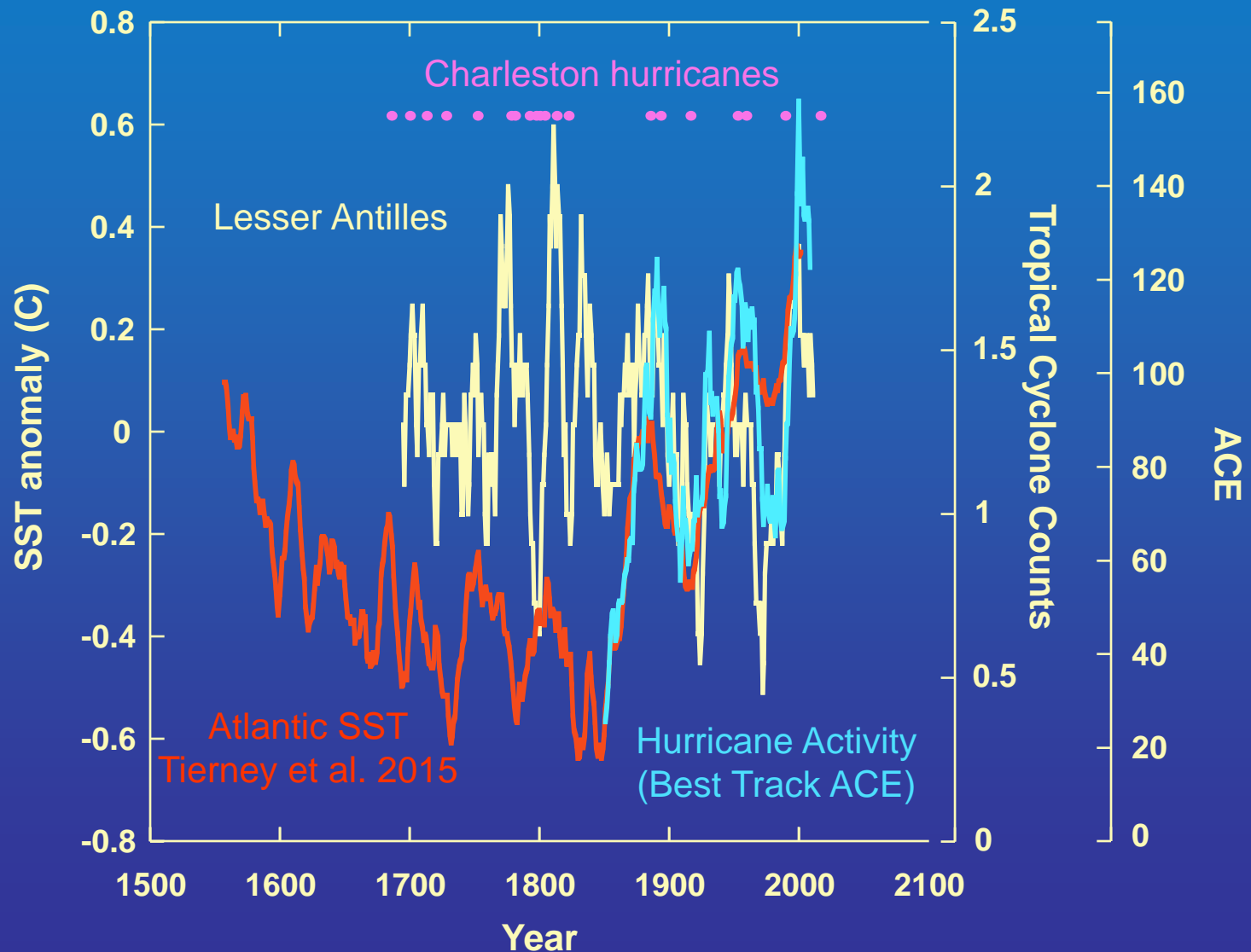
Hurricanes and Sea Surface Temp



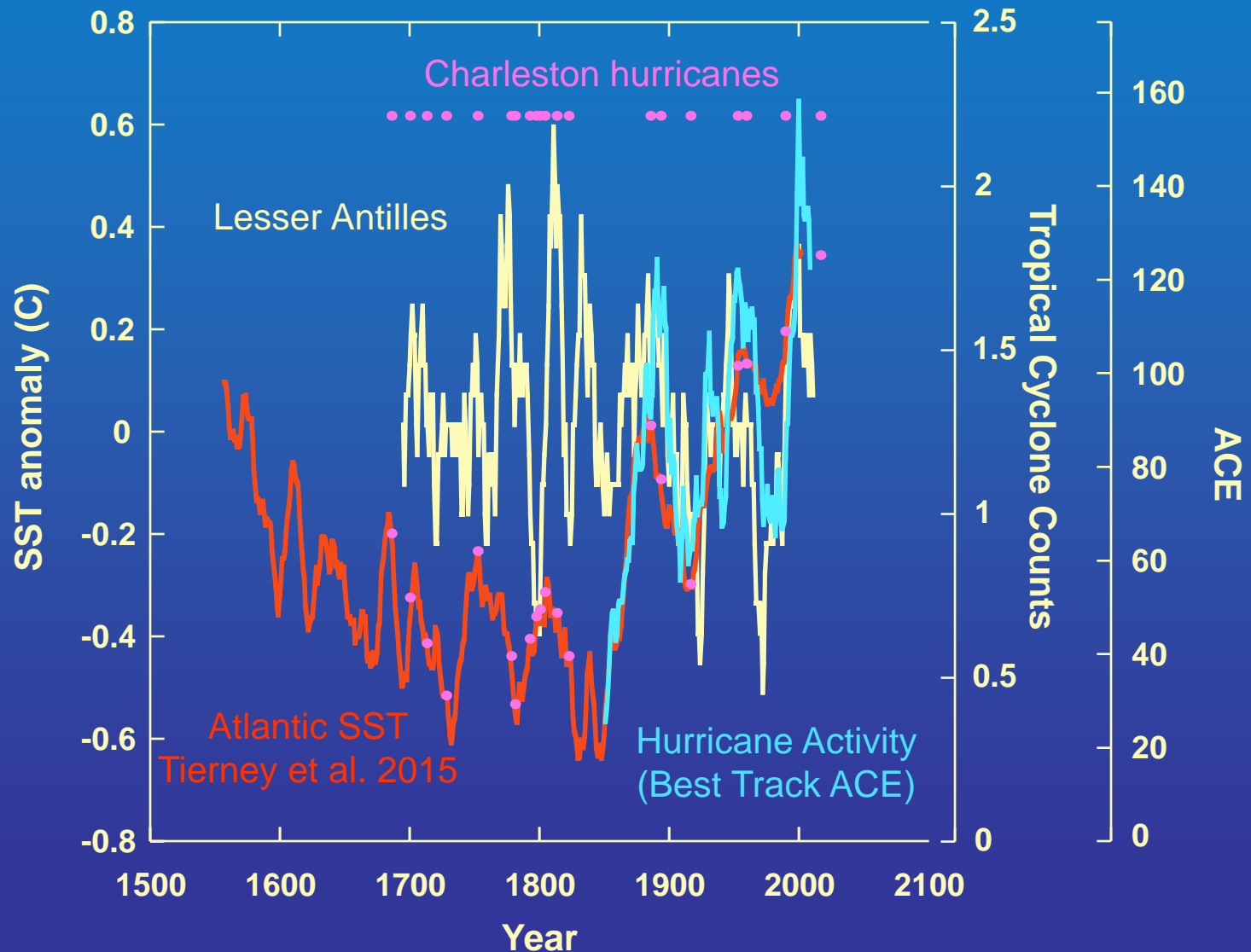
Hurricanes and Sea Surface Temp



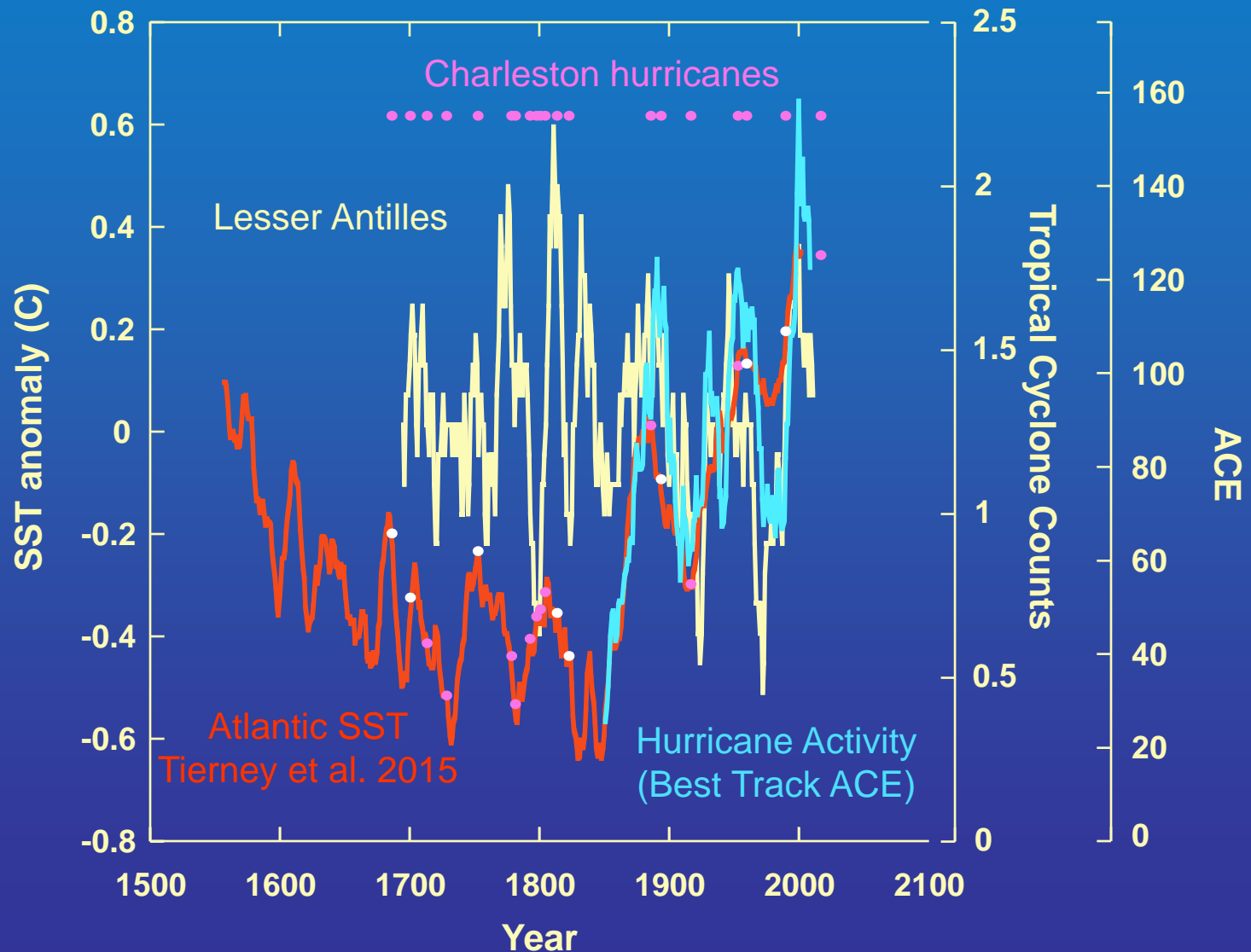
Hurricanes and Sea Surface Temp



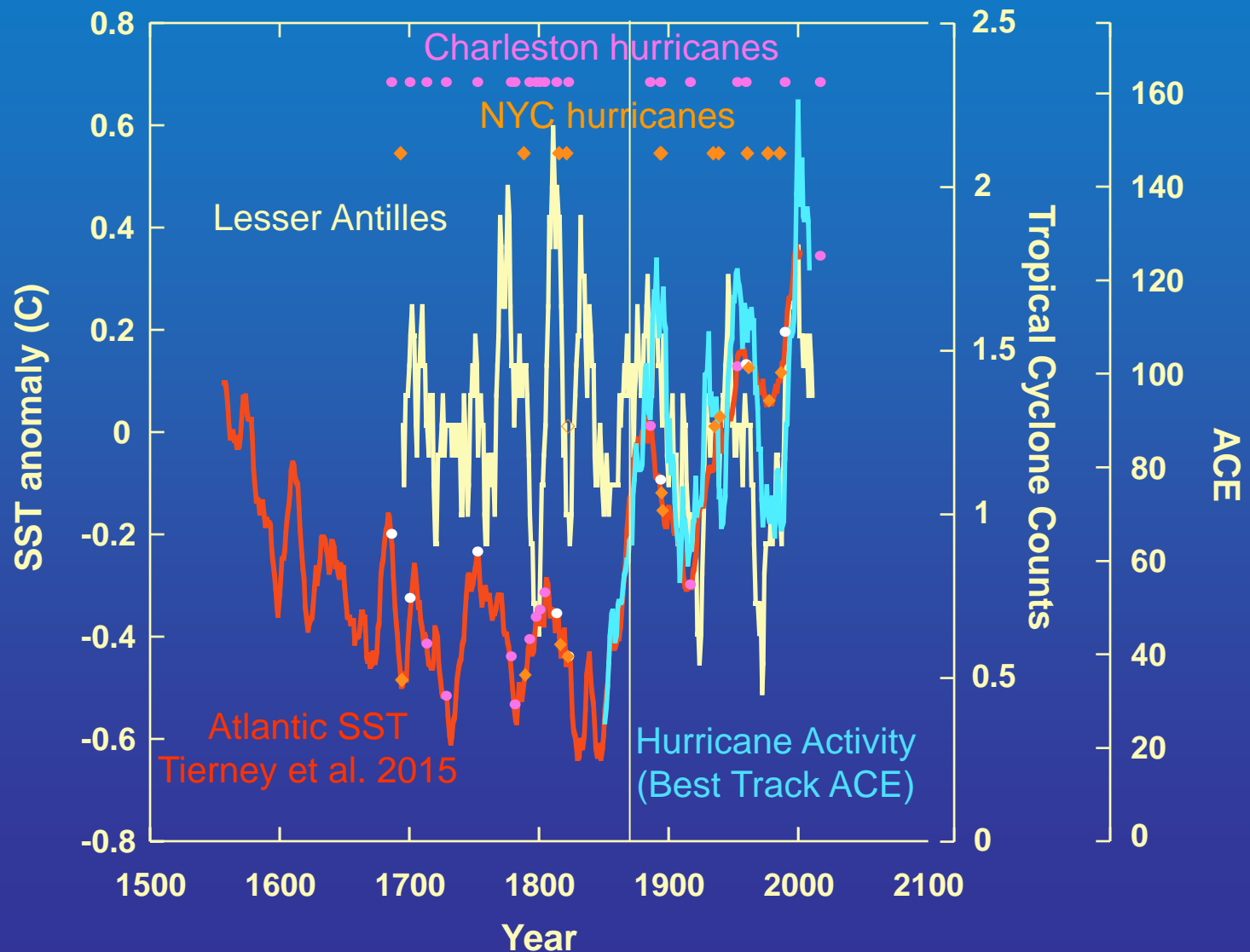
Hurricanes and Sea Surface Temp



Hurricanes and Sea Surface Temp



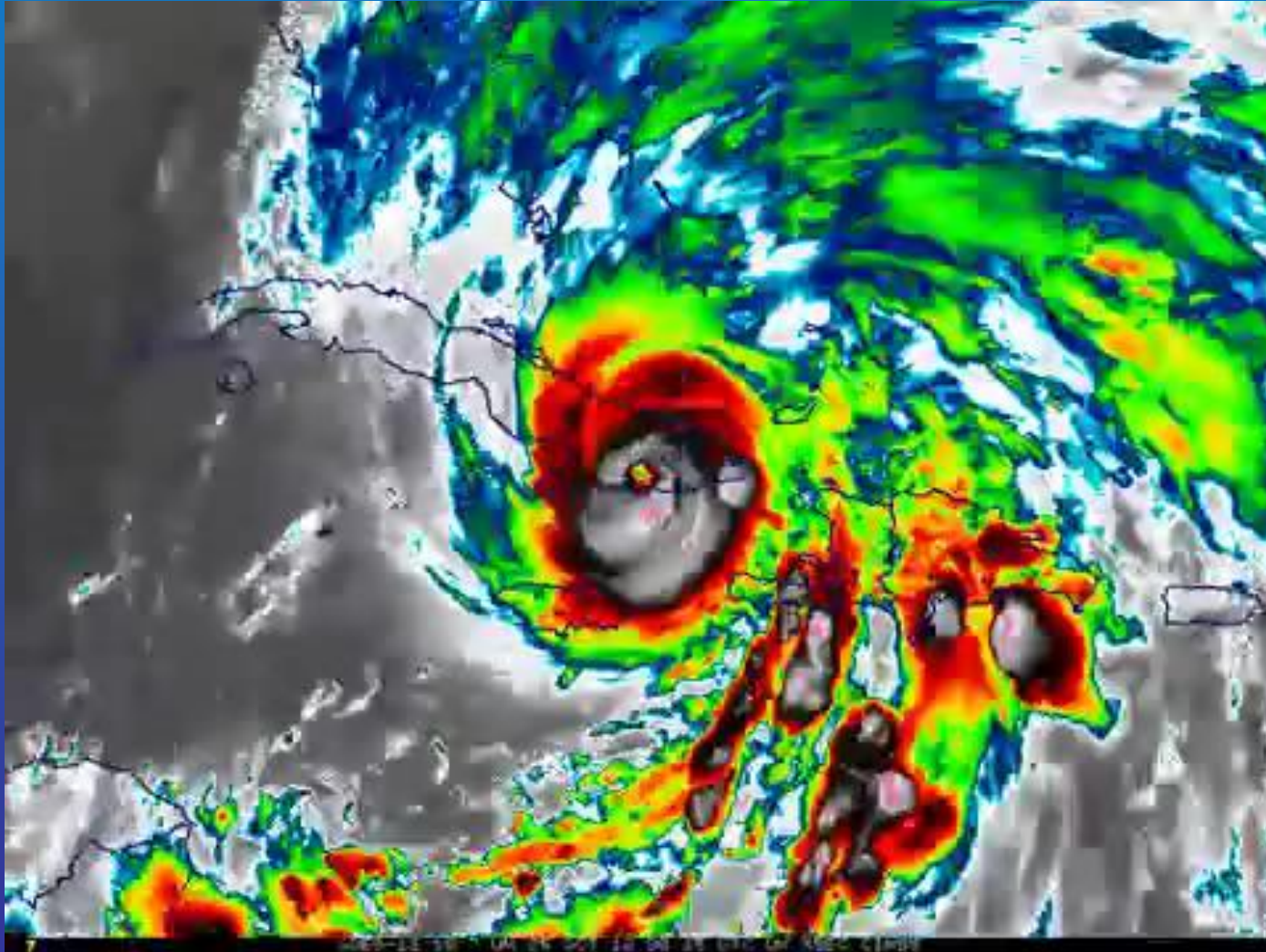
Hurricanes and Sea Surface Temp



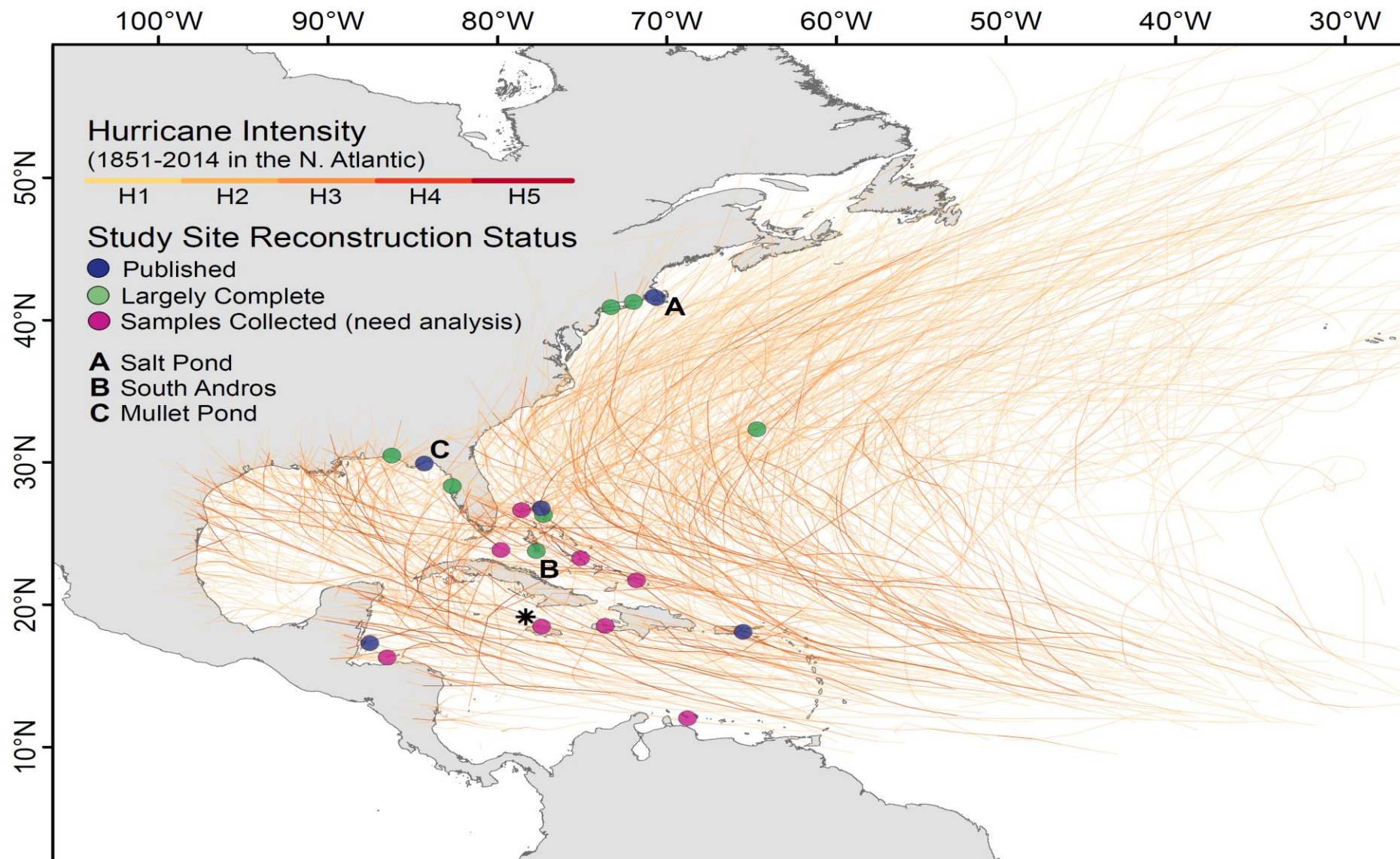
Hurricane Sandy 2012



68 billion in damage
148 fatalities



Sedimentary Records of Hurricane Strikes

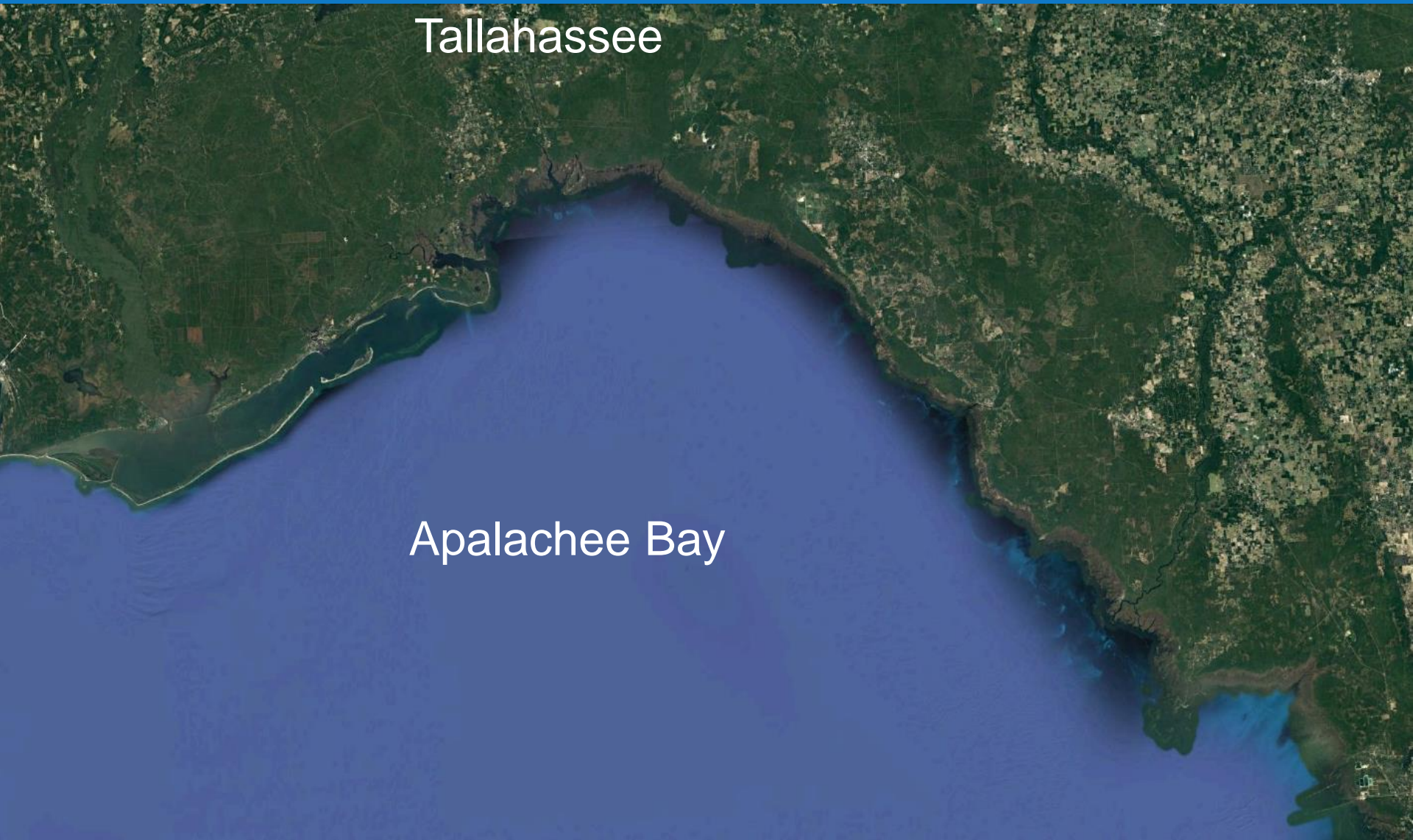


Record from Florida Panhandle (Mullet Pond)

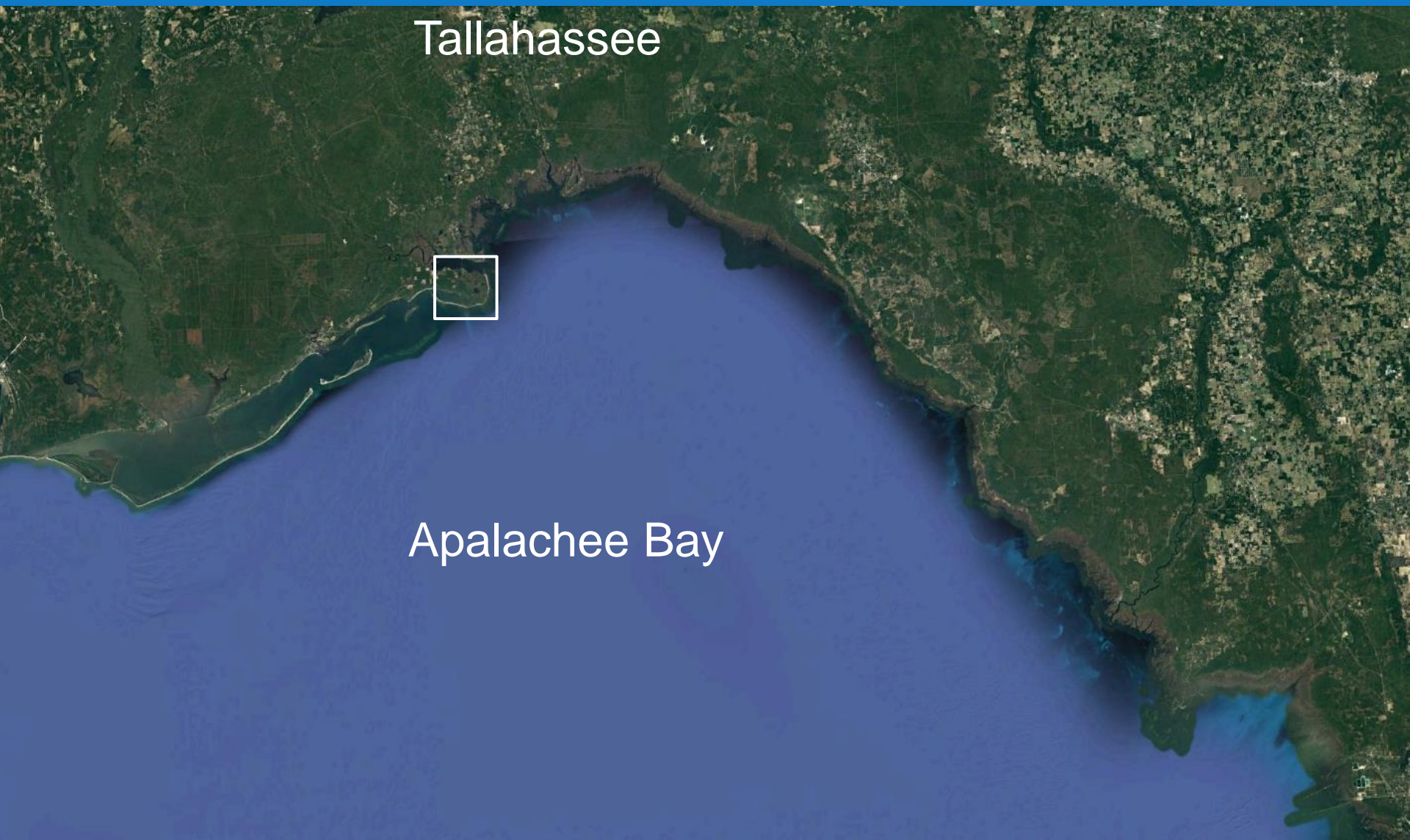


Tallahassee

Apalachee Bay



Record from Florida Panhandle (Mullet Pond)



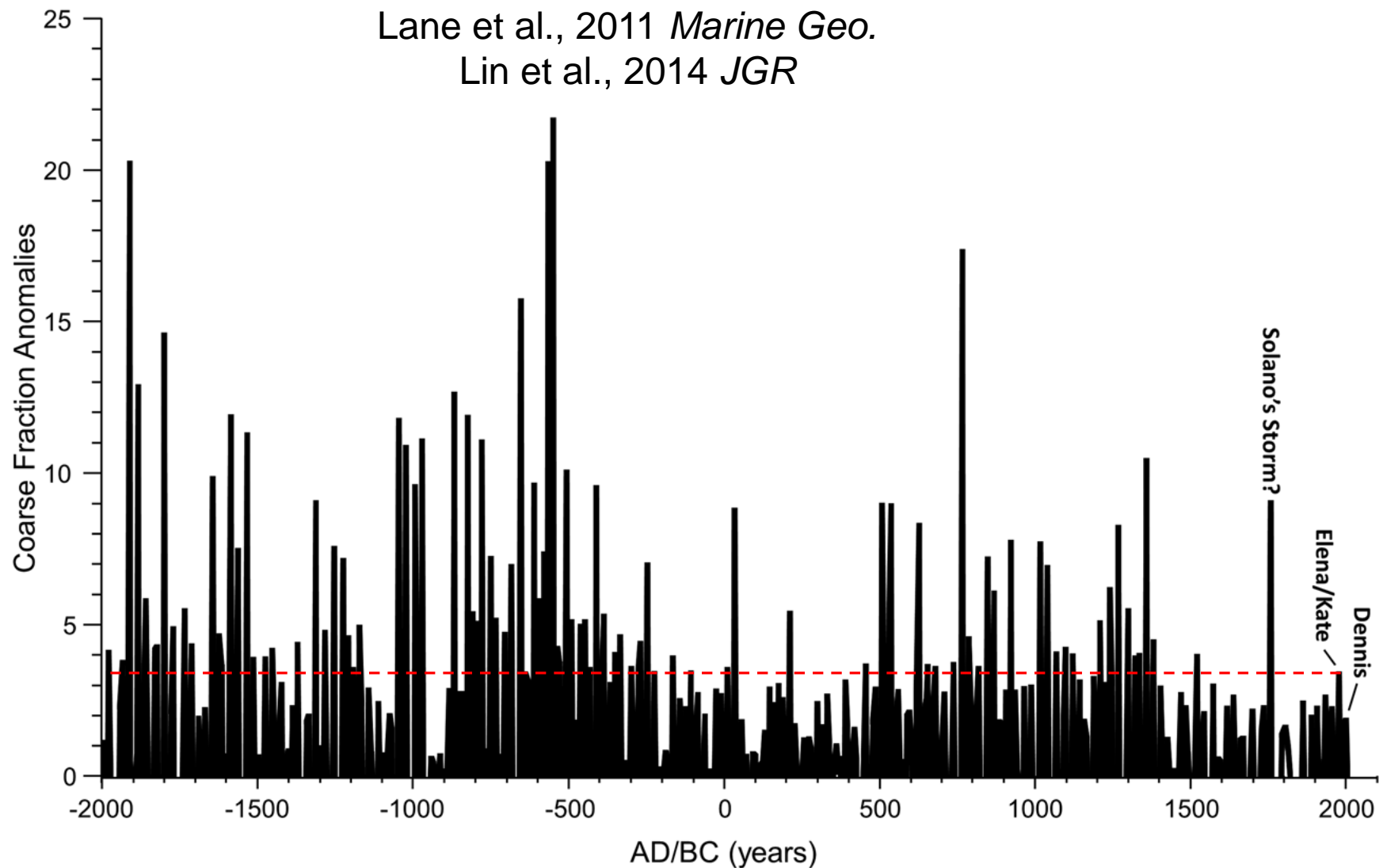
Record from Florida Panhandle (Mullet Pond)



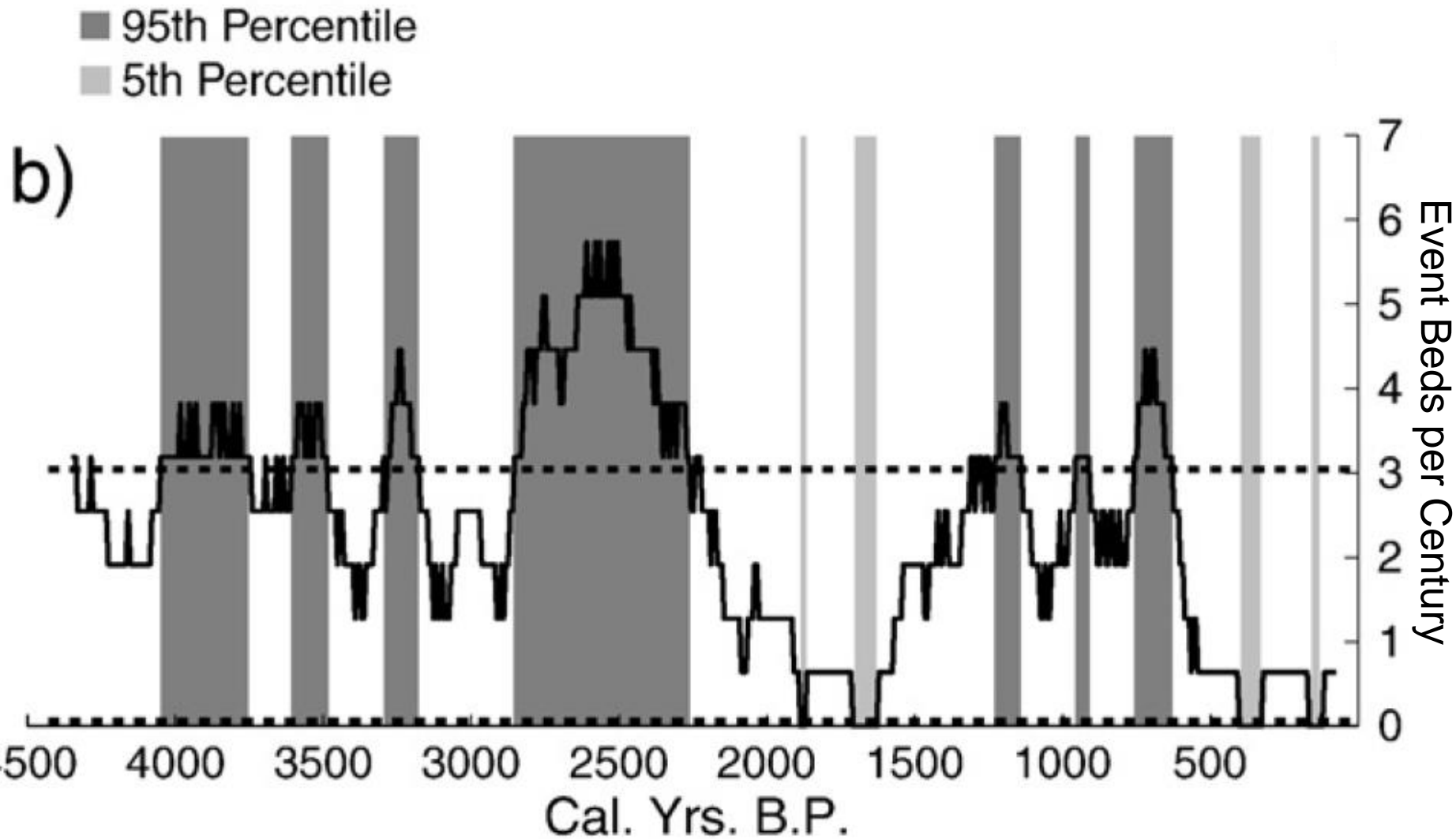
Tallahassee



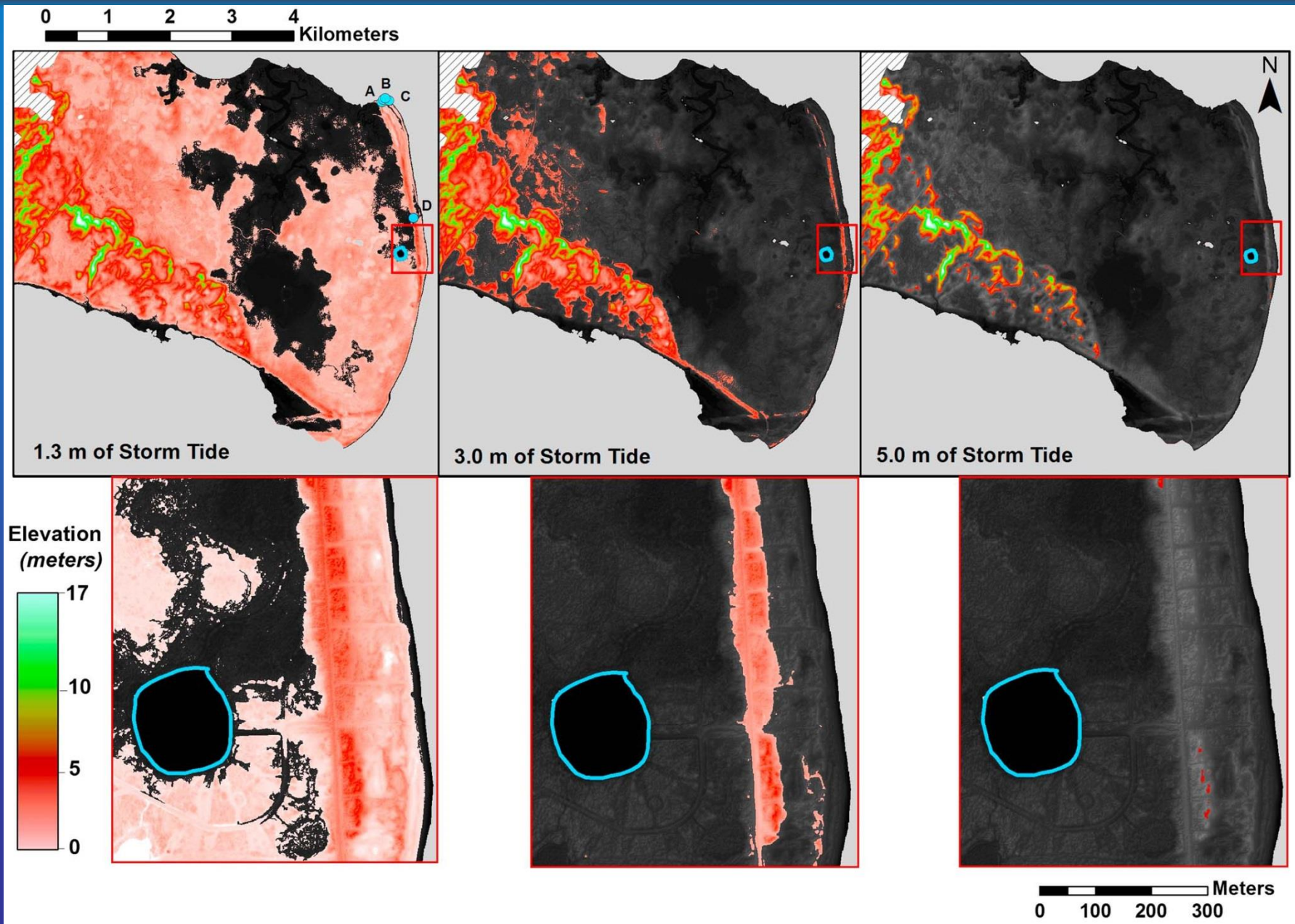
Record from Florida Panhandle (Mullet Pond)



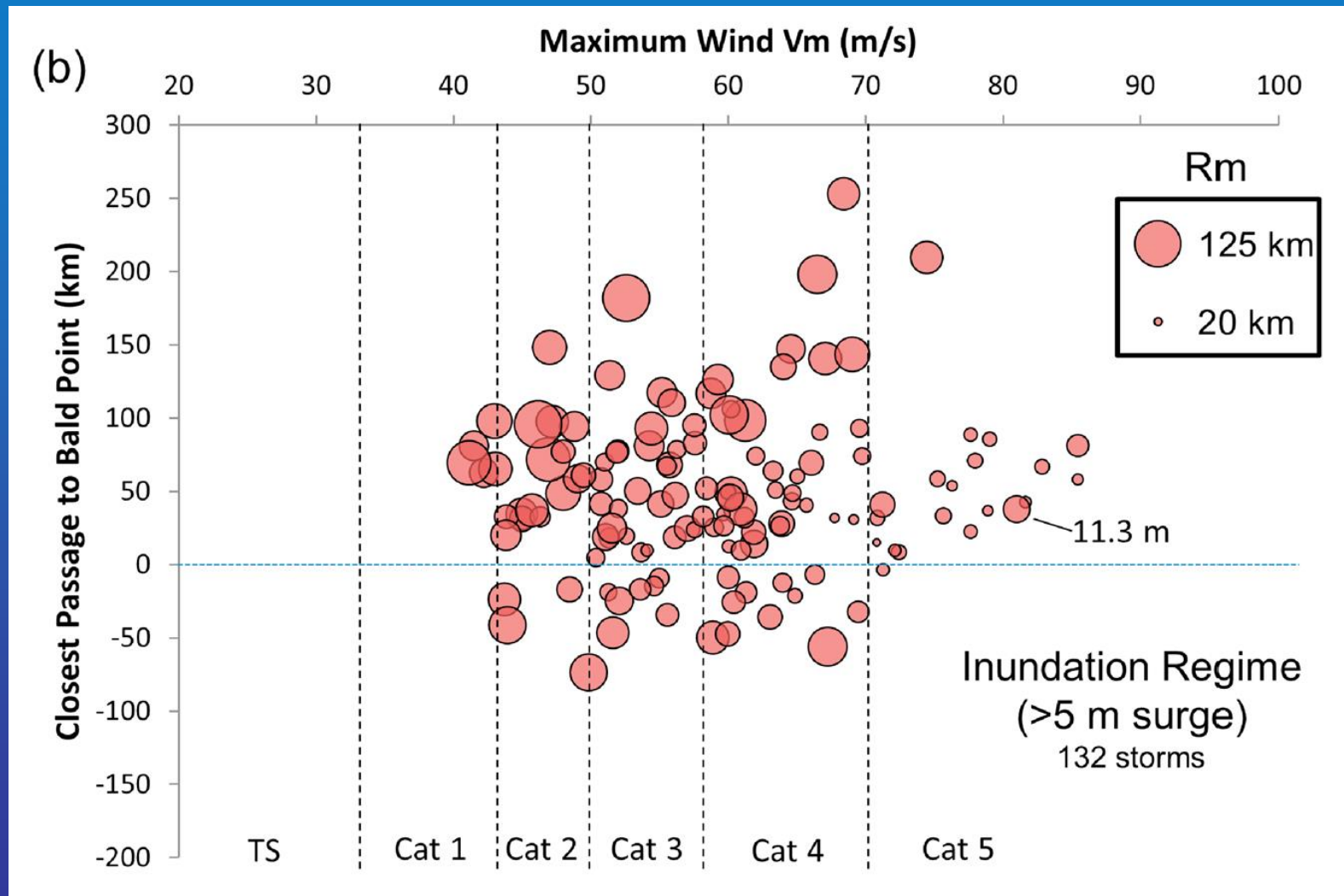
Record from Florida Panhandle (Mullet Pond)



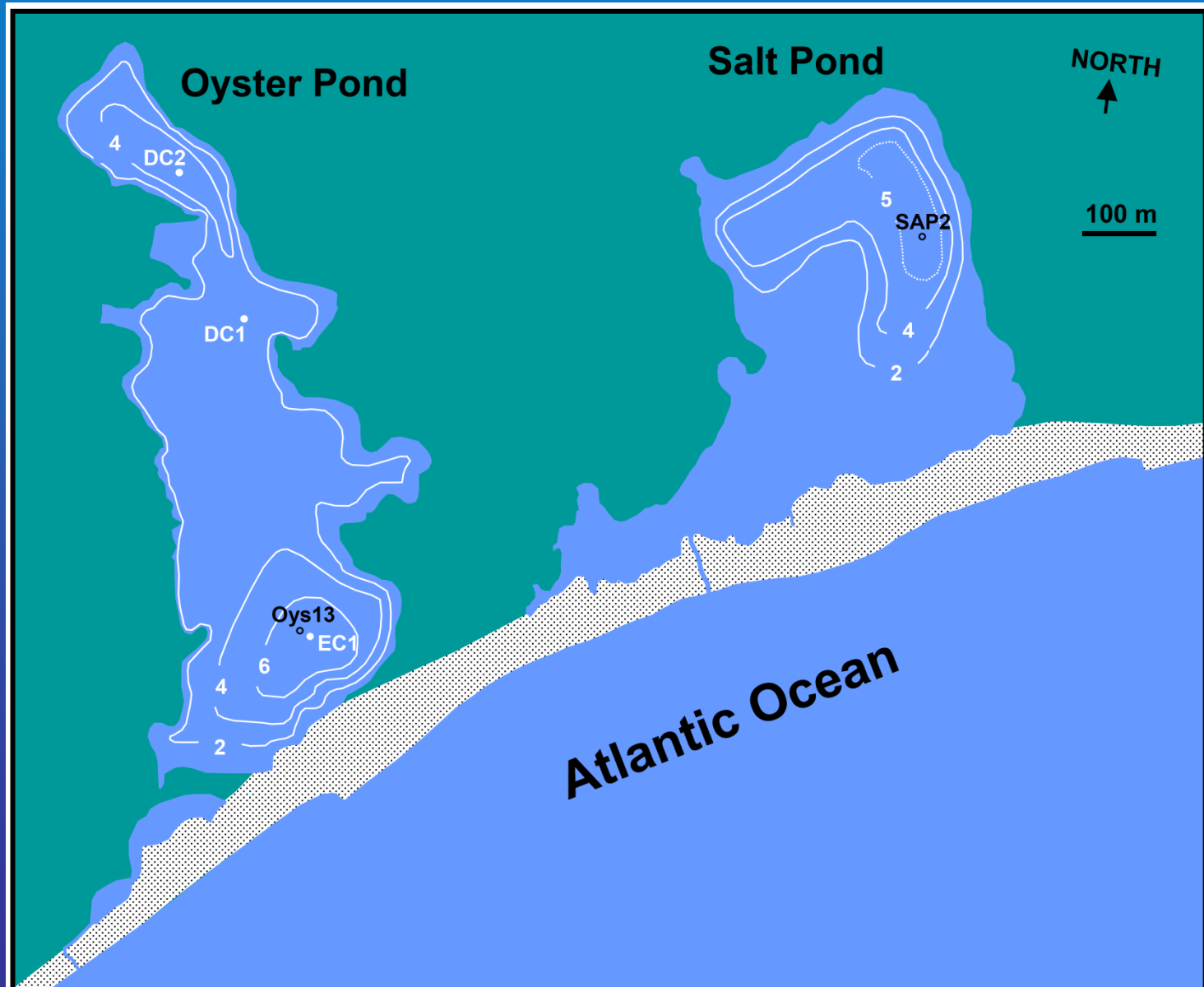
Record from Florida Panhandle (Mullet Pond)



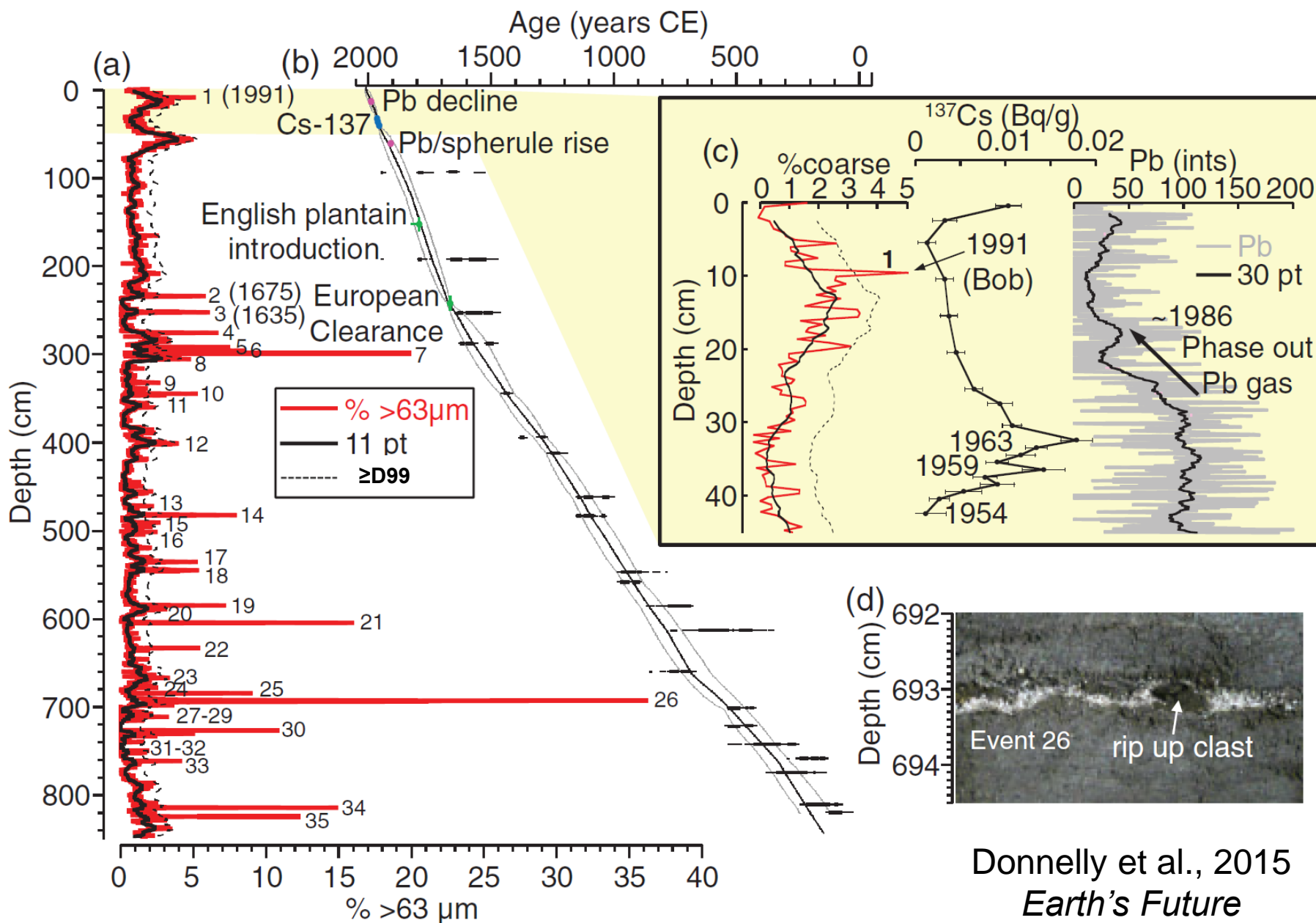
Record from Florida Panhandle (Mullet Pond)



Salt Pond Reconstruction



Salt Pond Reconstruction



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”

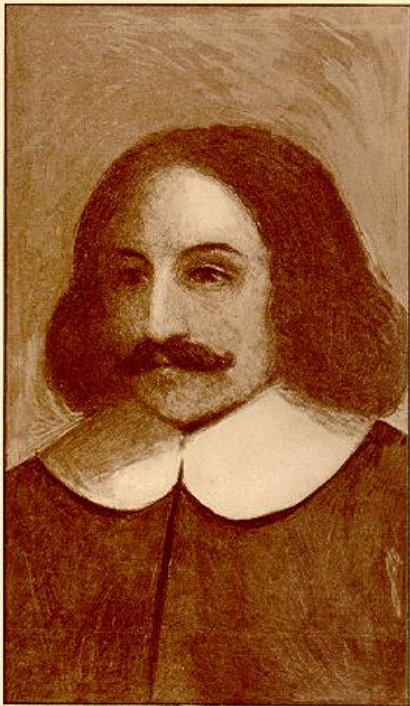


William Bradford (Governor of Plymouth Colony)

“...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”



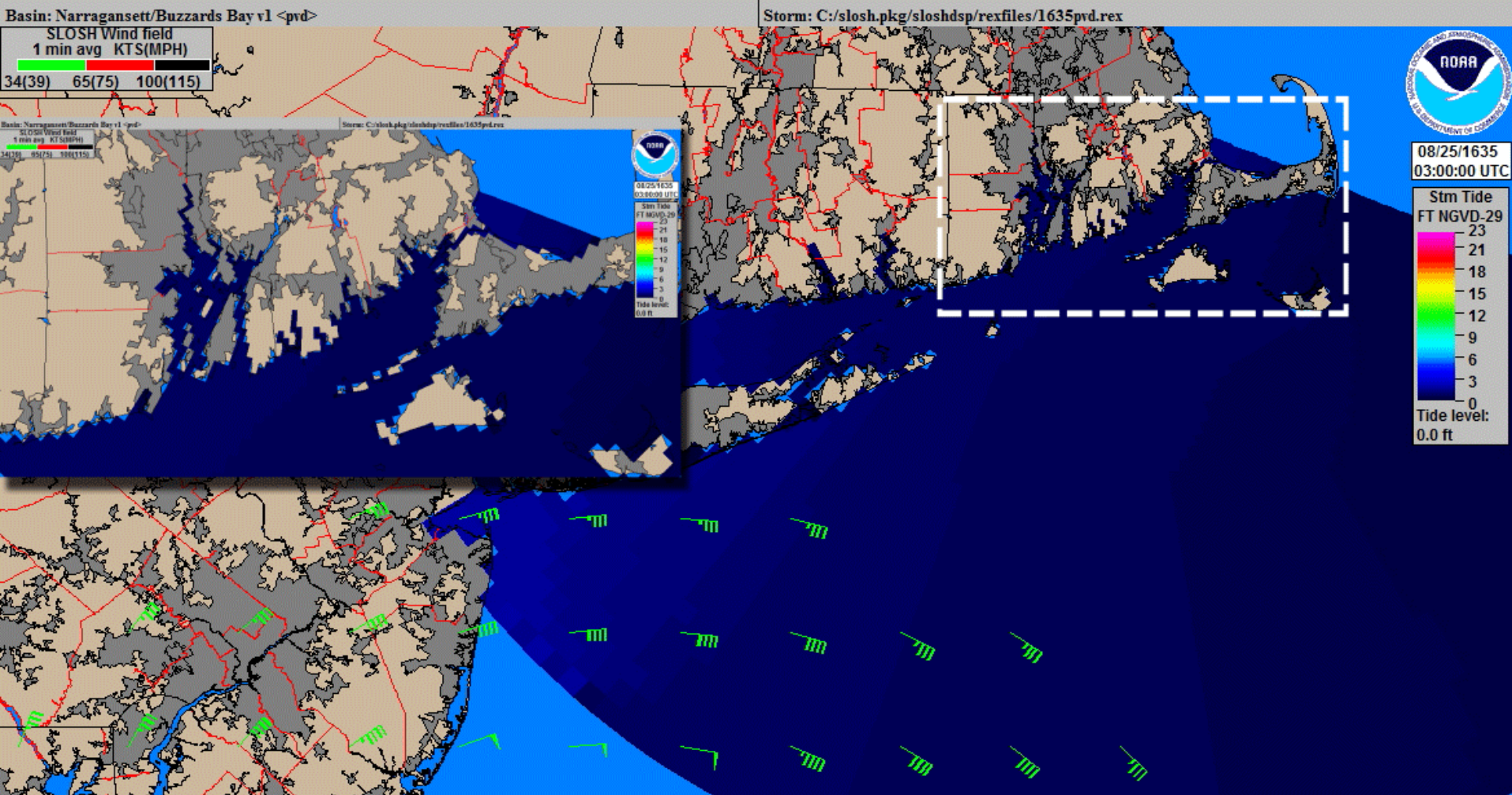
Copyright, 1894, by A. S. Forester, Plymouth

GOVERNOR WILLIAM BRADFORD

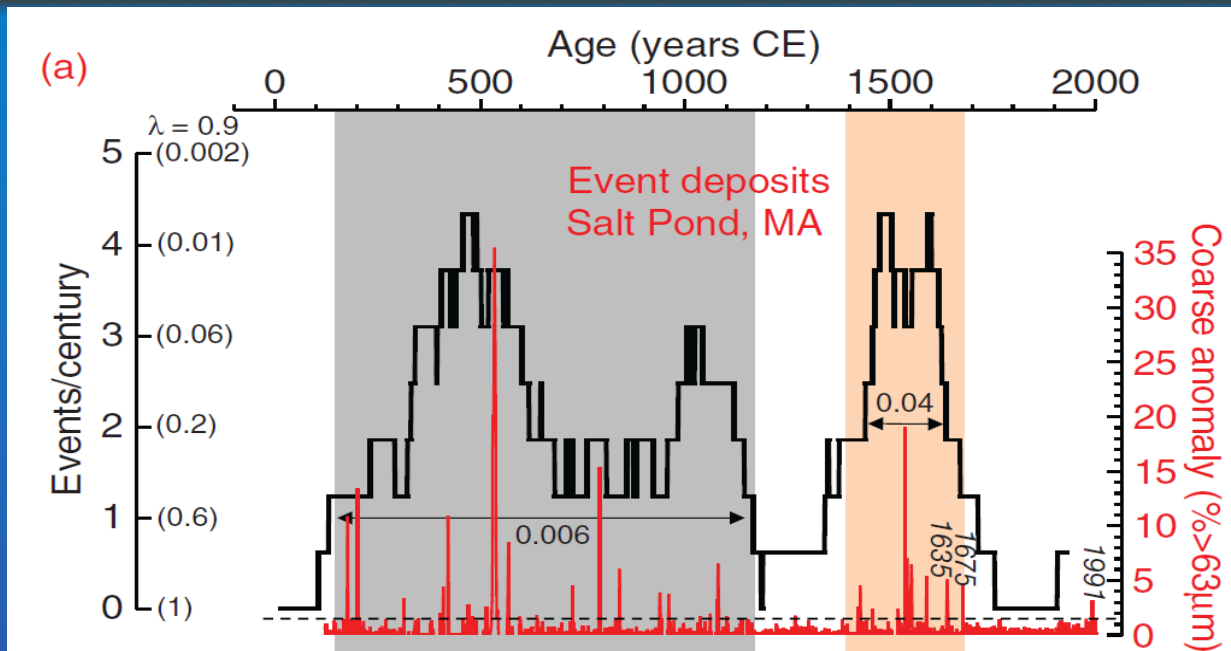
Great Colonial Hurricane of 1635



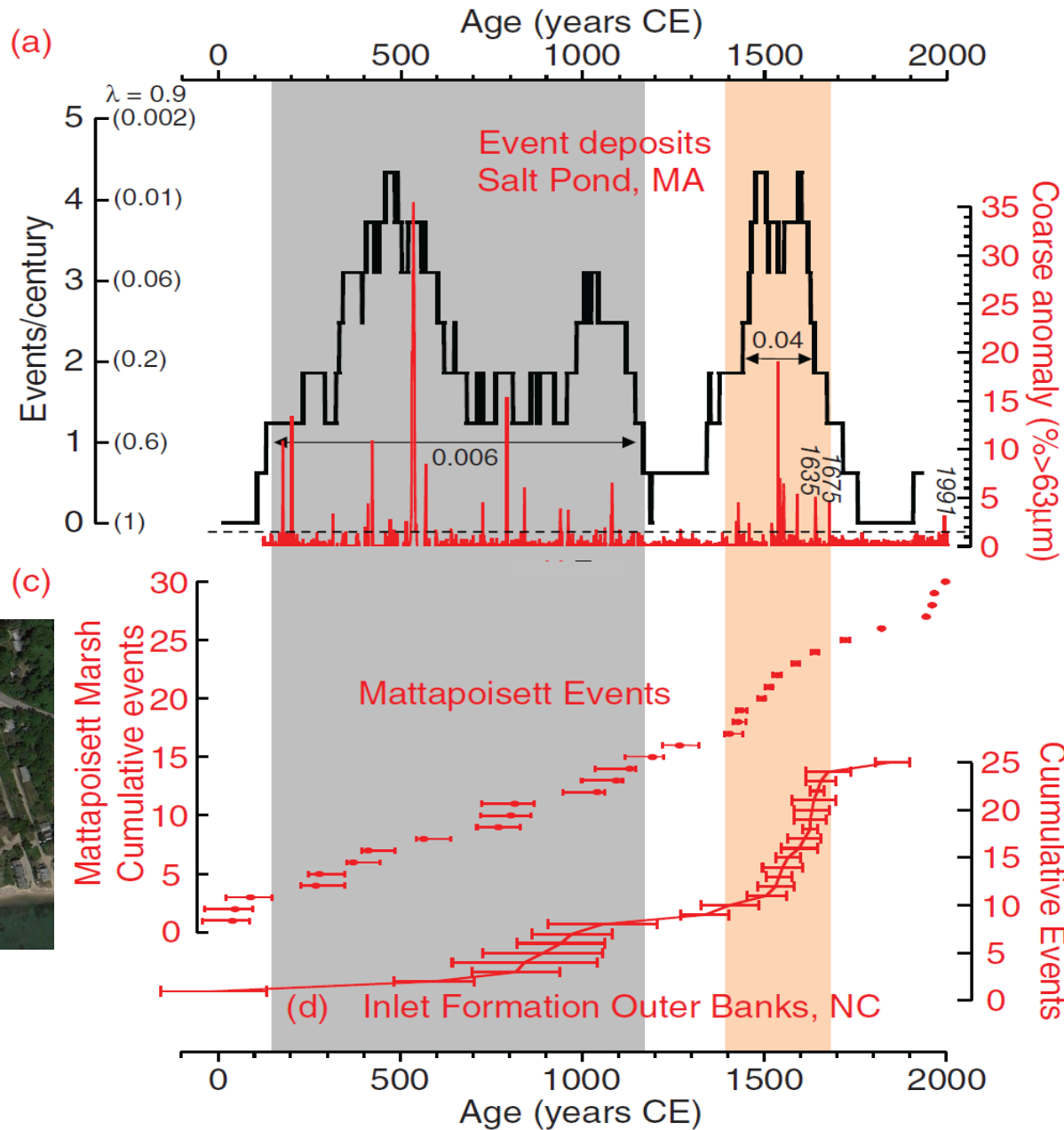
Hindcast SLOSH model simulation



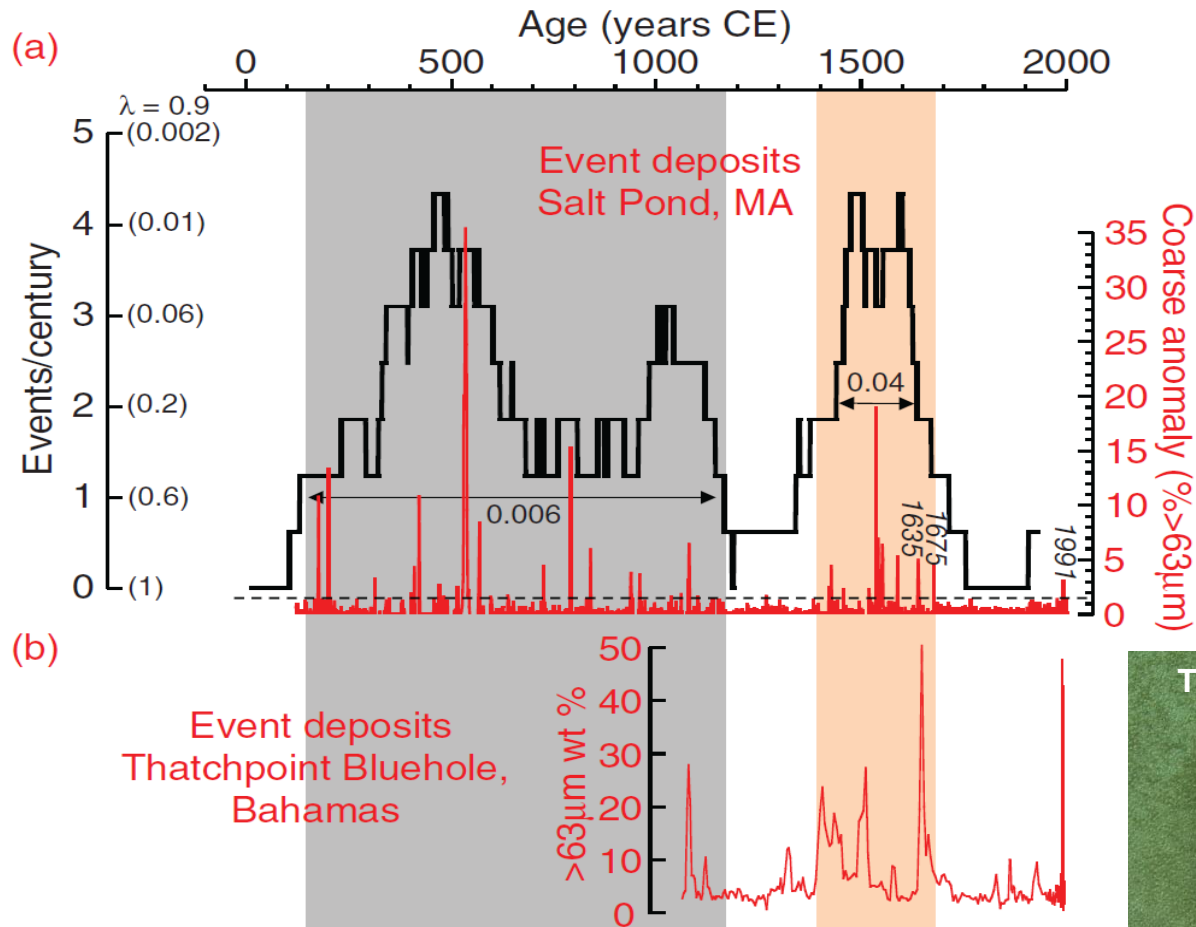
Salt Pond Reconstruction



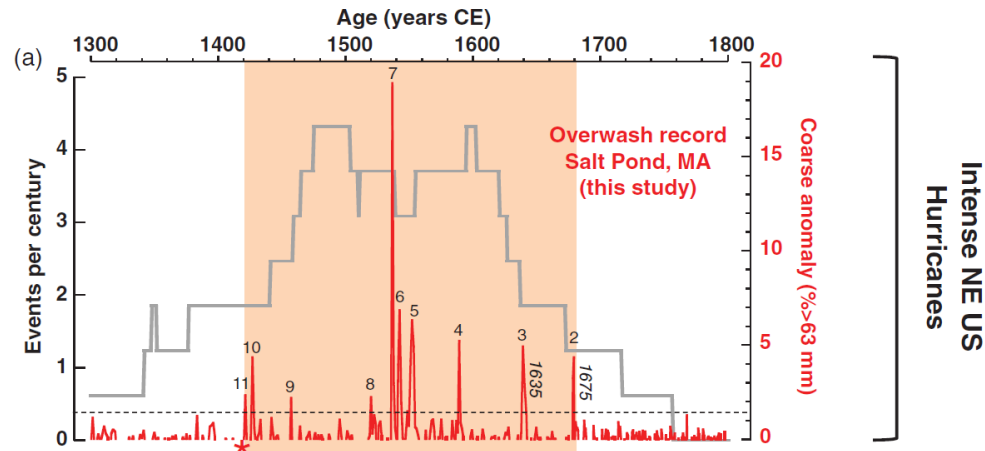
Salt Pond Reconstruction



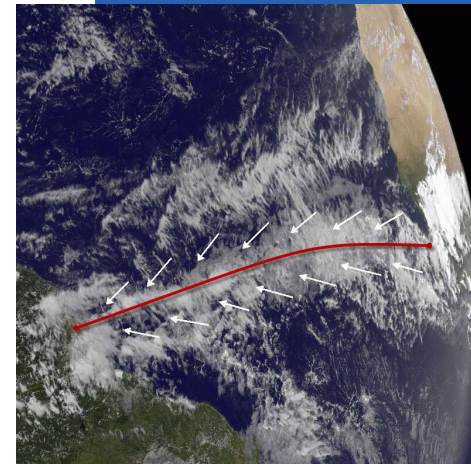
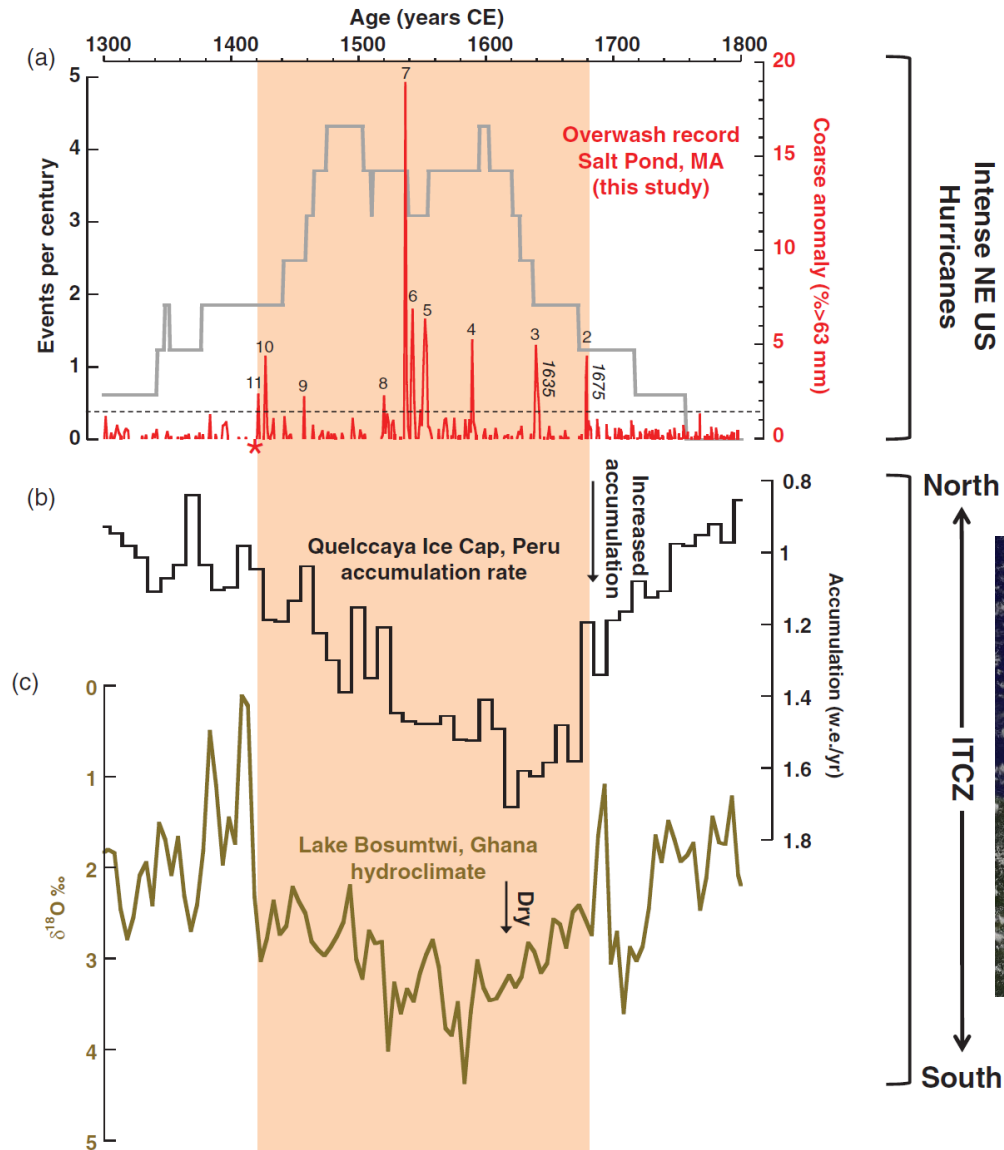
Salt Pond Reconstruction



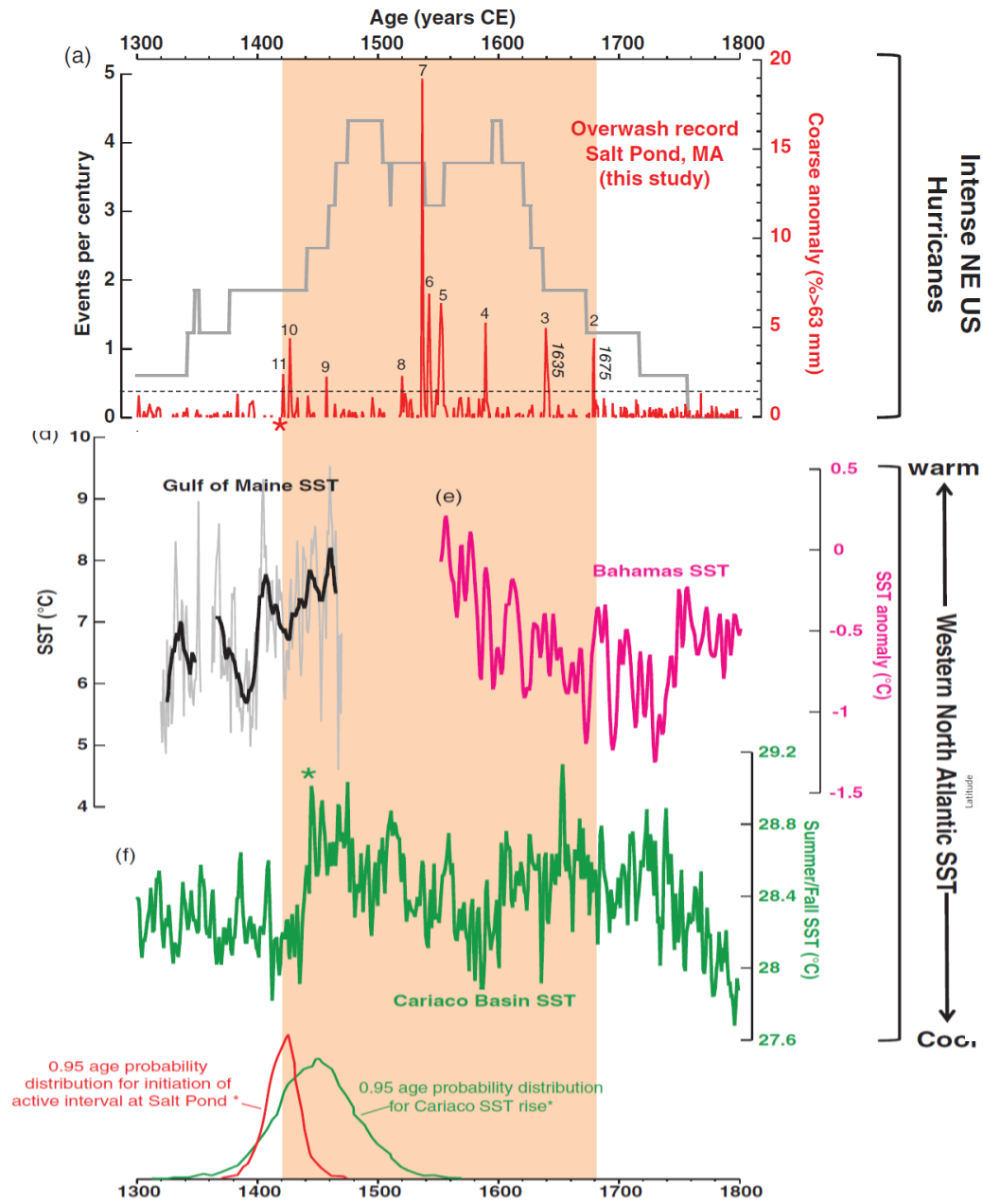
Climate Forcing



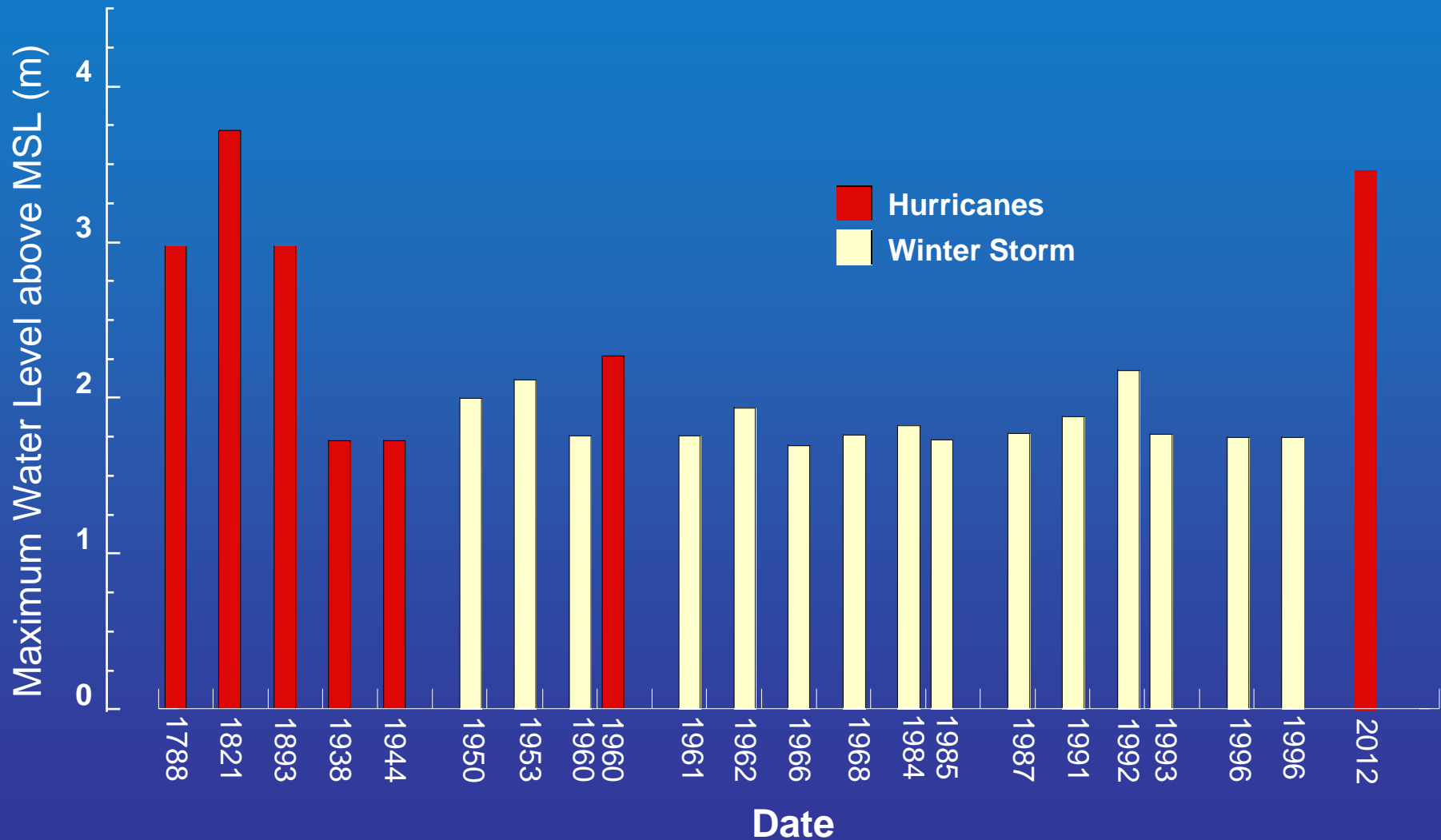
Climate Forcing



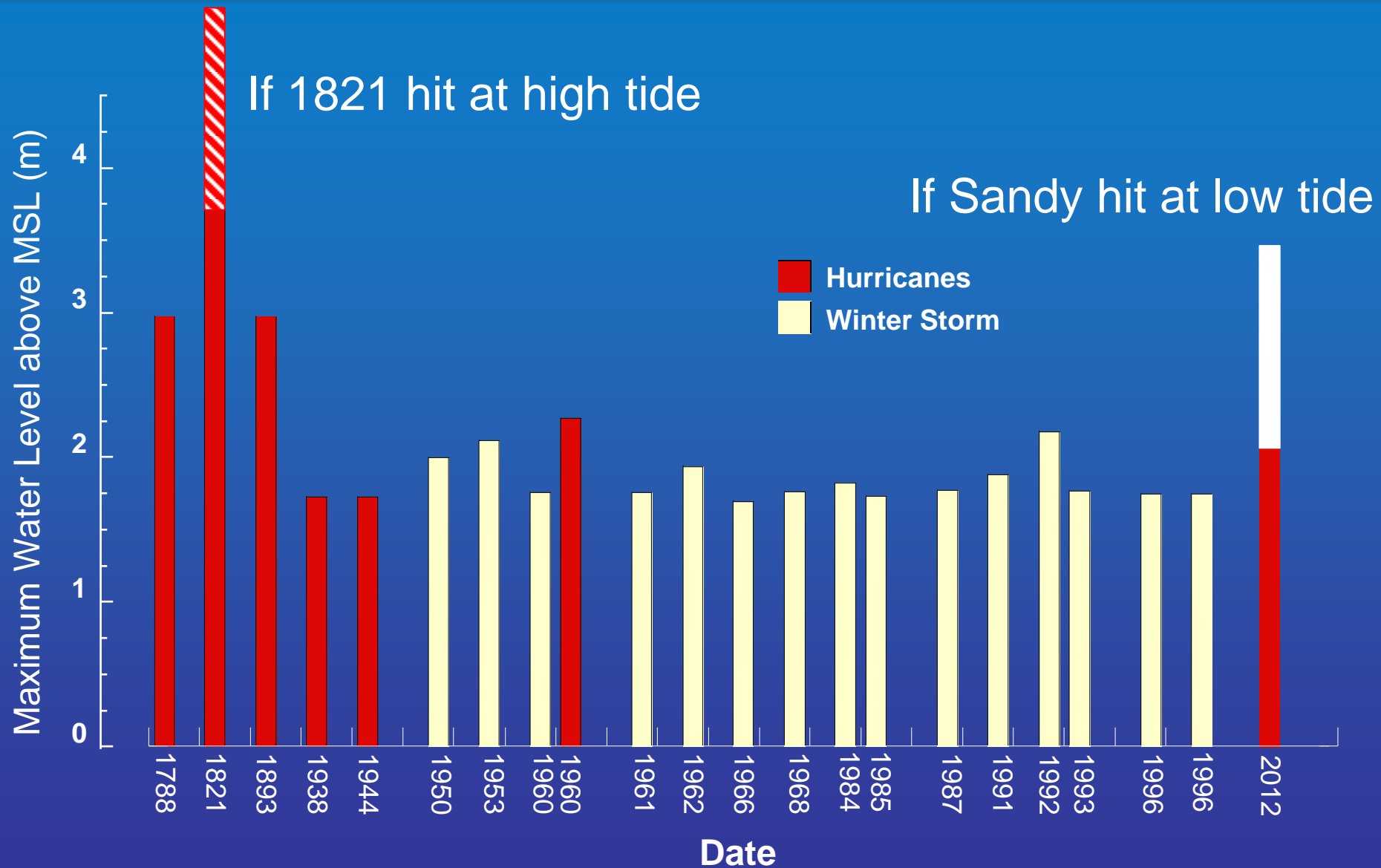
Climate Forcing



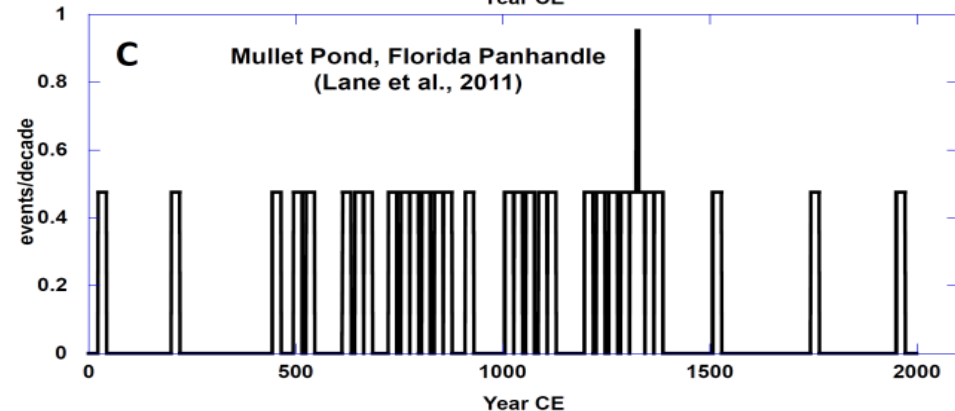
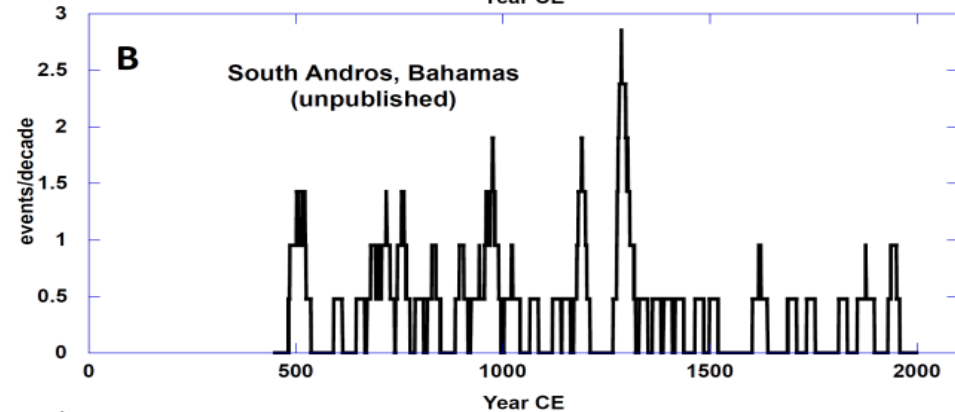
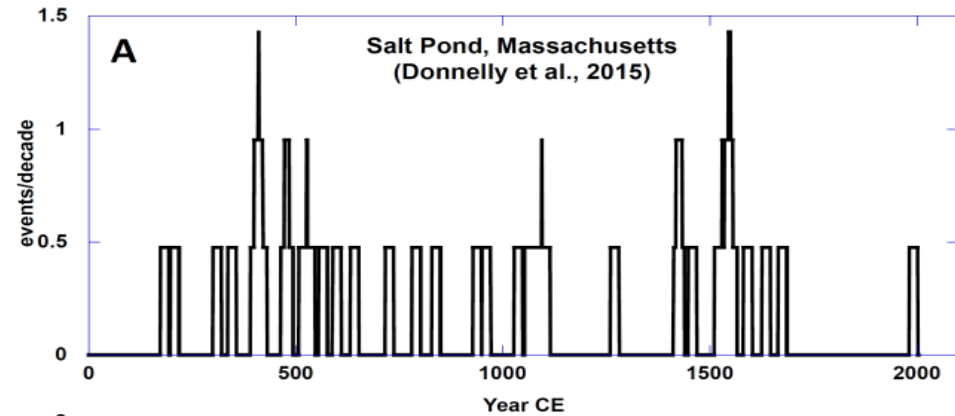
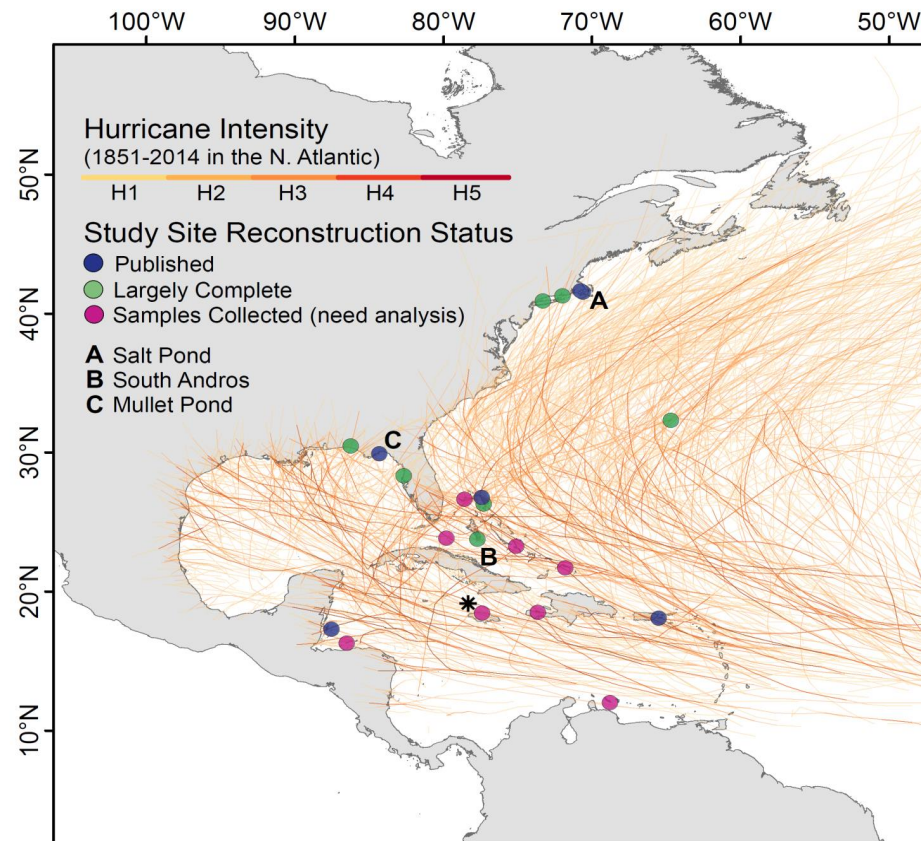
Storm tides in lower Manhattan

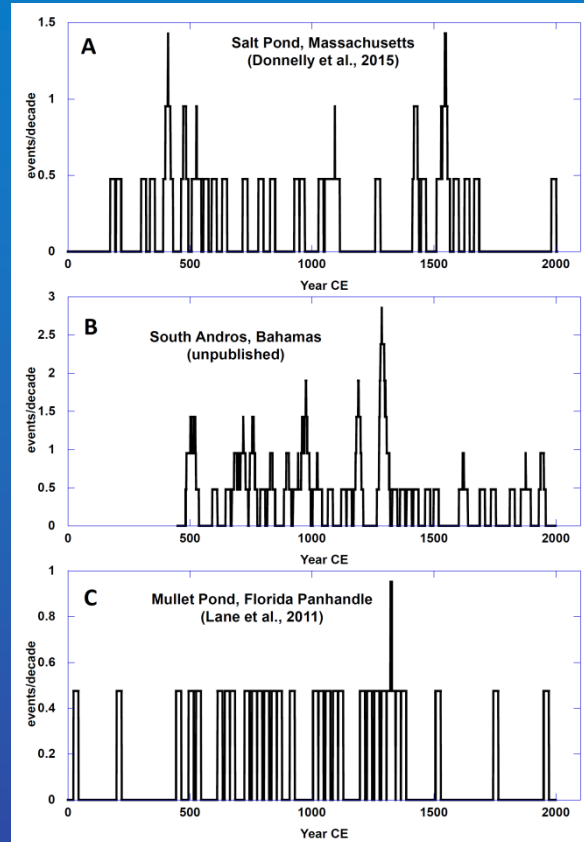


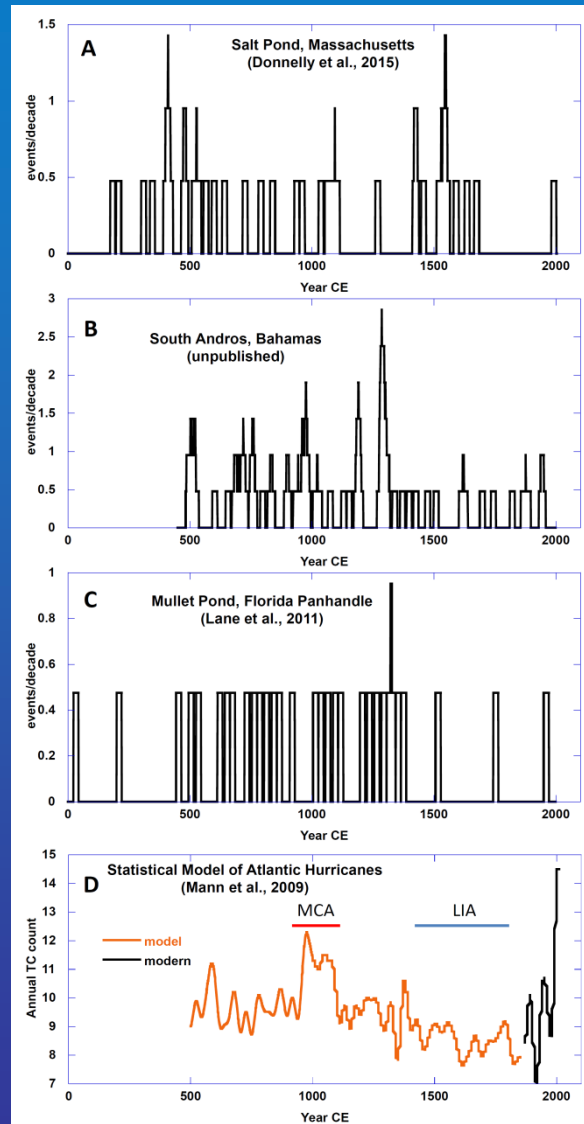
Storm tides in lower Manhattan

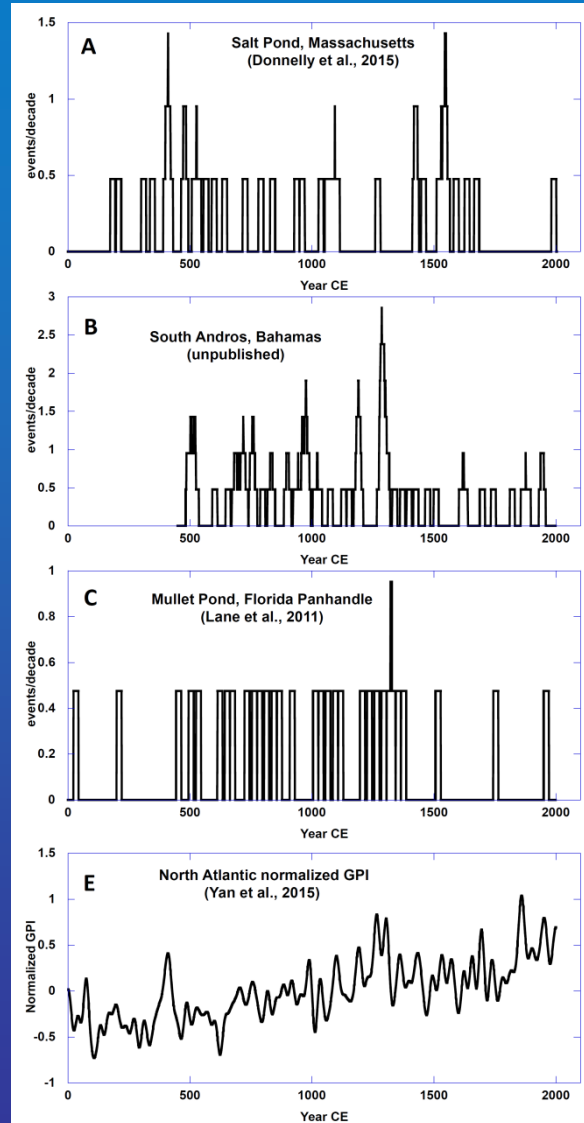


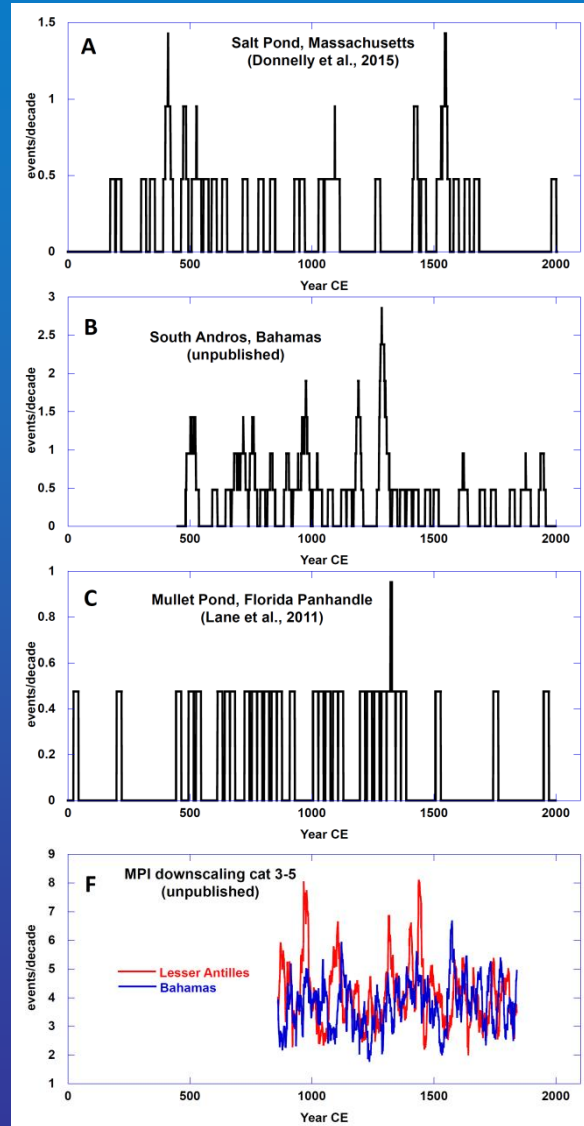
Regional Patterns





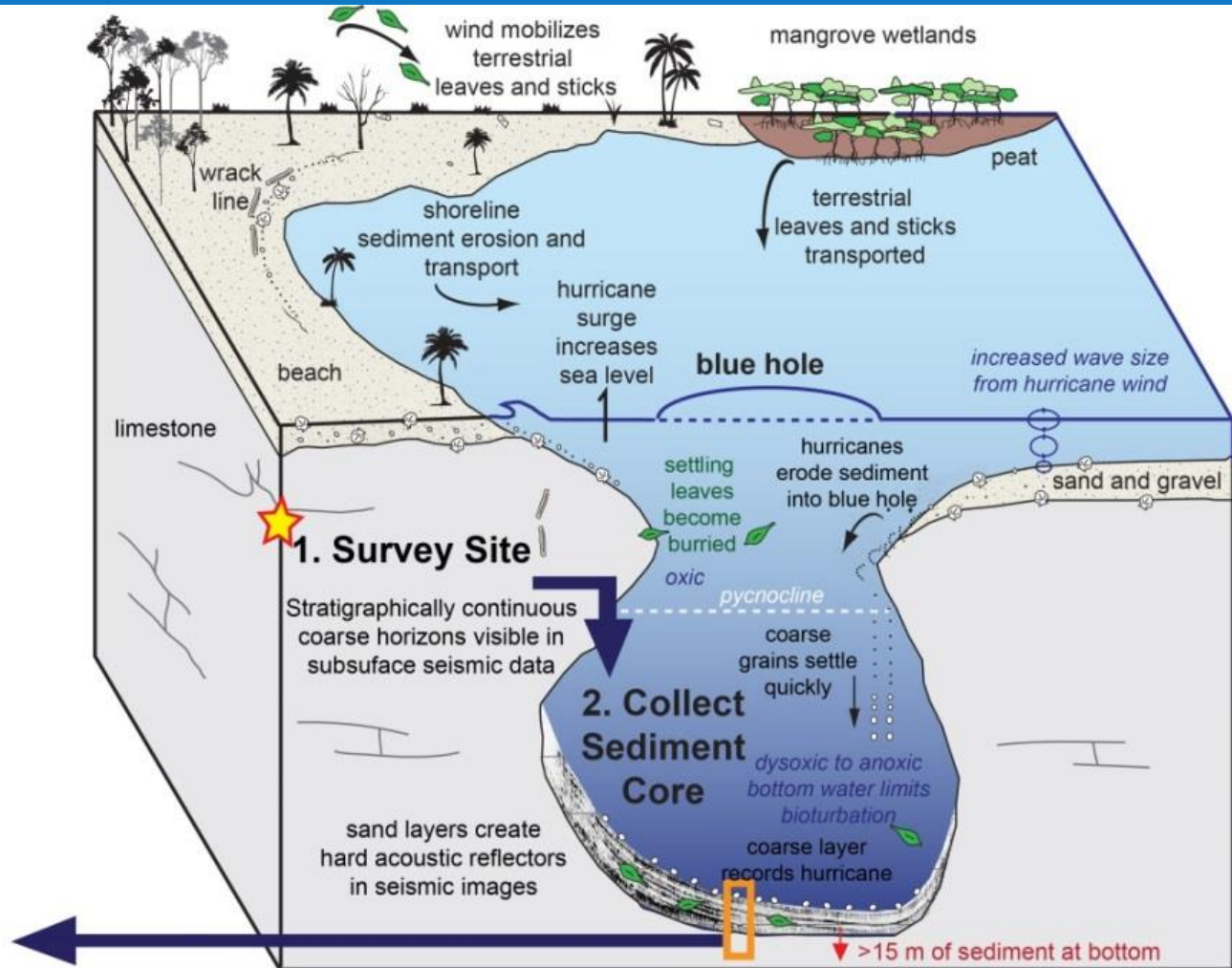
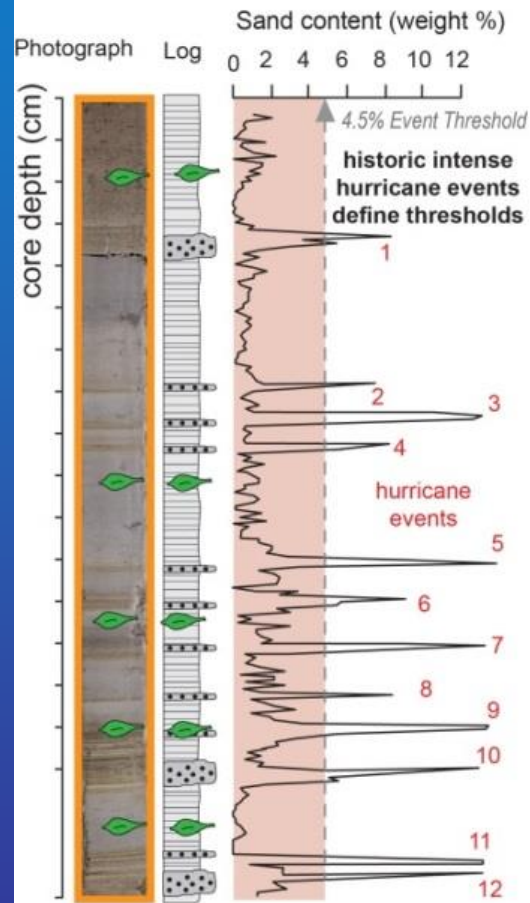




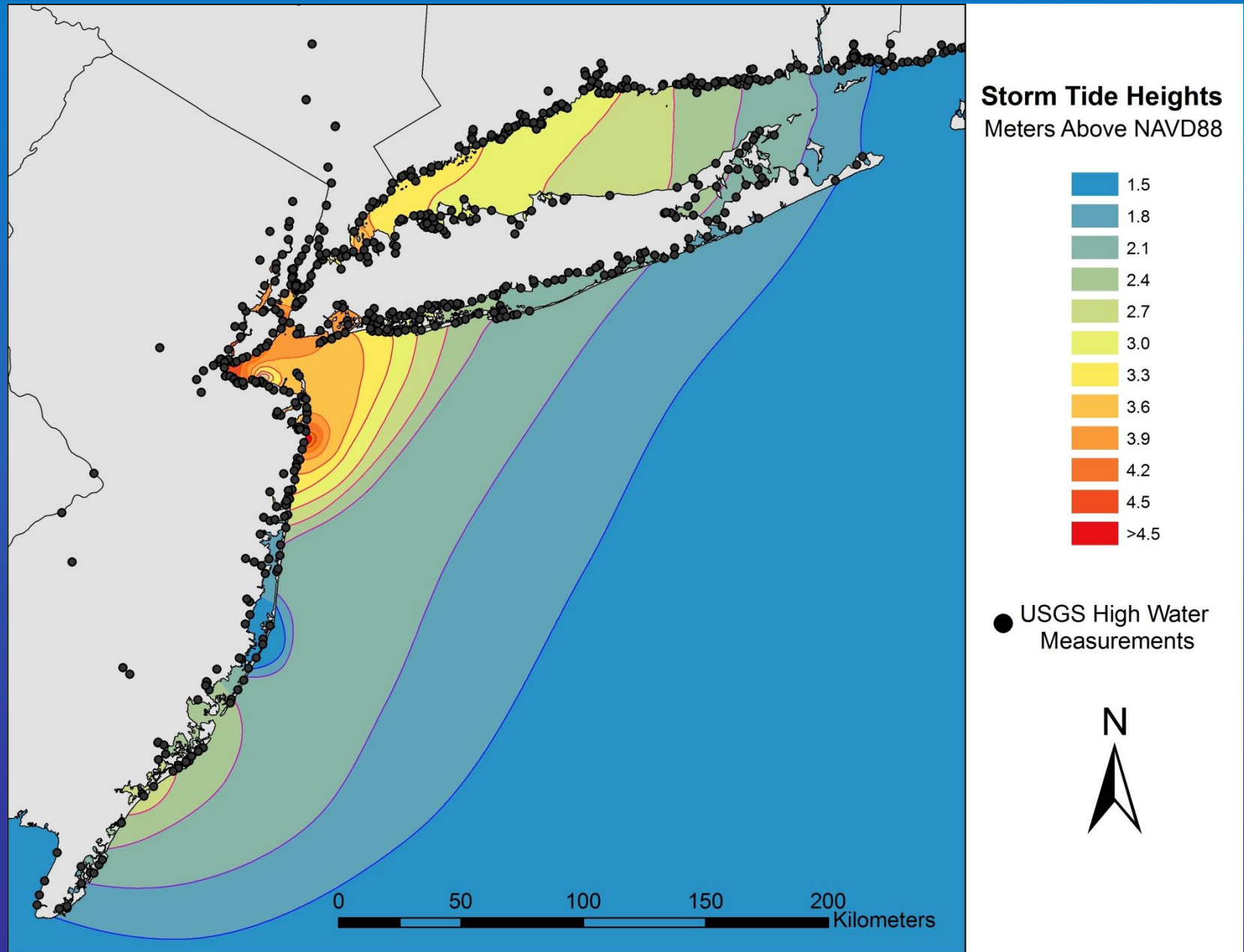


Hurricane Records from Blue Holes

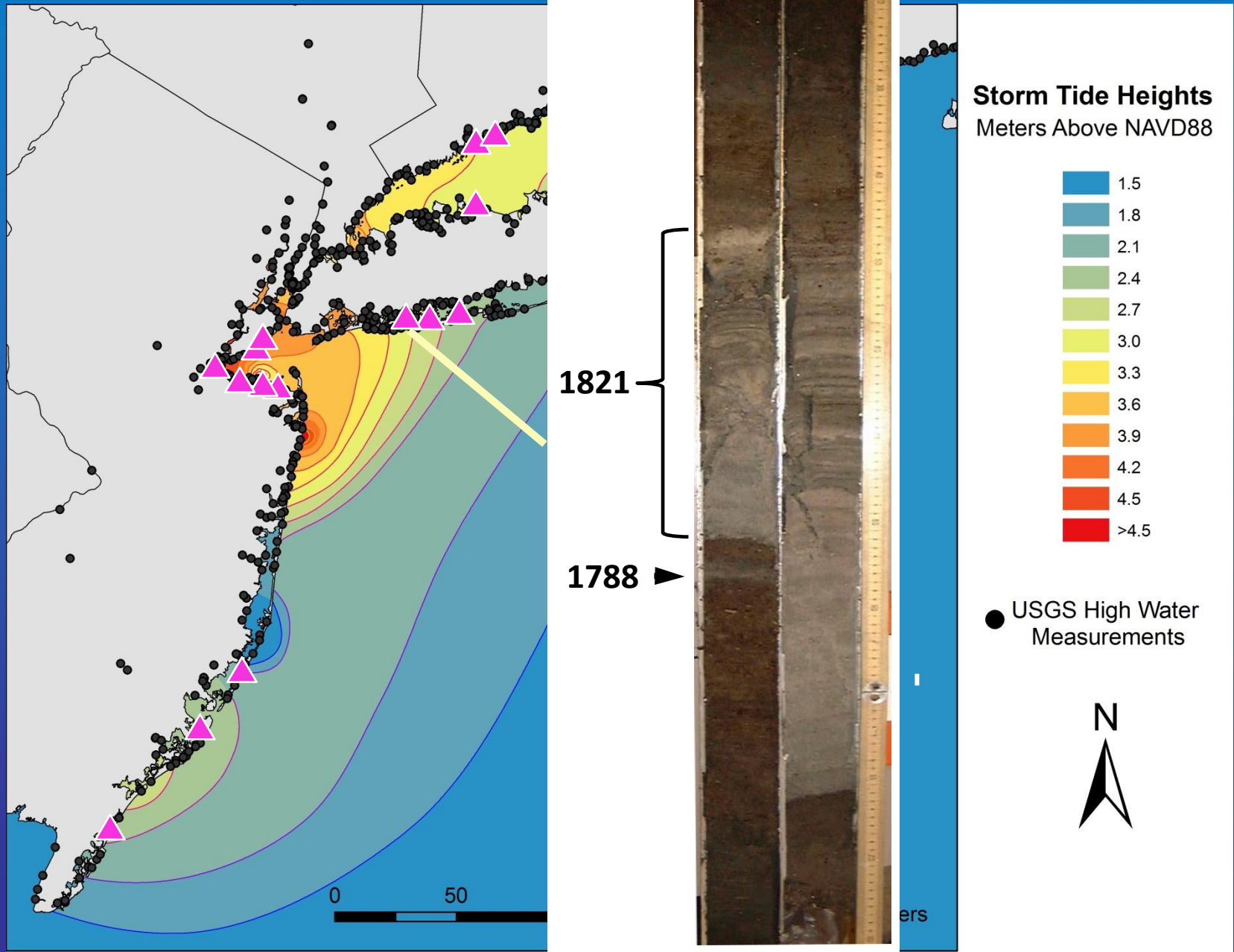
3. Quantify grain size distributions



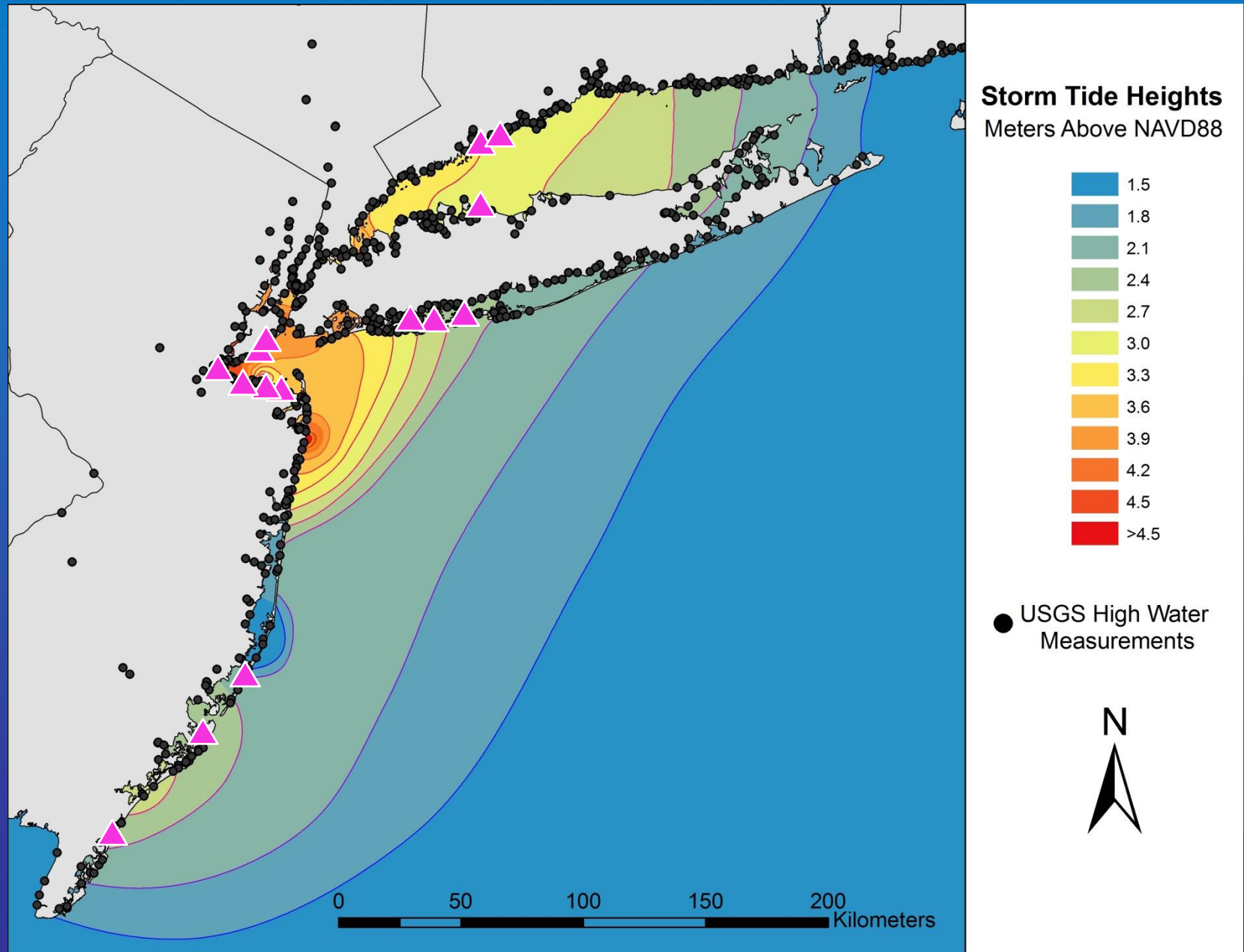
Hurricane Sandy Storm Tide



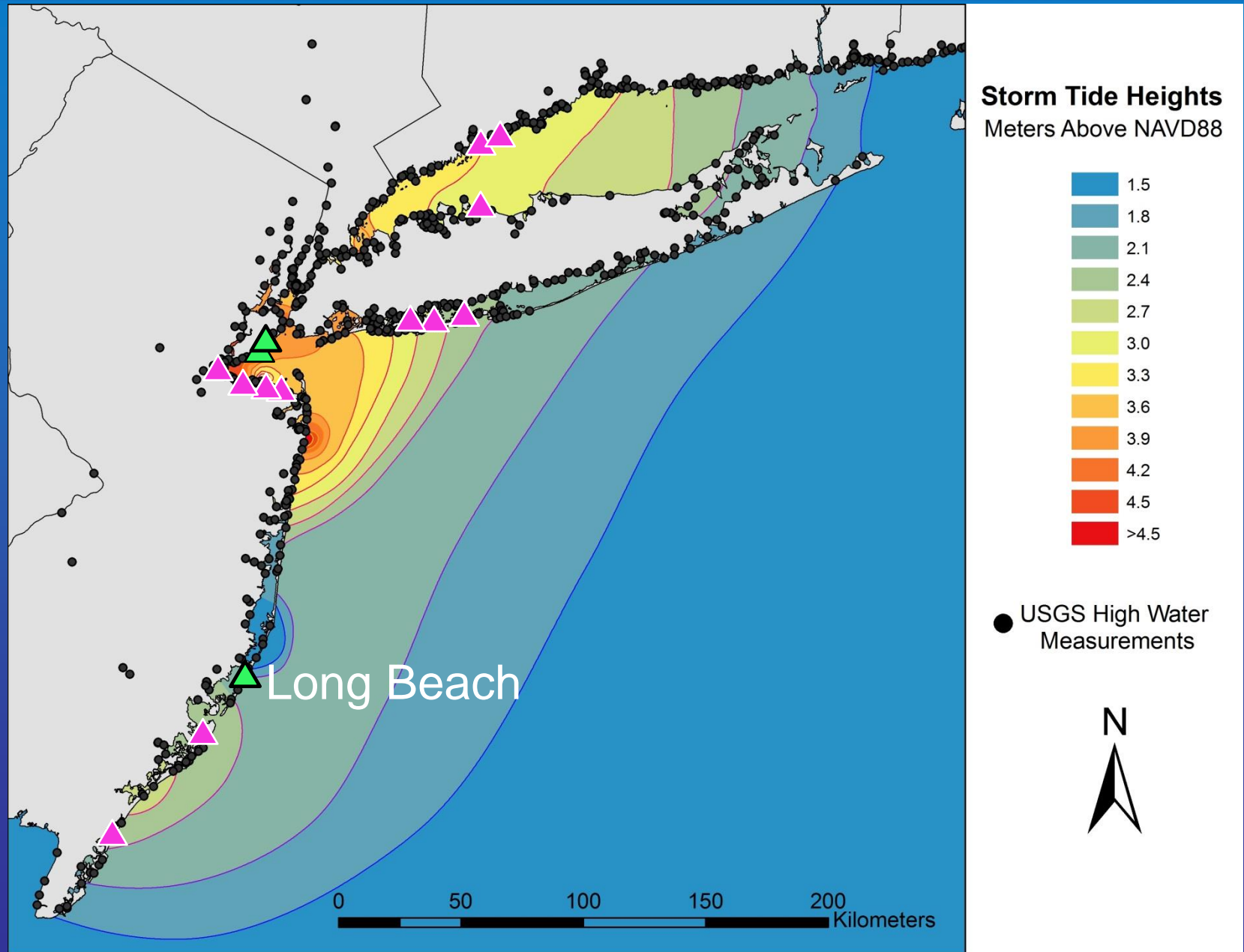
Hurricane Sandy Storm Tide



Hurricane Sandy Storm Tide



Hurricane Sandy Storm Tide



Long Beach Washover



Pre Sandy



Post Sandy

Long Beach Washover



Prudential

Zack Shore Properties



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Research and education to advance understanding of the ocean and its interaction with the Earth system for the benefit of society

Research and education to advance understanding of the ocean and its interaction with the Earth system for the benefit of society



In other words, how did the ocean end up in the NYC subway?

Woods Hole Oceanographic Institution



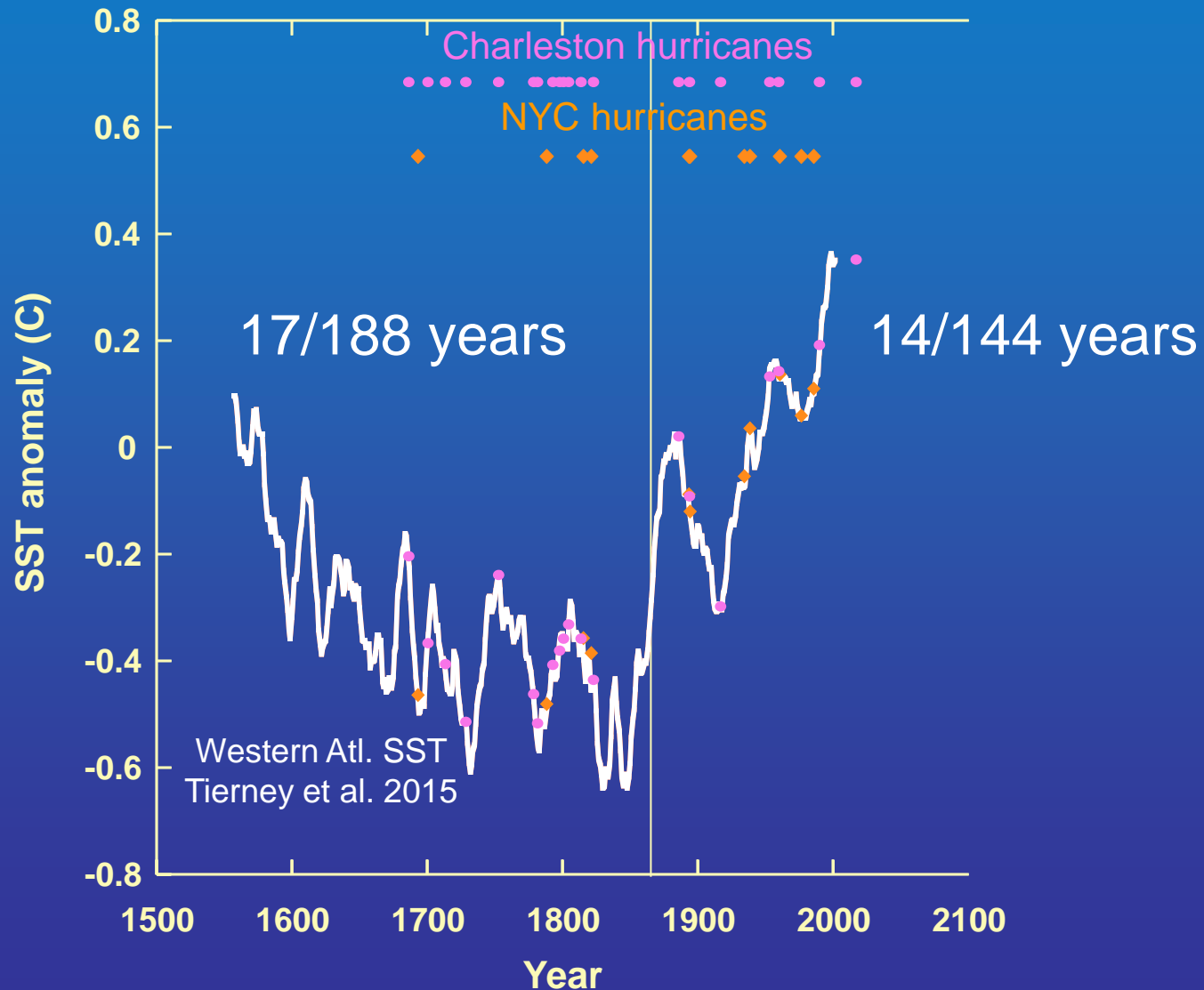
Research and education to advance understanding of the ocean and its interaction with the Earth system
for the benefit of society



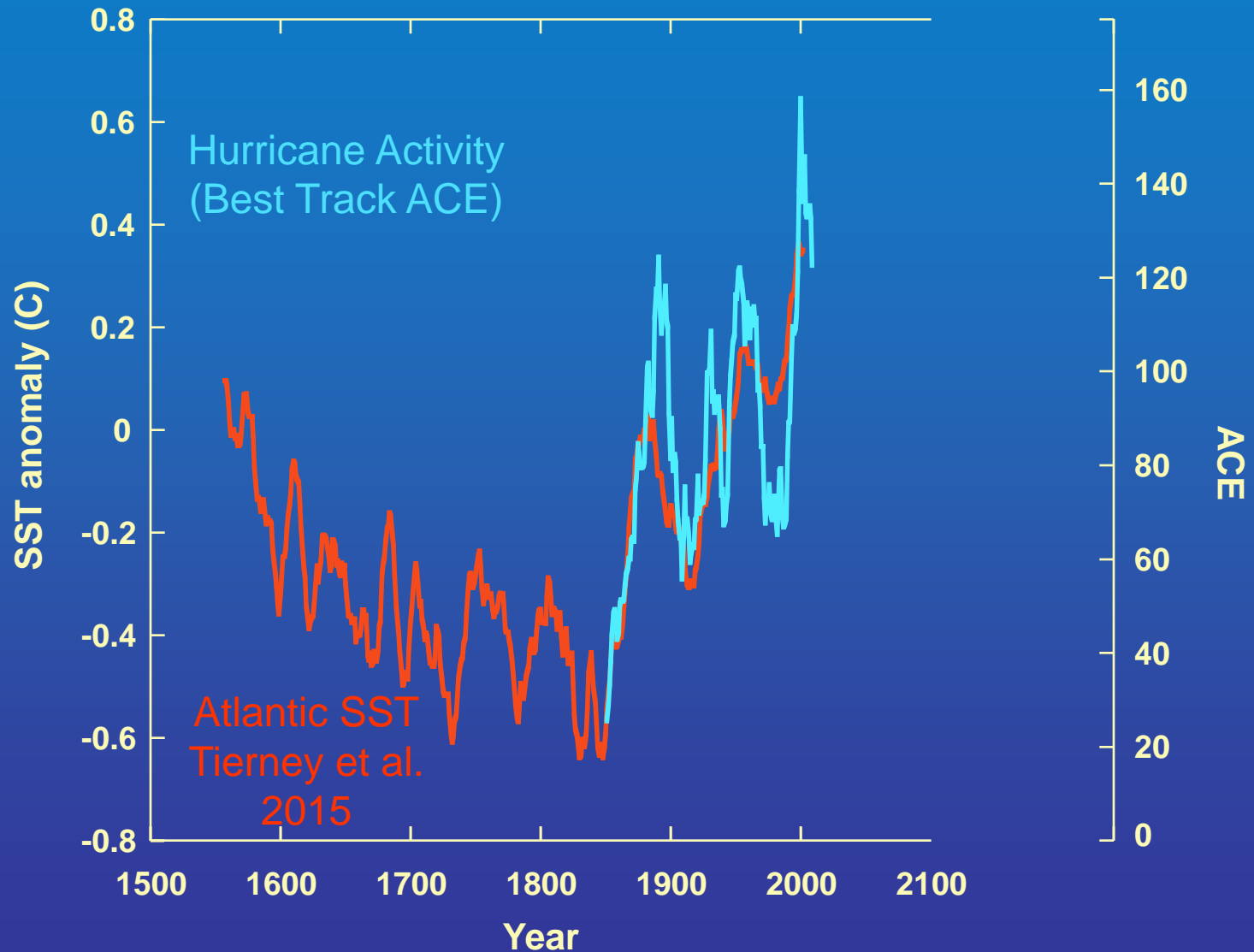
Historical Hurricanes and Sea Surface Temp



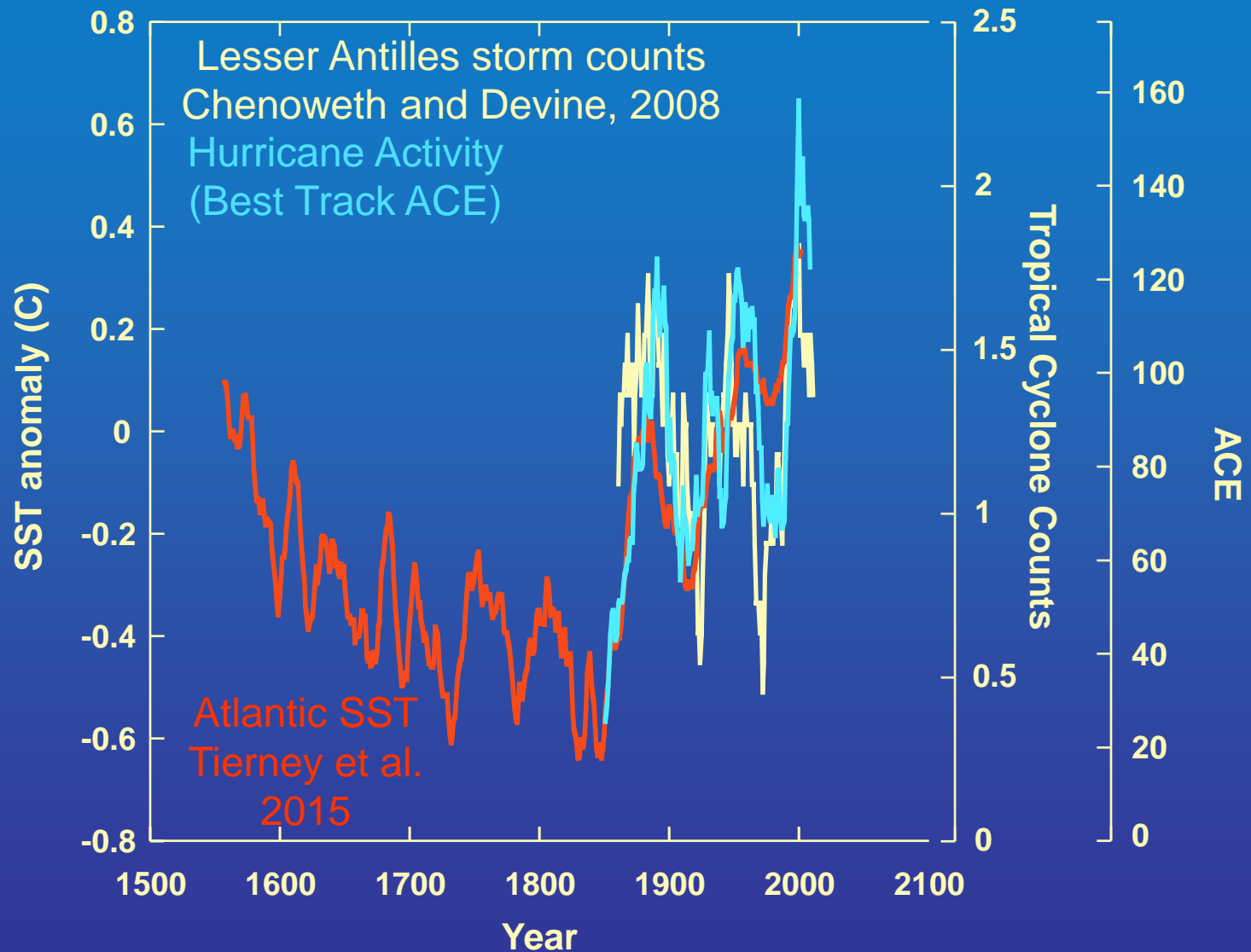
Is there other evidence for elevated LIA activity?



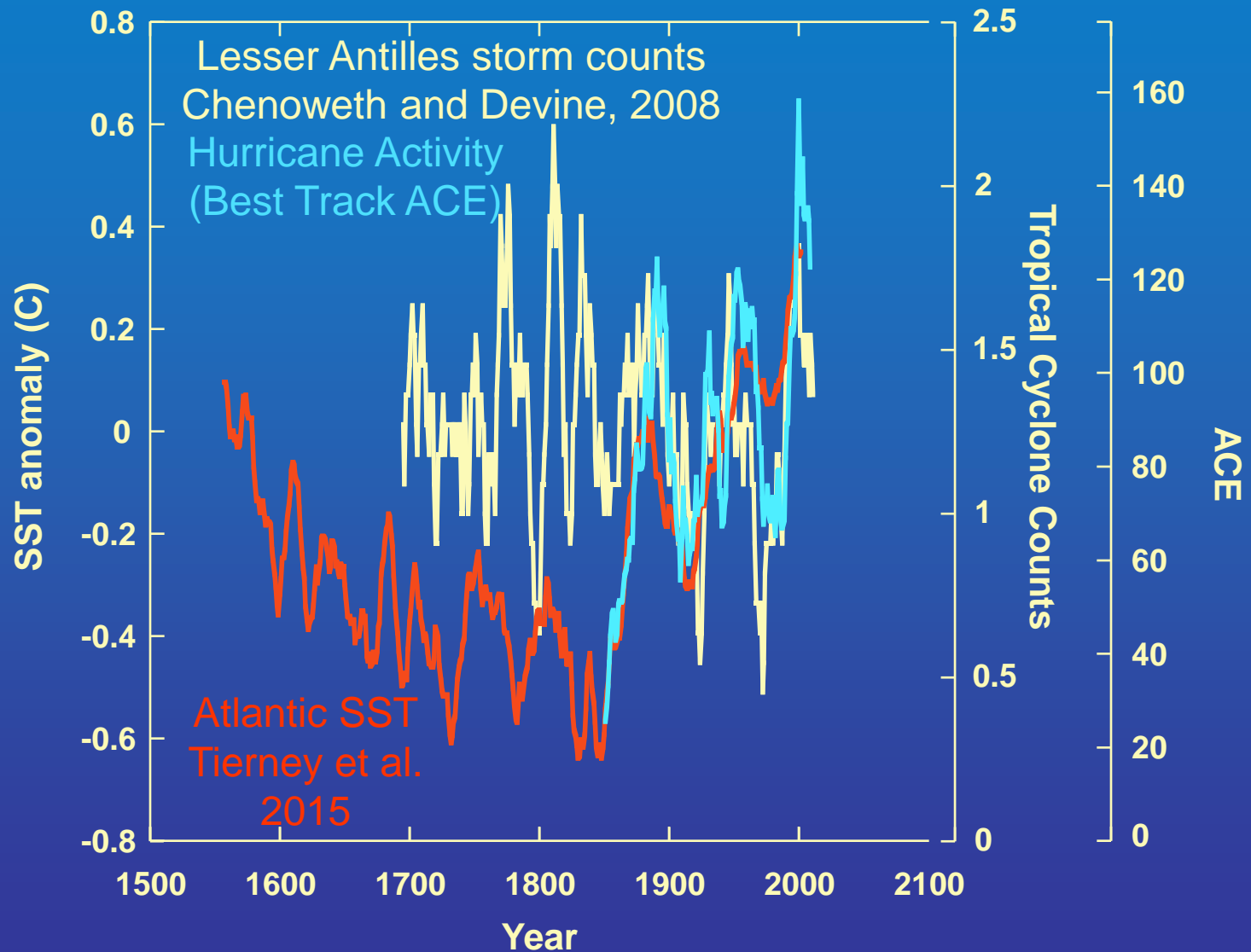
Hurricanes and Sea Surface Temp



Hurricanes and Sea Surface Temp



Hurricanes and Sea Surface Temp



Questions and some answers



- Why so much damage from Sandy? Coastal population growth and development in low lying areas

- What is the relationship with SST and Atlantic hurricane activity during the historic period? Positive correlation falls apart prior to 20th century
- How has hurricane activity varied prehistorically?
- Is there a relationship between changes prehistoric hurricane activity and SST?
- How well does climate modeling capture historical and prehistoric hurricane activity? Should we trust them to predict the future?

Summary



NJ/NYC were fortunate throughout the 20th century (unfortunately this was a time of unprecedented coastal development)

Summary



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Storms of far greater intensity than Hurricane Sandy (and Bob) impacted the area historically (and prehistorically)

Summary



NJ/NYC were fortunate throughout the 20th century (unfortunately this was a time of unprecedented coastal development)

Storms of far greater intensity than Hurricane Sandy (and Bob) impacted the area historically (and prehistorically)

Over the last two millennium historically unprecedented intense hurricane activity occurred during intervals of elevated sea surface temperatures

Summary



Despite cool SSTs in the Little Ice Age the Lesser Antilles saw heightened levels of hurricane activity

Summary



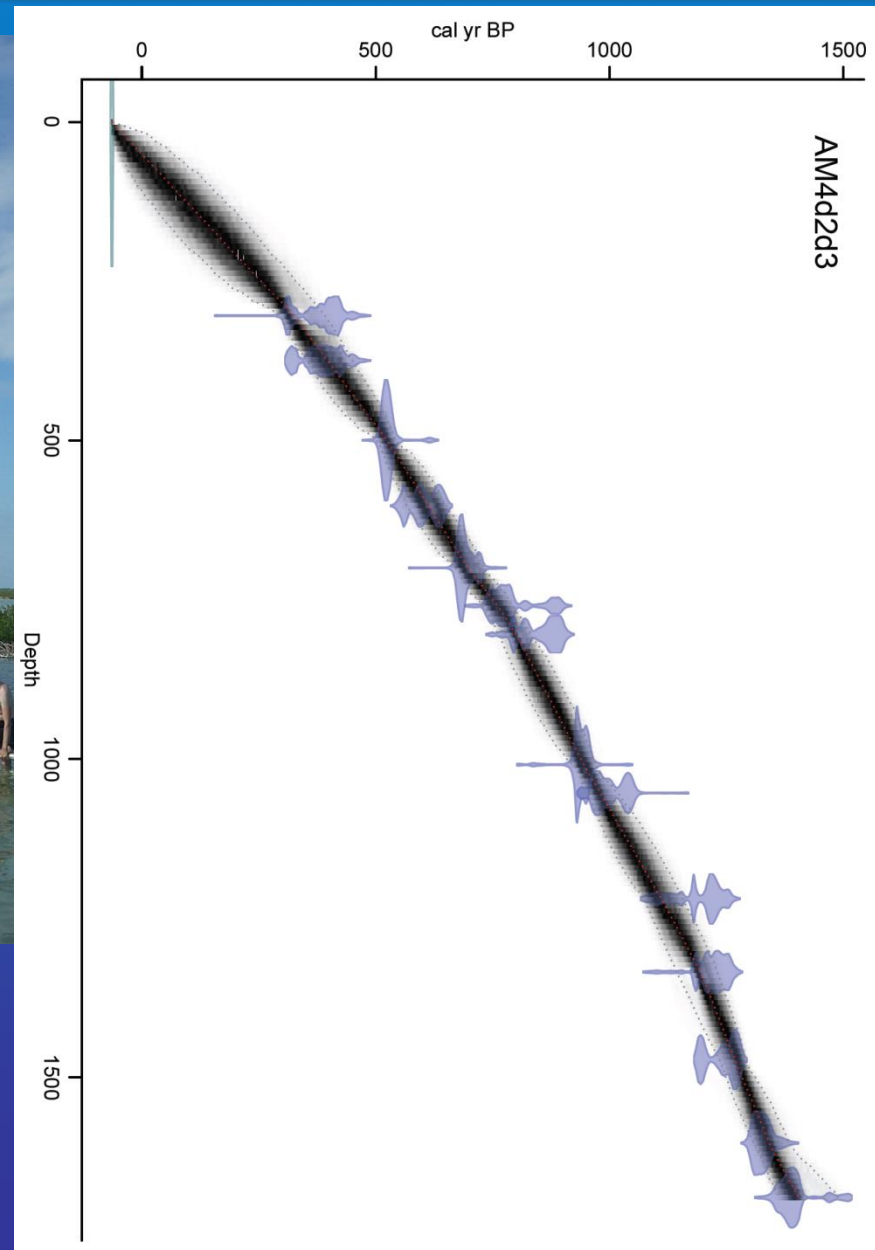
Despite cool SSTs in the Little Ice Age the Lesser Antilles saw heightened levels of hurricane activity

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

Current and Future Work



Record from South Andros Bahamas



Oyster Pond Core 13

