Unit 7: Introduction to Storm Surge

FEMA L311 Course

National Hurricane Conference Orlando, Florida

26 March 2012

Robbie Berg
Hurricane Specialist

Jamie Rhome
Storm Surge Team Lead

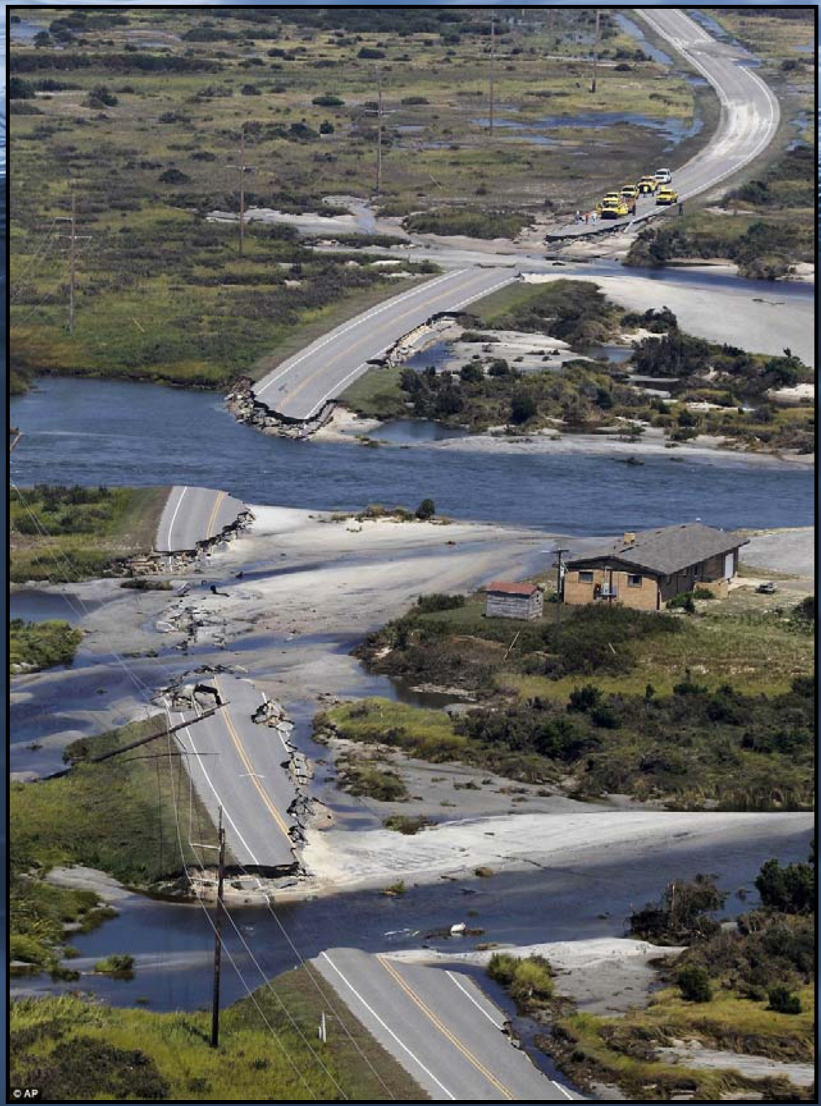
Hurricane Katrina (2005) – Mississippi

1200 deaths, $108 billion damage

Hurricane Ike (2008) - Bolivar Peninsula, Texas

20 deaths, $29.5 billion

Hurricane Irene (2011) - Outer Banks, NC
41 deaths, at least $7 billion (still pending)



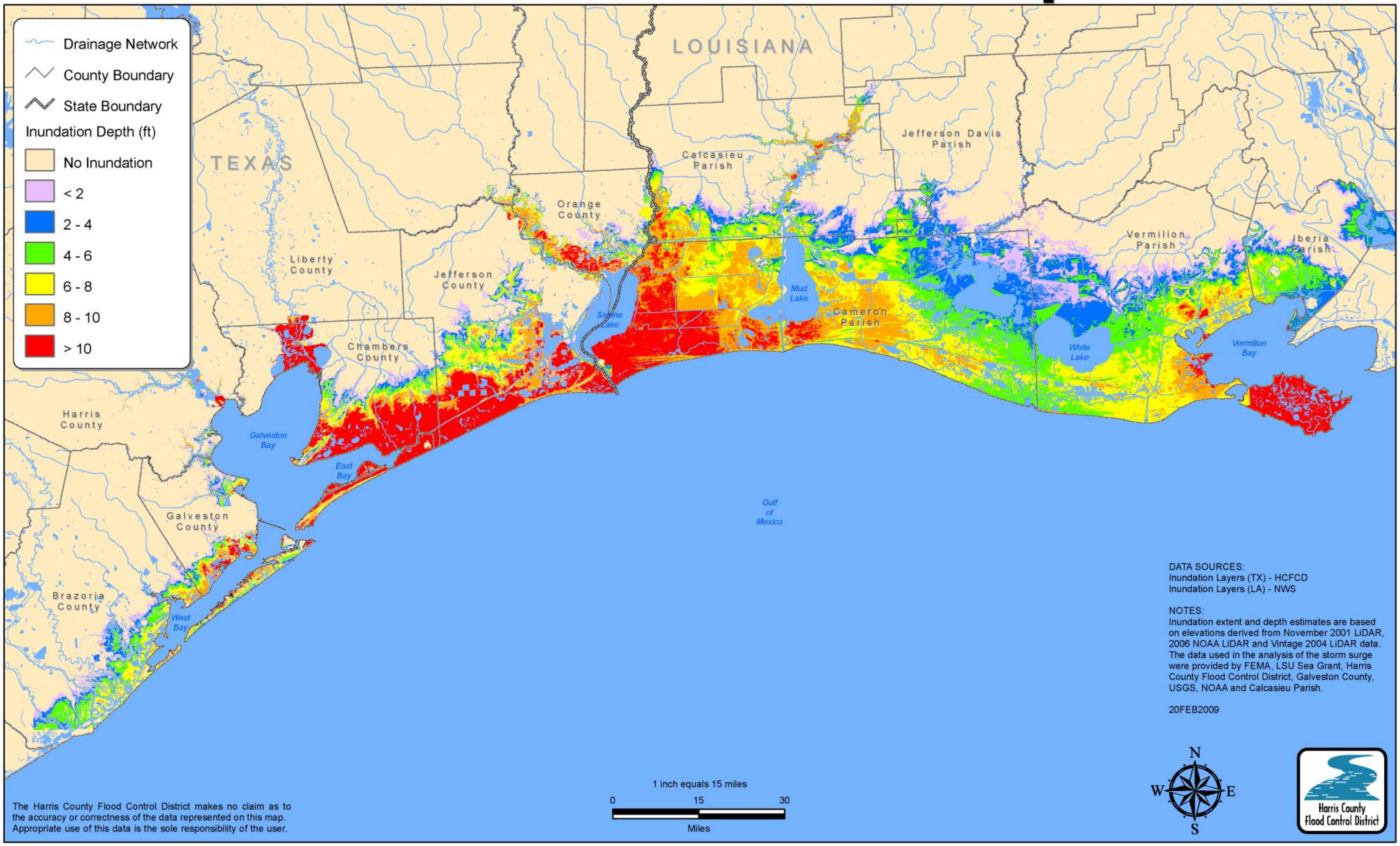
Unit Outline

- Introduction to Storm Surge
  - Who is vulnerable?
  - What is Storm Surge?
  - Factors affecting Storm Surge
- Measuring Storm Surge
  - Data and associated limitations

Why is Surge an Important Issue?

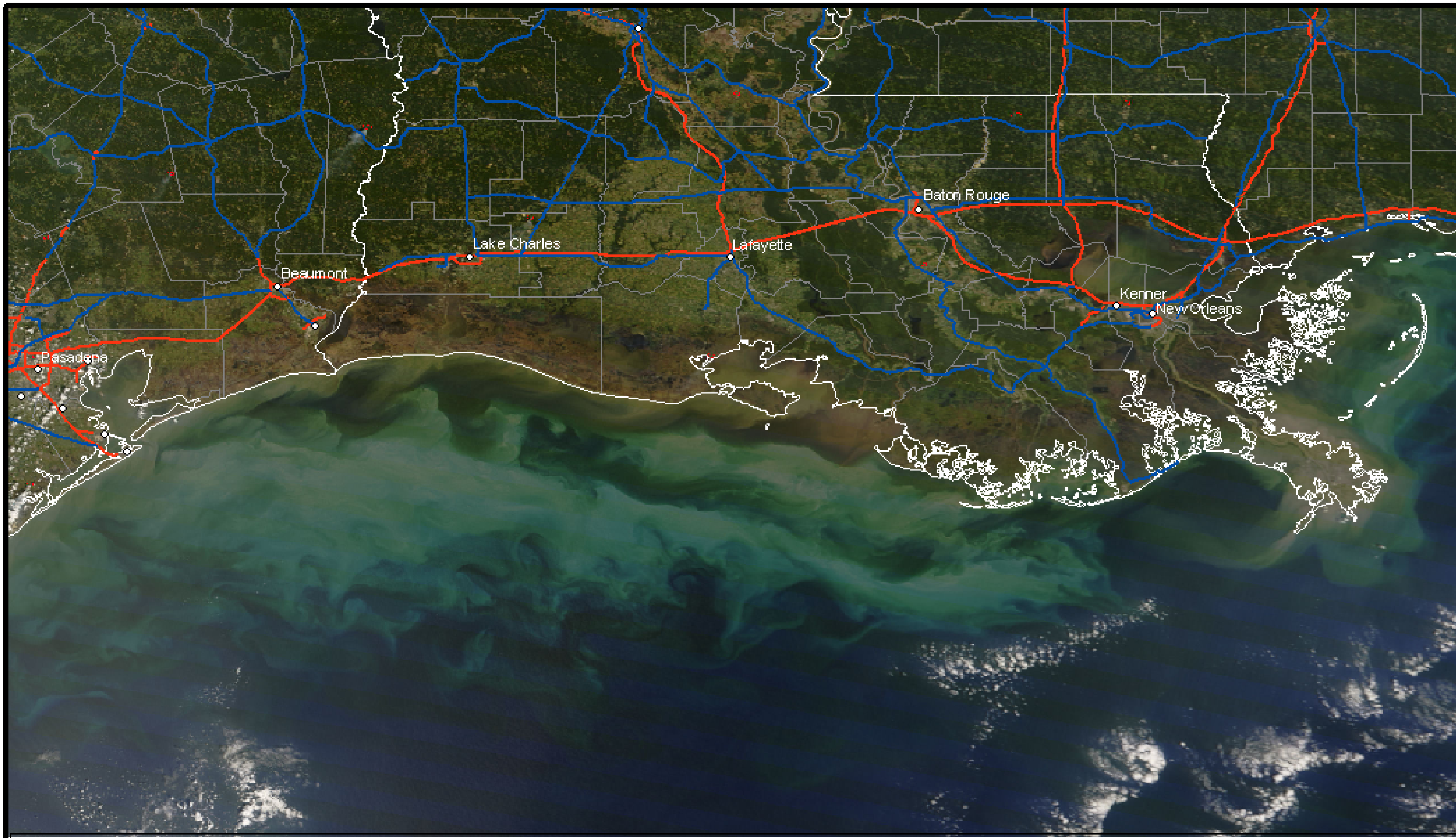
- From 1990-2008, **population** density increased by **32% in Gulf coastal counties**, 17% in Atlantic coastal counties, and 16% in Hawaii (U.S. Census Bureau 2010)
- Over half of the Nation's **economic productivity** is located within coastal zones
- 72% of ports, 27% of major roads, and 9% of rail lines within the Gulf Coast region are at or below 4 ft elevation (CCSP, SAP 4-7)
- Storm surge of 23 ft: 67% of **interstates**, 57% of arterials, almost half of rail miles, 29 **airports**, and virtually all **ports** in the Gulf Coast area subject to inundation (CCSP SAP 4-7)

Hurricane Ike Inundation Depth



S:\Open\GIS\work_directory\IKE\InundationMaps\ikeinun_extendedareadepth_11x17.pdf

Dying Vegetation due to Salt Water Intrusion



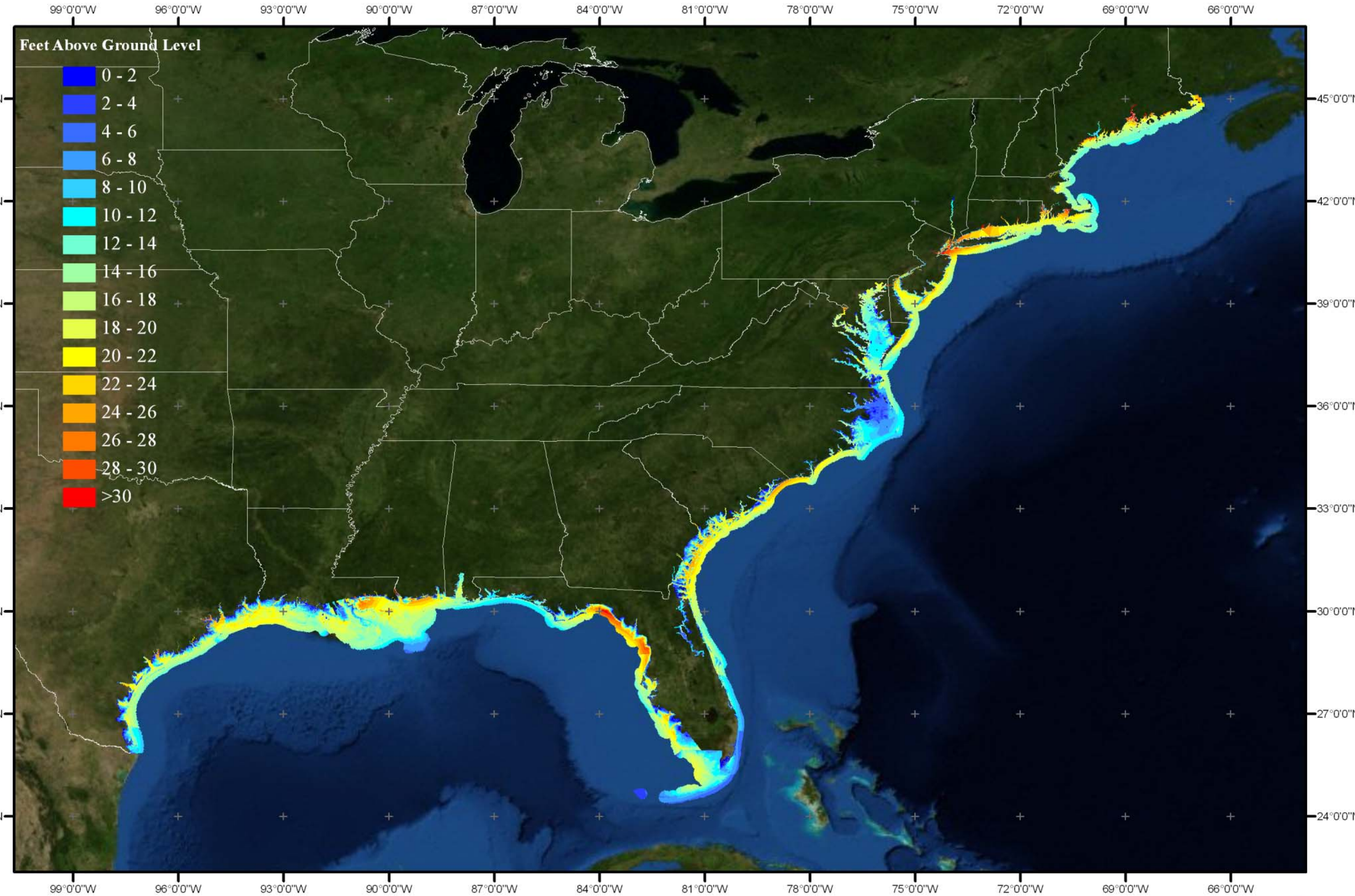
The brown region along the coast indicates dying vegetation due to Salt Water burn. The brown area in the Gulf of Mexico indicates a high concentration of sediment that was taken from the coastal areas when the surge waters flowed back into the gulf. Imagery courtesy of NASA. Map made by Donovan Landreneau and Jonathan Brazzell NWS Lake Charles

House of David and Kimberly King
Waveland, Mississippi

Vulnerability

- Coastal areas are at increasing risk from sea-level rise and storm surge
  - Sea-level rise and storm surge place many U.S. coastal areas at increasing risk of erosion and flooding. Energy and transportation infrastructure and other property in coastal areas are very likely to be adversely affected (Global Climate Change Impacts in the U.S. 2009)
- Rising sea-level provides a higher “base” for future surge/inundation events thus producing an increasing threat to:
  - Coastal communities
  - Ecosystems (wetlands, critical species, habitat loss, etc)
  - Transportation systems (highway systems, ports, rail)
  - Economic viability (tourism, transport of goods, natural resources)
  - Energy

Storm Surge Vulnerability: Category 4 Hurricane



Data Source:
NWS/NHC/Storm Surge Unit

FOR EDUCATIONAL PURPOSES ONLY
NOT TO BE USED TO MAKE LIFE OR DEATH DECISIONS

N W E S
0 25 50 100 150 200 Miles

Gulf Coast

Biloxi, Mississippi
Katrina (2005)

Key West, Florida
Georges (1998)

Laffite, Louisiana
Rita (2005)

Galveston, Texas
Ike (2008)

Southeast

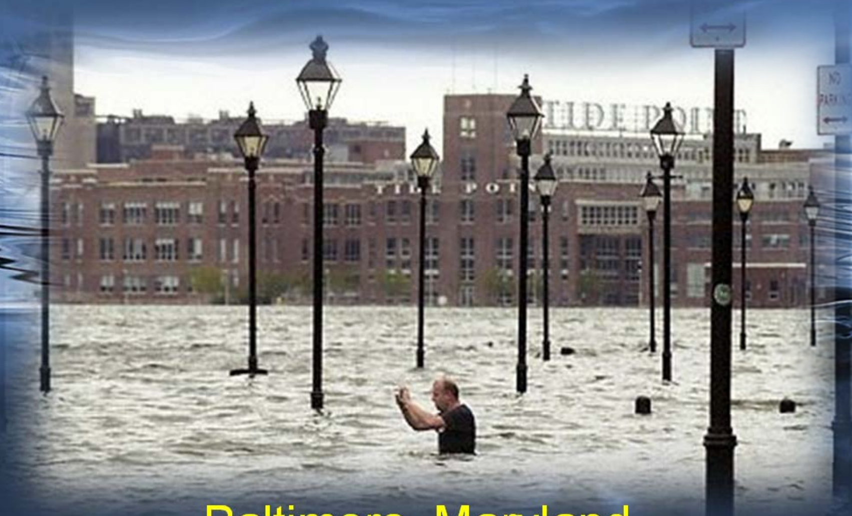
Rodanthe, North Carolina
Isabel (2003)

Pawley's Island, South Carolina
Hugo (1989)

Jacksonville, Florida
Fay (2008)

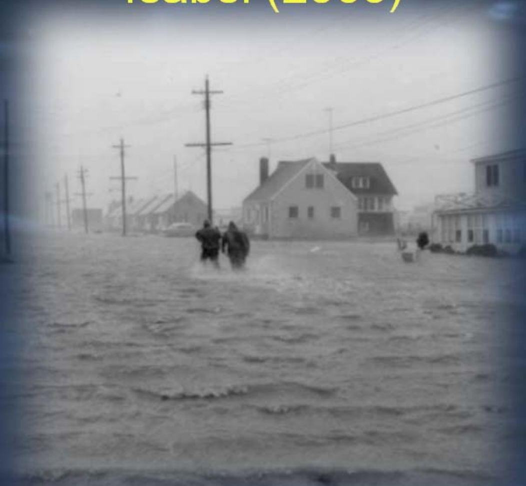
North Hutchinson Island, Florida
(Jeanne 2004)

Mid-Atlantic



Baltimore, Maryland
Isabel (2003)

Hampton, Virginia
Isabel (2003)



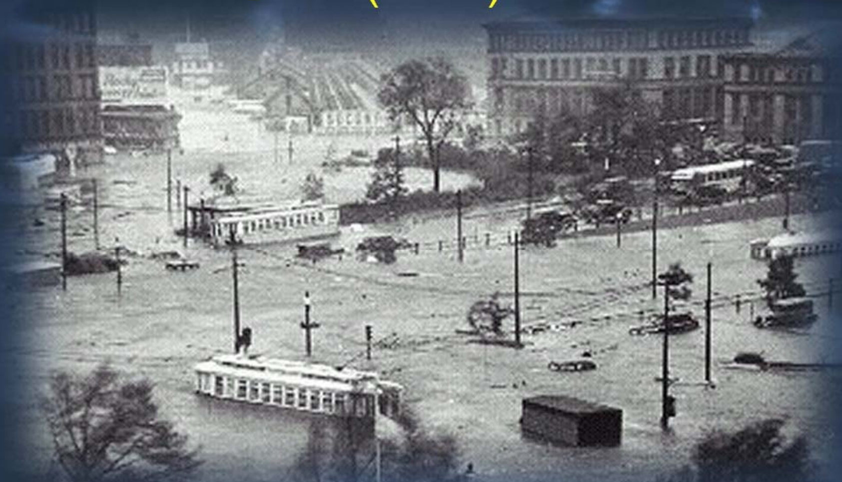
Surf City, New Jersey
Donna (1960)

Manhatten, New York
(Irene 2011)

New England

Narragansett Bay, Rhode Island
Carol (1954)

Westport, Massachusetts
Irene (2011)



Providence, Rhode Island
1938 Hurricane

Connecticut
Carol (1954)

Return Period for Major Hurricanes (center within 75 miles)

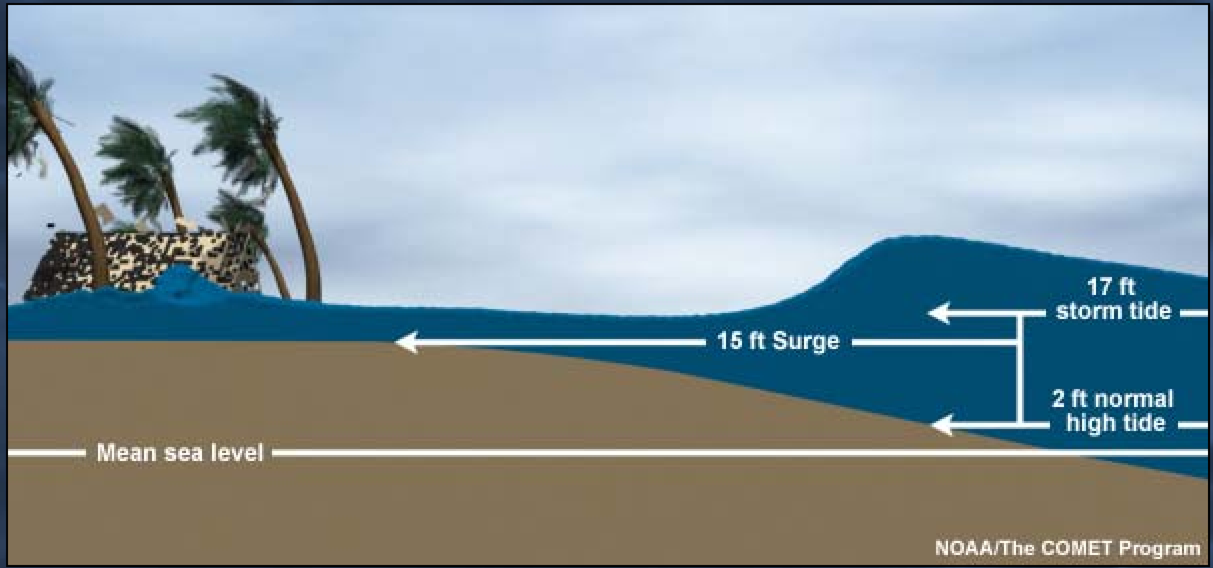
Major Hurricane expected to make landfall in the Gulf every 2 years

- Brownsville, TX 25 years
  - 1980 (Allen)
- Galveston, TX 18 years
  - 1983 (Alicia)
- New Orleans, LA 19 years
  - 2005 (Katrina)
- Houma, LA 18 years
  - 1992 (Andrew)
- Biloxi, MS 18 years
  - 2005 (Katrina)
- Mobile, AL 23 years
  - 2004 (Ivan)
- Tampa, FL 23 years
  - 1921
- Naples, FL 14 years
  - 2005 (Wilma)

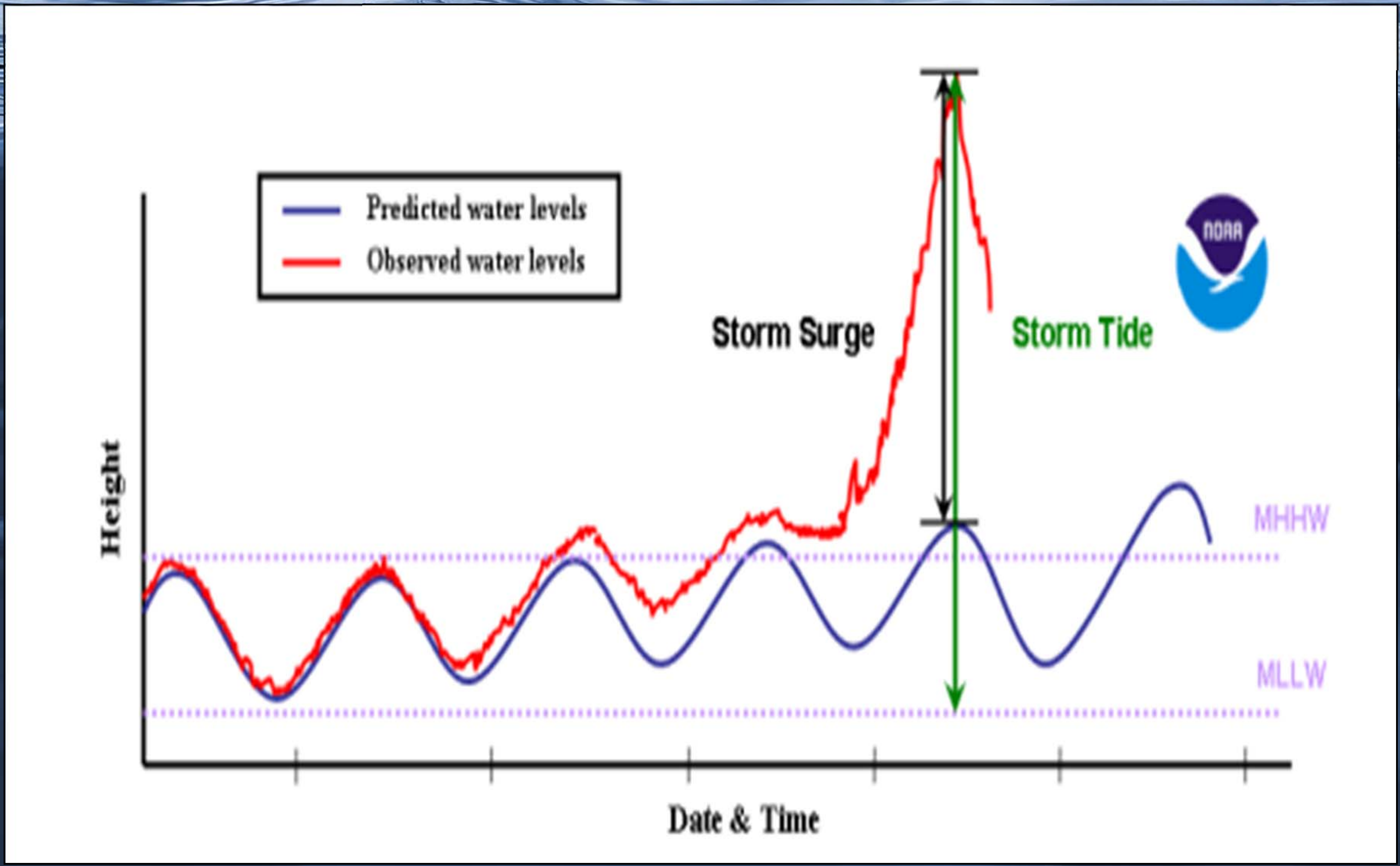
What is Storm Surge?

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

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

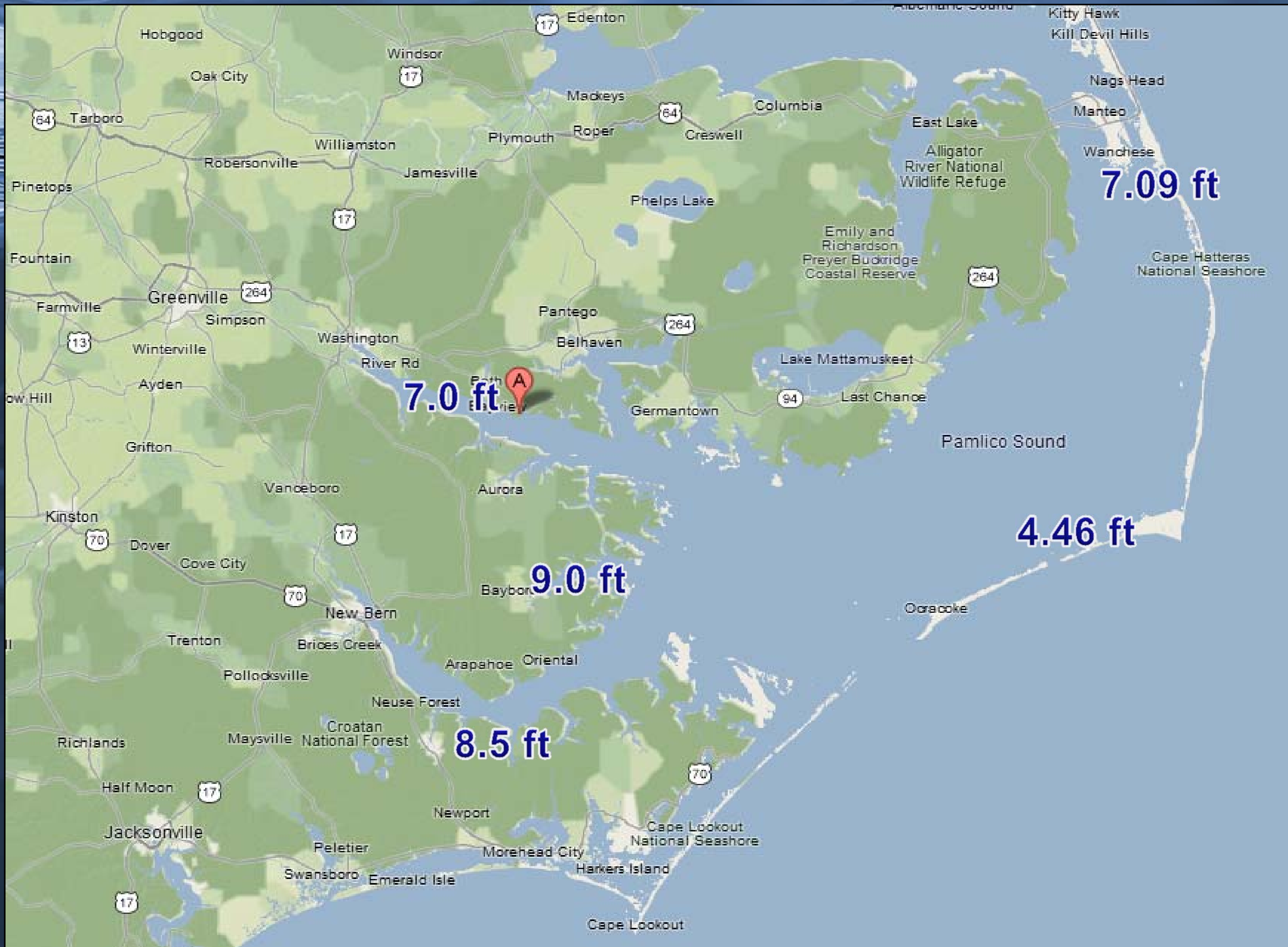


Storm Surge / Storm Tide



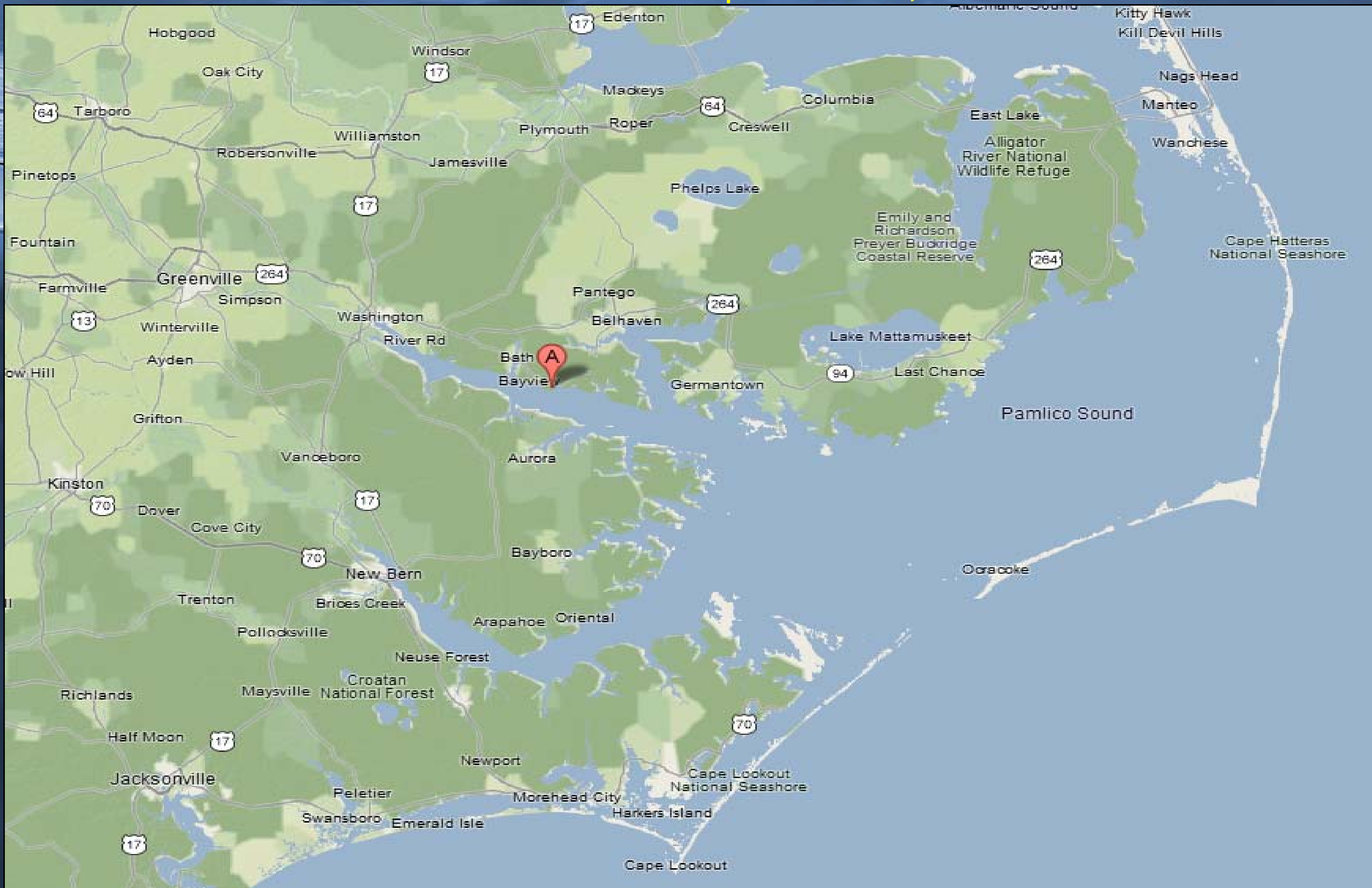
Storm Surge from Hurricane Irene

Rumley Marsh on the Pamlico River in North Carolina



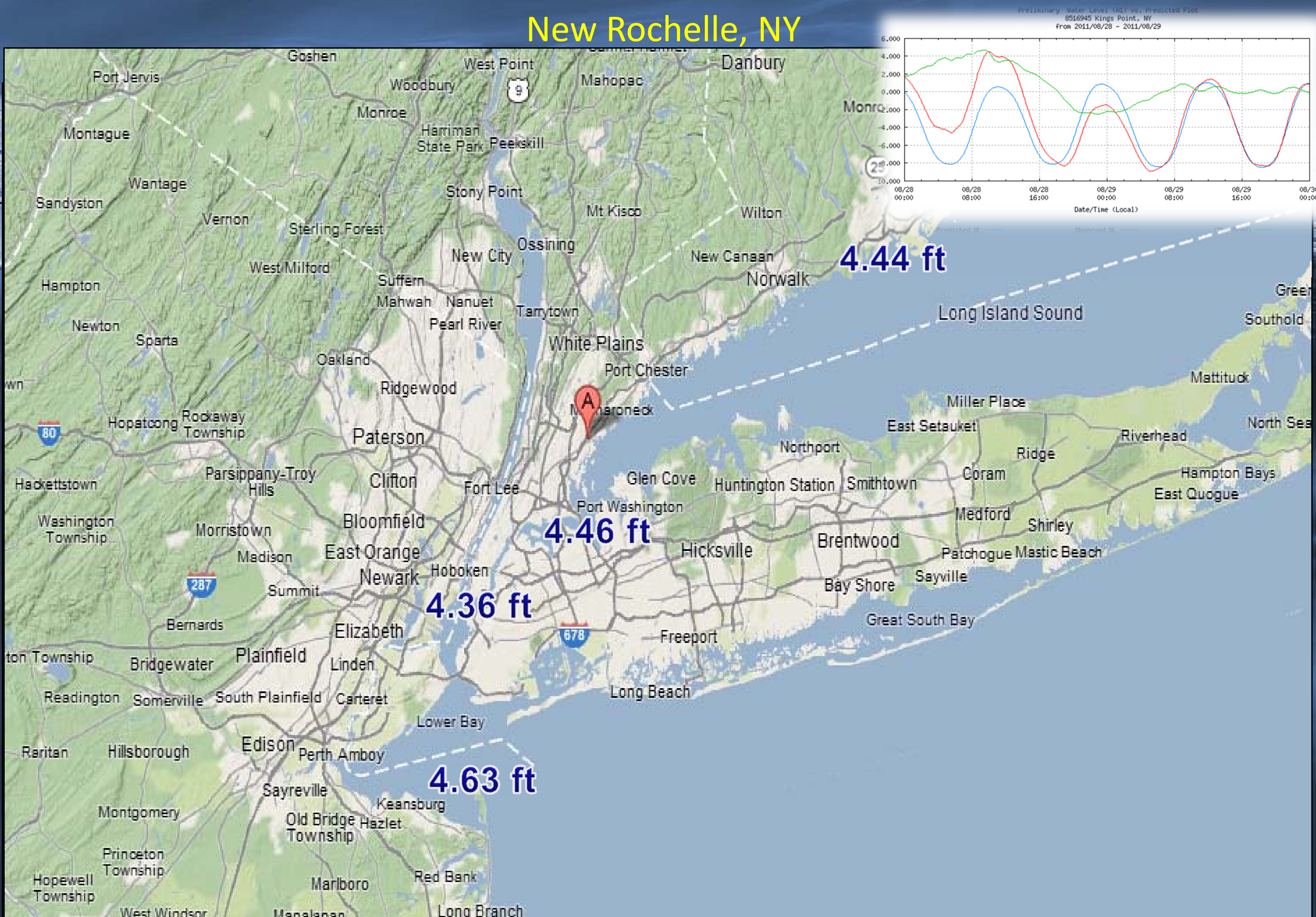
Low Water from Hurricane Irene

Pamlico Sound at Cape Hatteras, NC



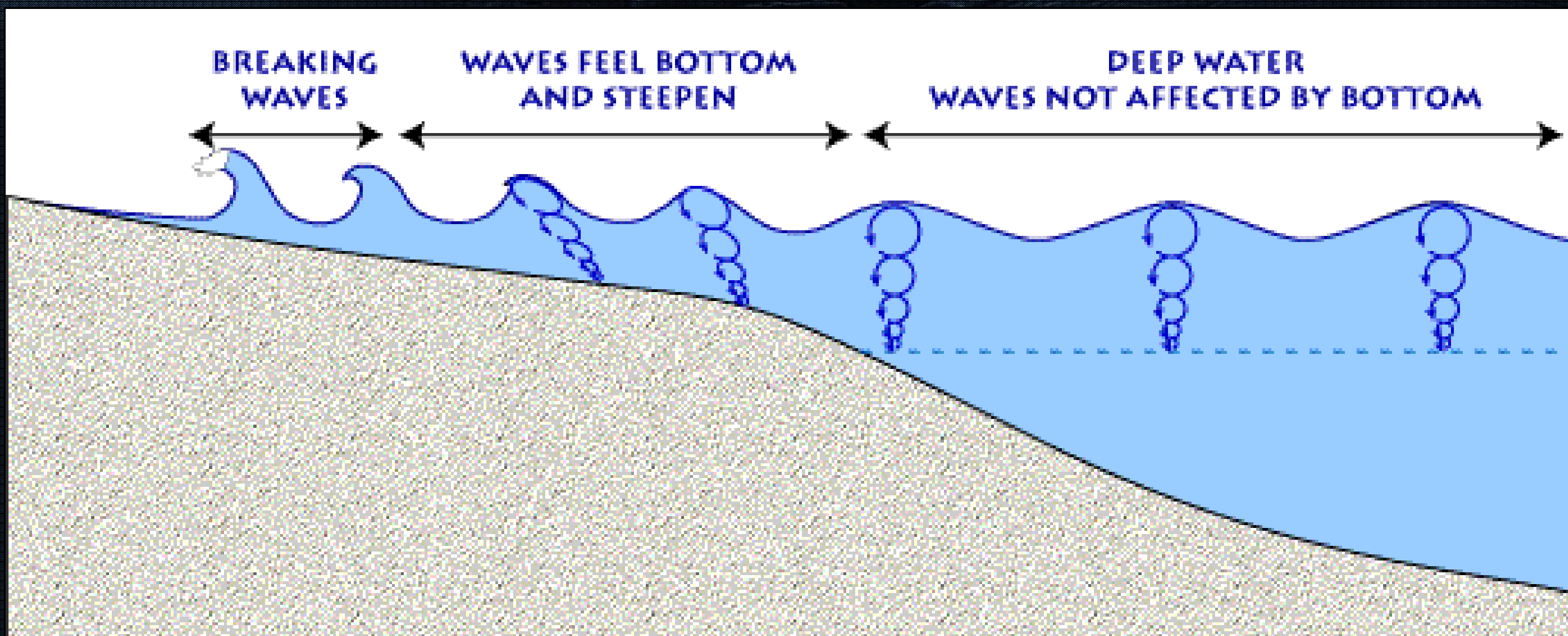
Storm Surge from Hurricane Irene

New Rochelle, NY



What about Waves?

- Breaking waves also contribute to the total water level through wave runup/setup



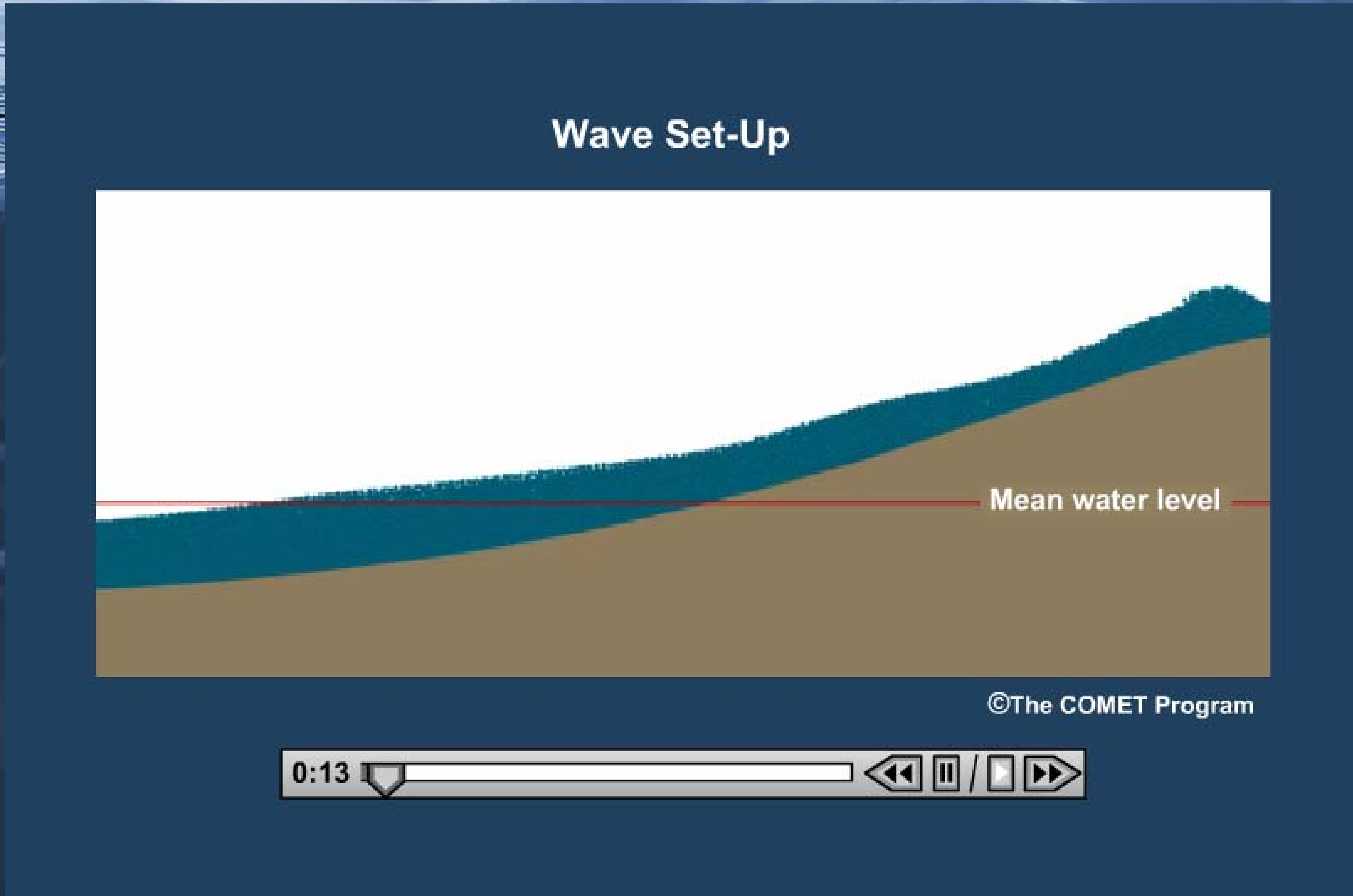
Wave Runup

Wave run-up at South Beach, Pacific Rim National Park Reserve, Vancouver Island

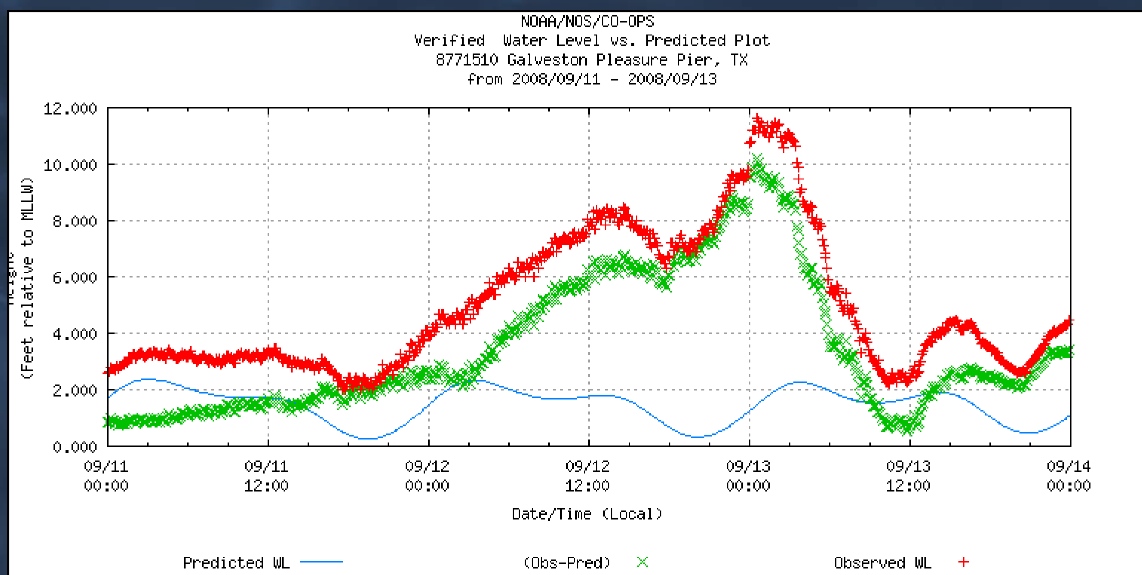
-1-

Wave Setup


SOUTHERNMOST
POINT
CONTINENTAL
U.S.A.


Wave Set-Up
Mean water level
©The COMET Program
0:13

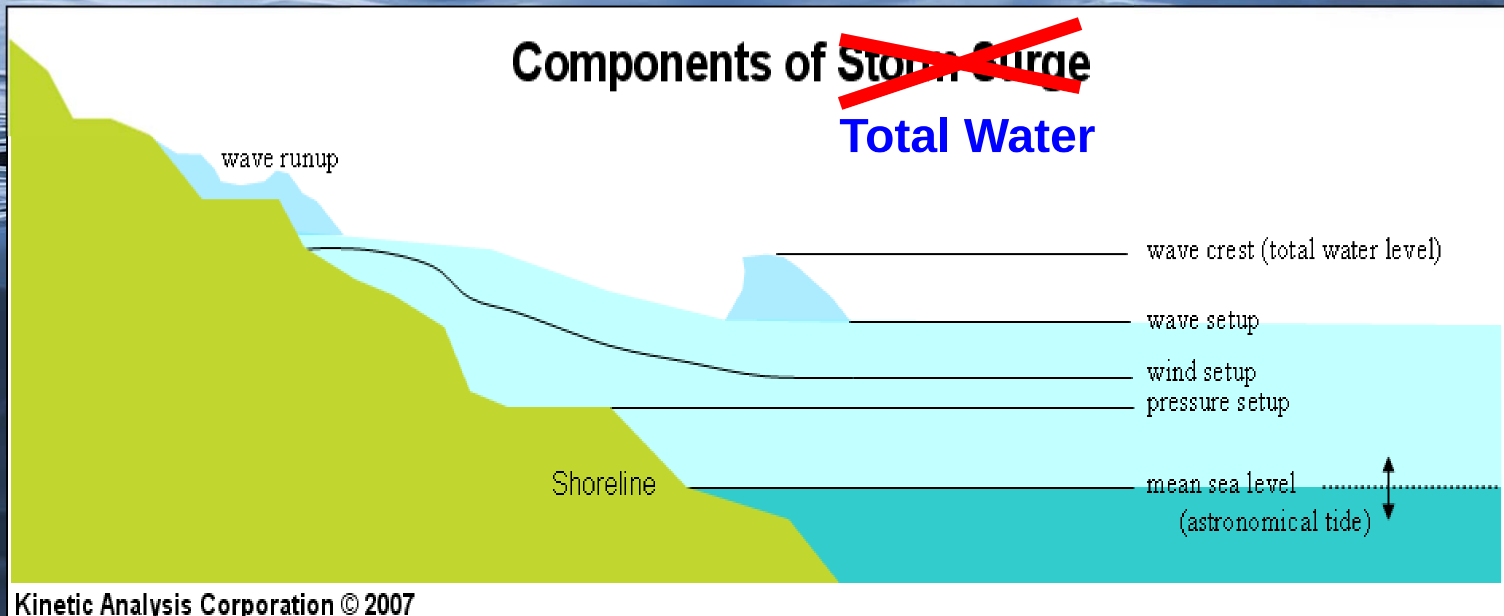
Galveston
Day before Ike arrived



Freshwater Input

- River input, esp. into bays and sounds
  - Mississippi River discharges 200,000 – 700,000 cubic feet per second
- Rainfall

Total Water



Total water level =

Storm surge +

Tides +

Wave setup +

Freshwater

No More Surge in the Saffir-Simpson Scale!

(it fits like a square peg in a round hole)

Category	Central Pressure Millibars	Central Pressure Inches	Winds (mph)	Surge	Damage
5	< 920	< 27.17	>155	>18'	Catastrophic
4	944-920	27.88-27.17	131-155	13'-18'	Extreme
3	964-945	28.47-27.91	111-130	9'-12'	Extensive
2	979-965	27.91-28.50	96-110	6'-8'	Moderate
1	≤ 980	≤ 28.94	74-95	4'-5'	Minimal

KATRINA (3)

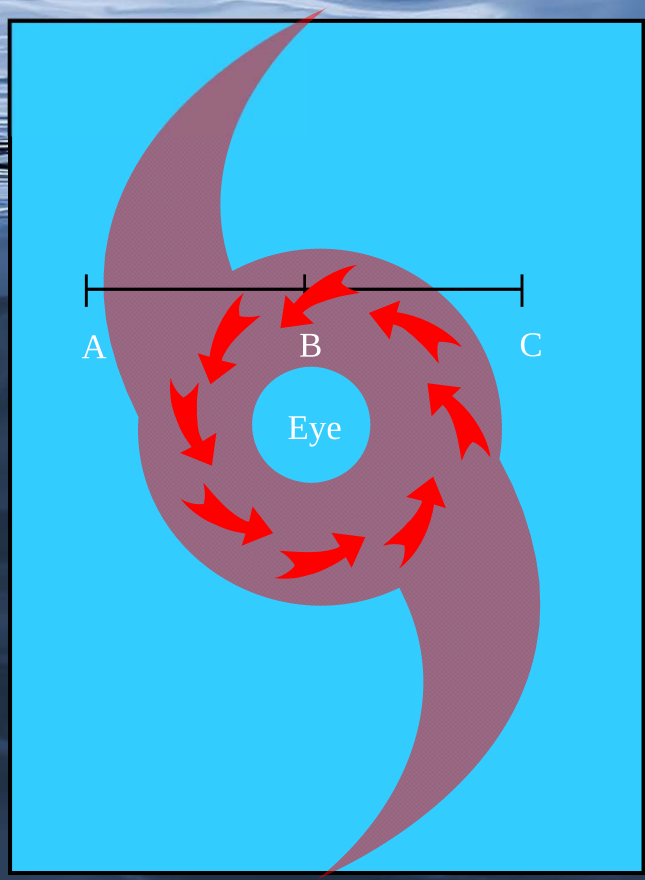
IKE (2)

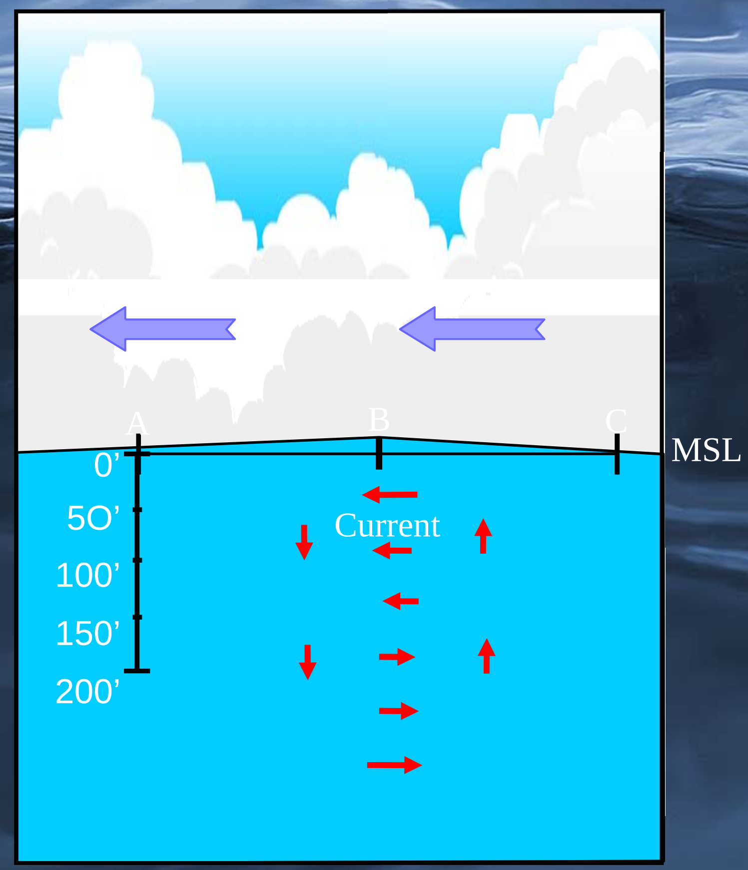
CHARLEY (4)

No Such Thing as “Just a Tropical Storm”

Louisiana State Rd. 23 near Myrtle Grove
Tropical Storm Lee (2011)

Deep Water

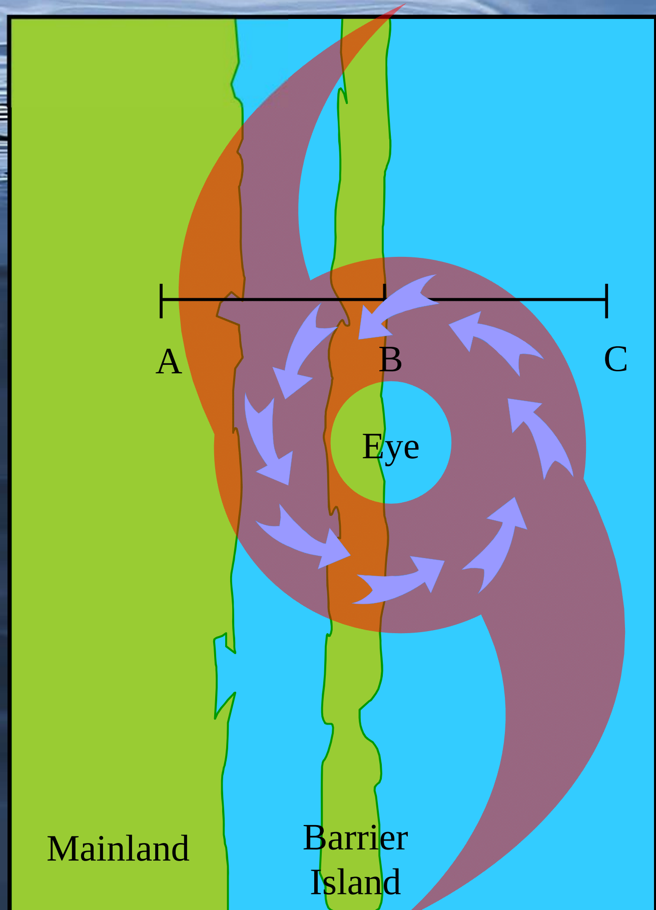




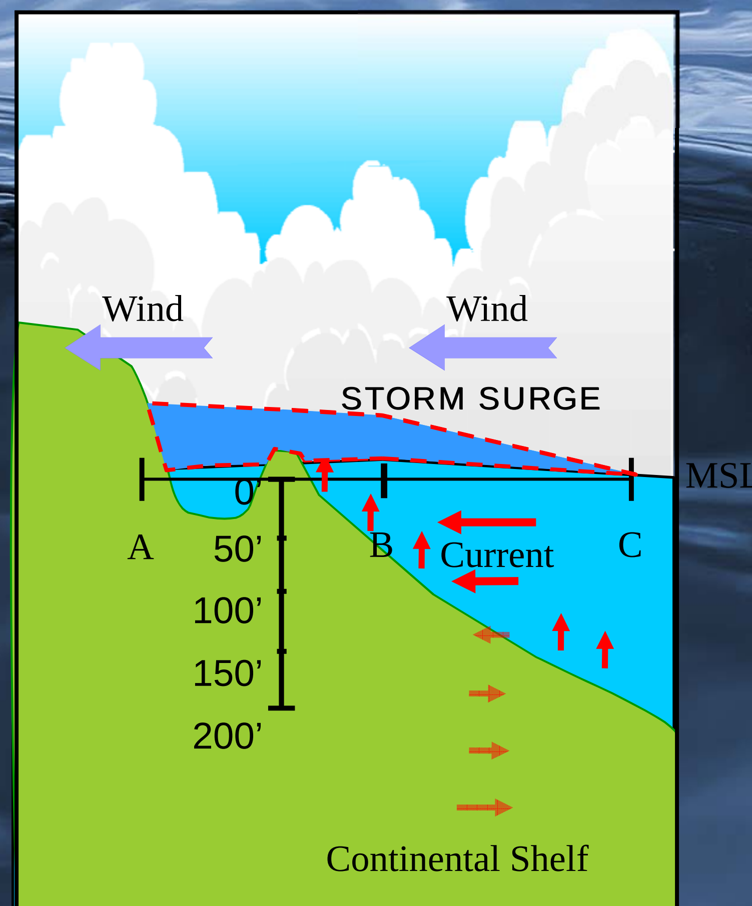
a. Top view of Sea Surface

b. Side view of Cross Section "ABC"

Landfall

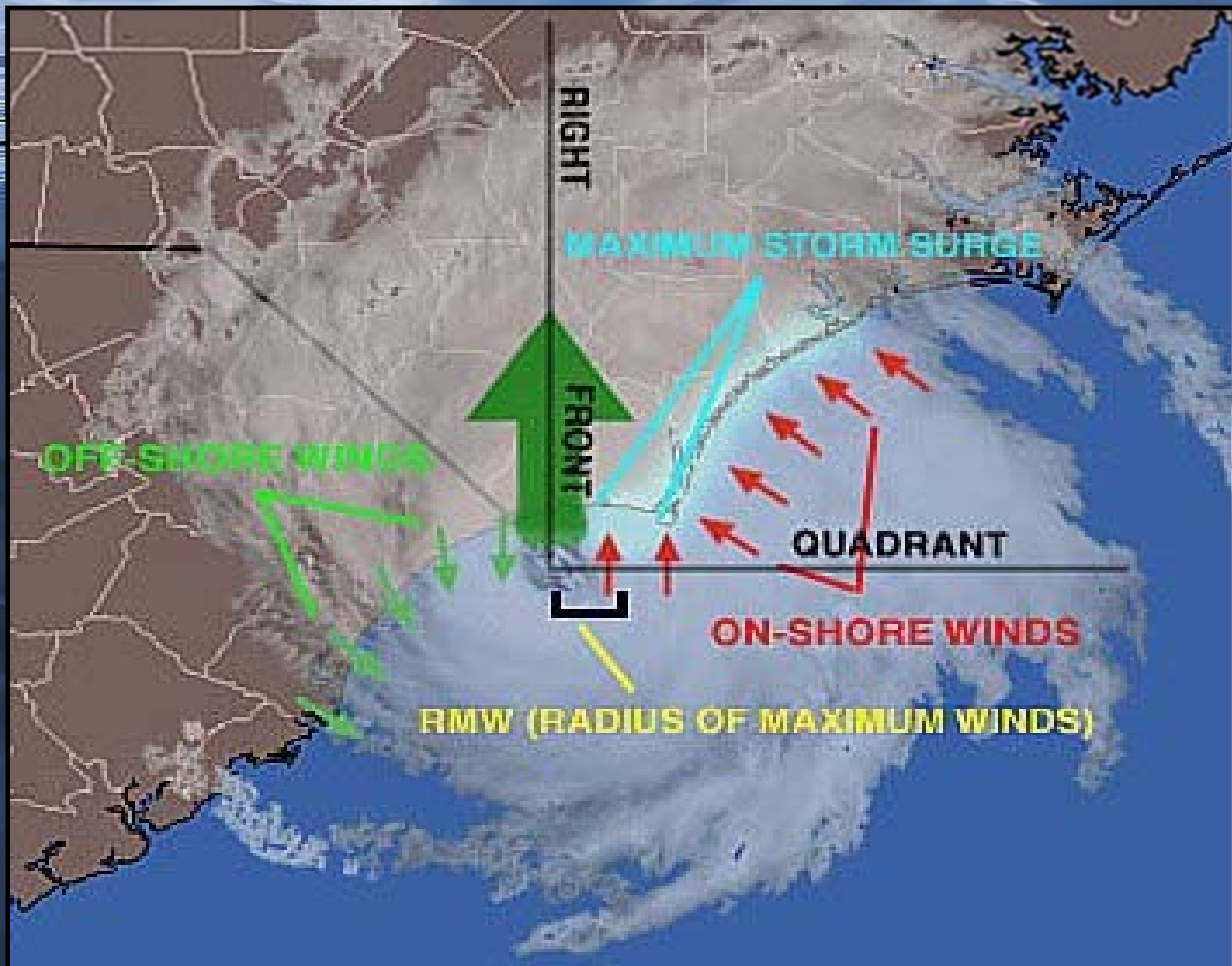


a. Top view of sea surface and land



b. Side view of Cross Section "ABC"

Understanding Surge



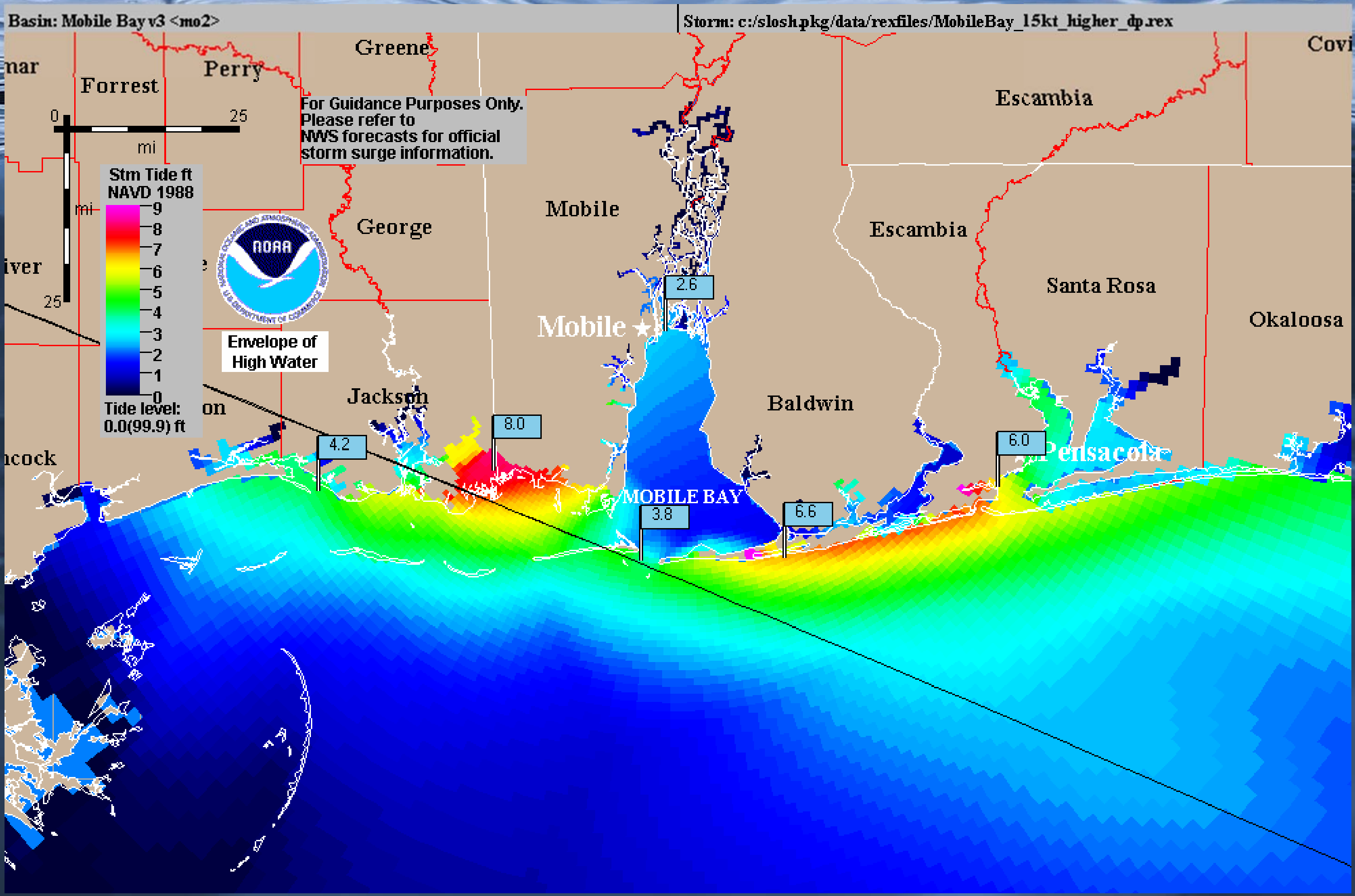
Factors Affecting Storm Surge

- **Central Pressure**
- **Intensity (wind speed)**
- **Forward Speed**
- **Size**
  - **Radius of Maximum Winds (RMW)**
- **Angle of Approach**
- **Width and Slope of Shelf**
- **Local features** – concavity of coastlines, bays, rivers, headlands, or islands

Effects of Low Pressure

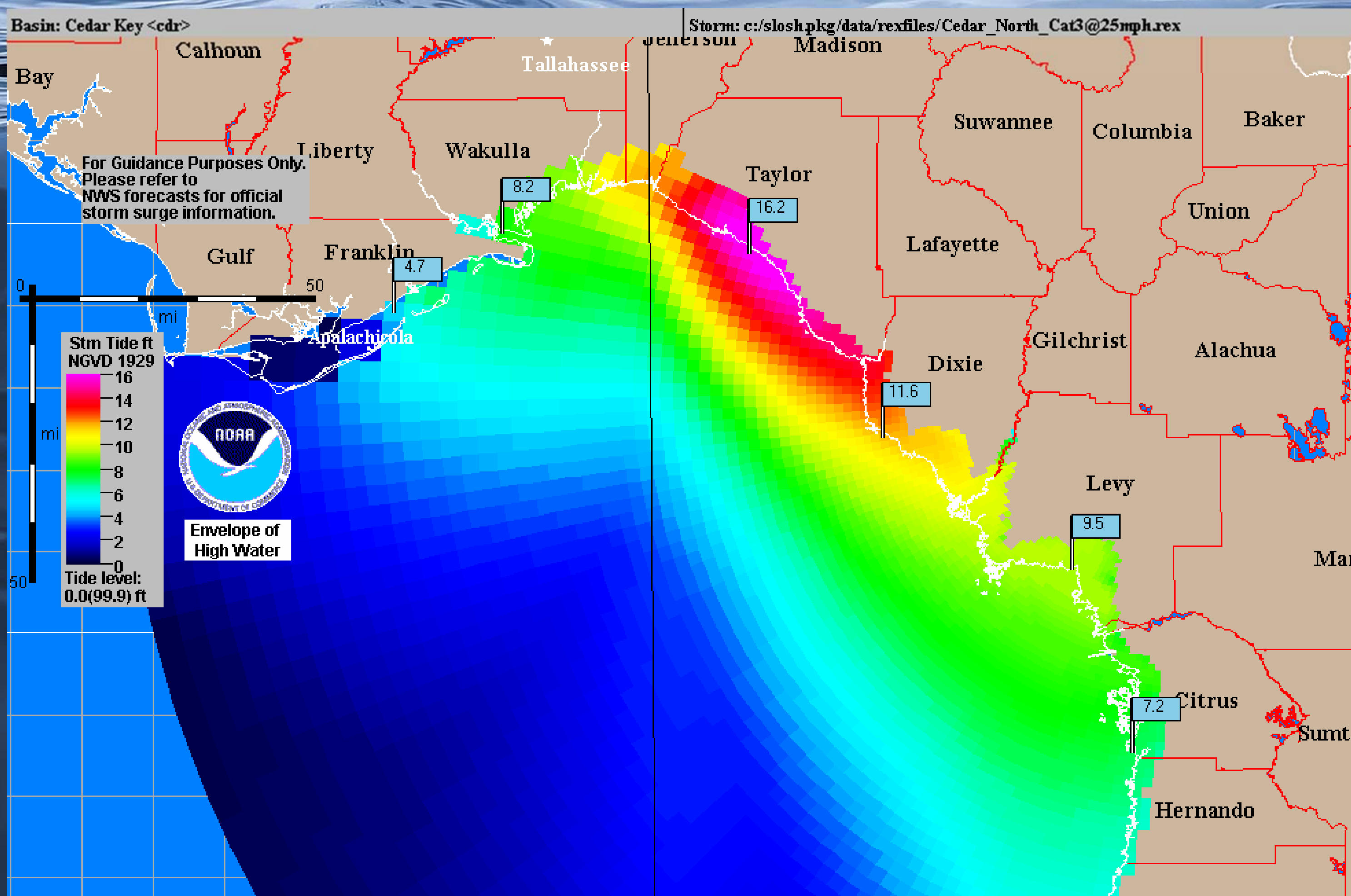
Intensity (Wind Speed)

15 mph stronger

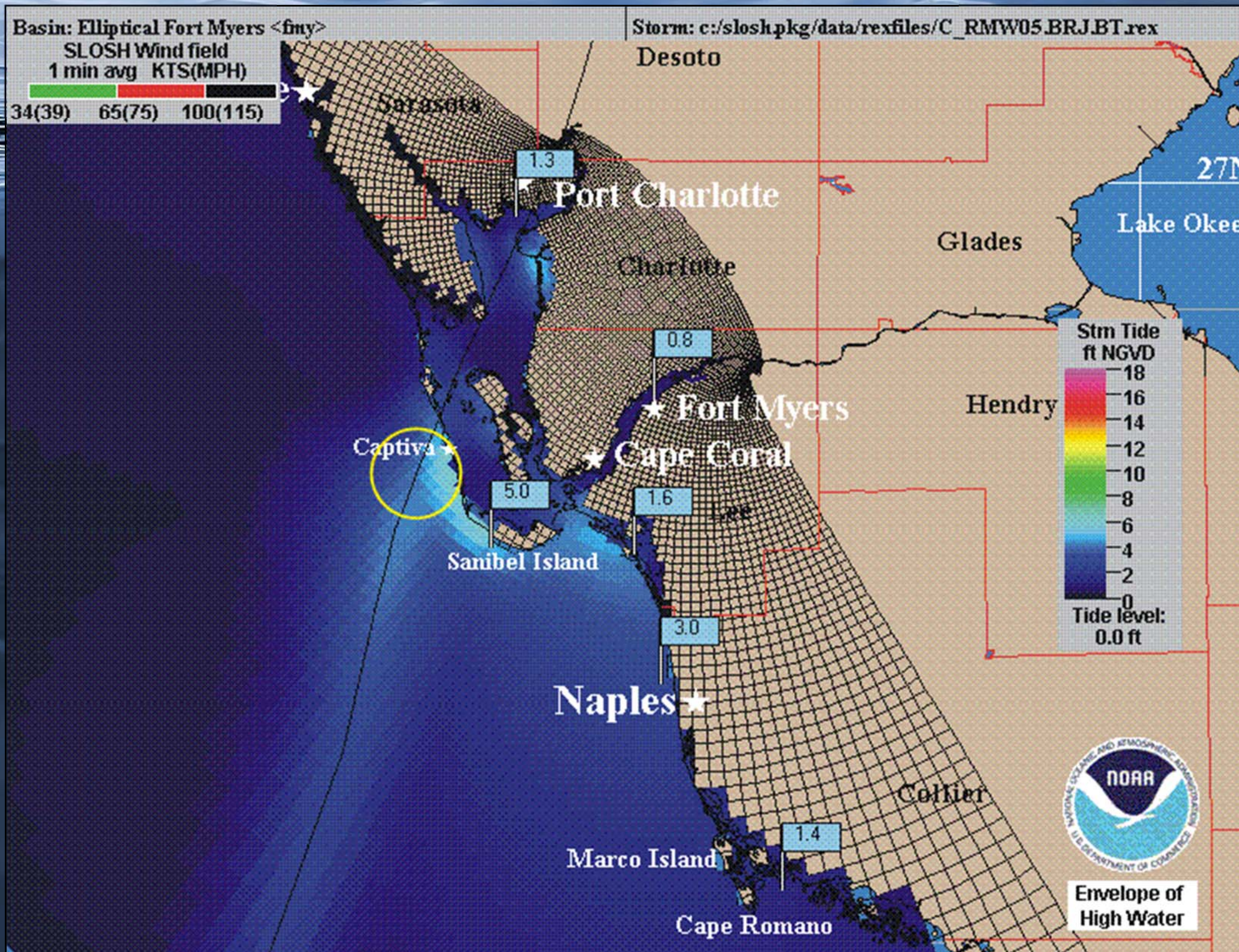


Forward Speed (Open Coast)

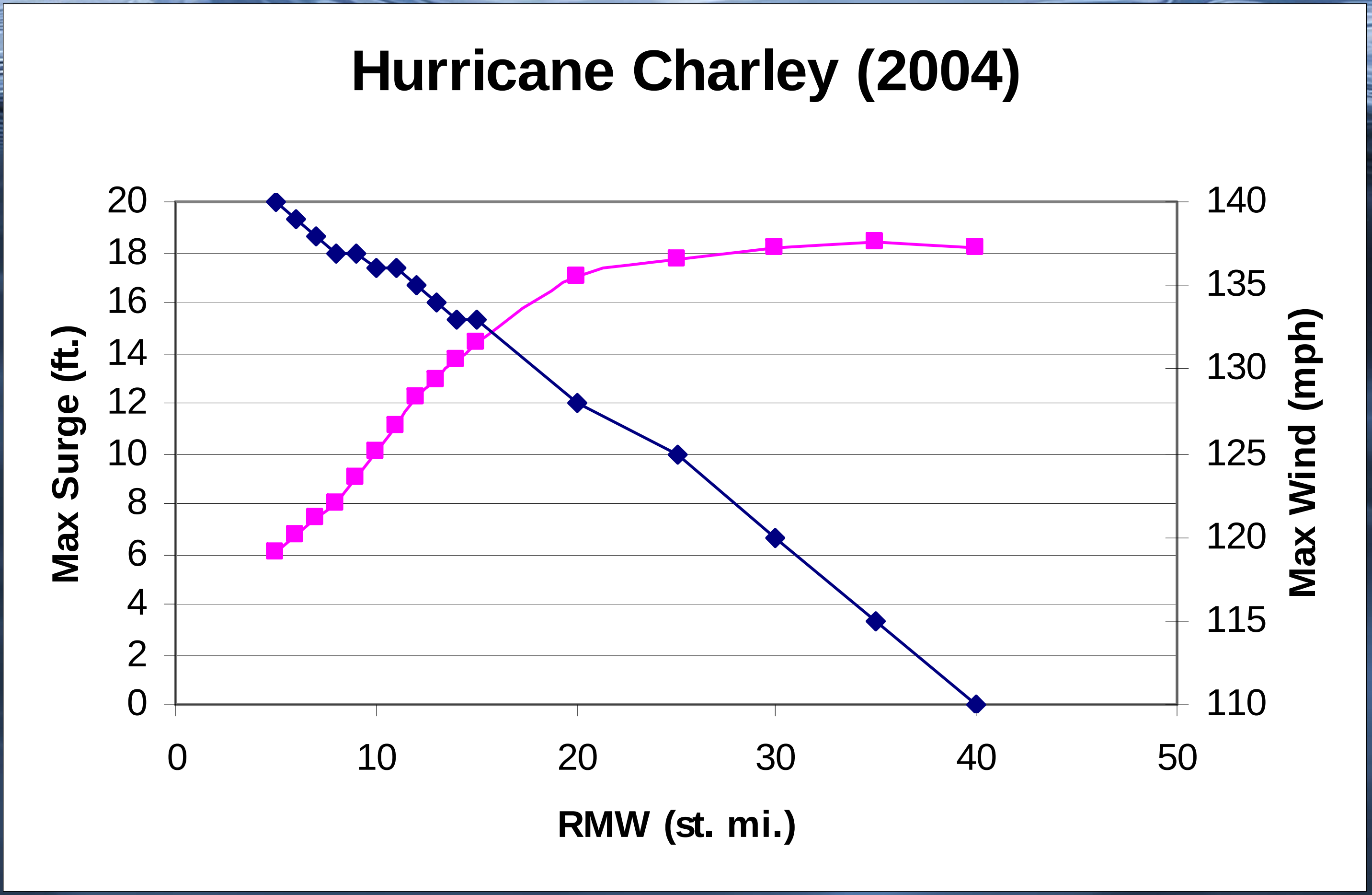
25 mph



Size
(Radius of Max Winds)

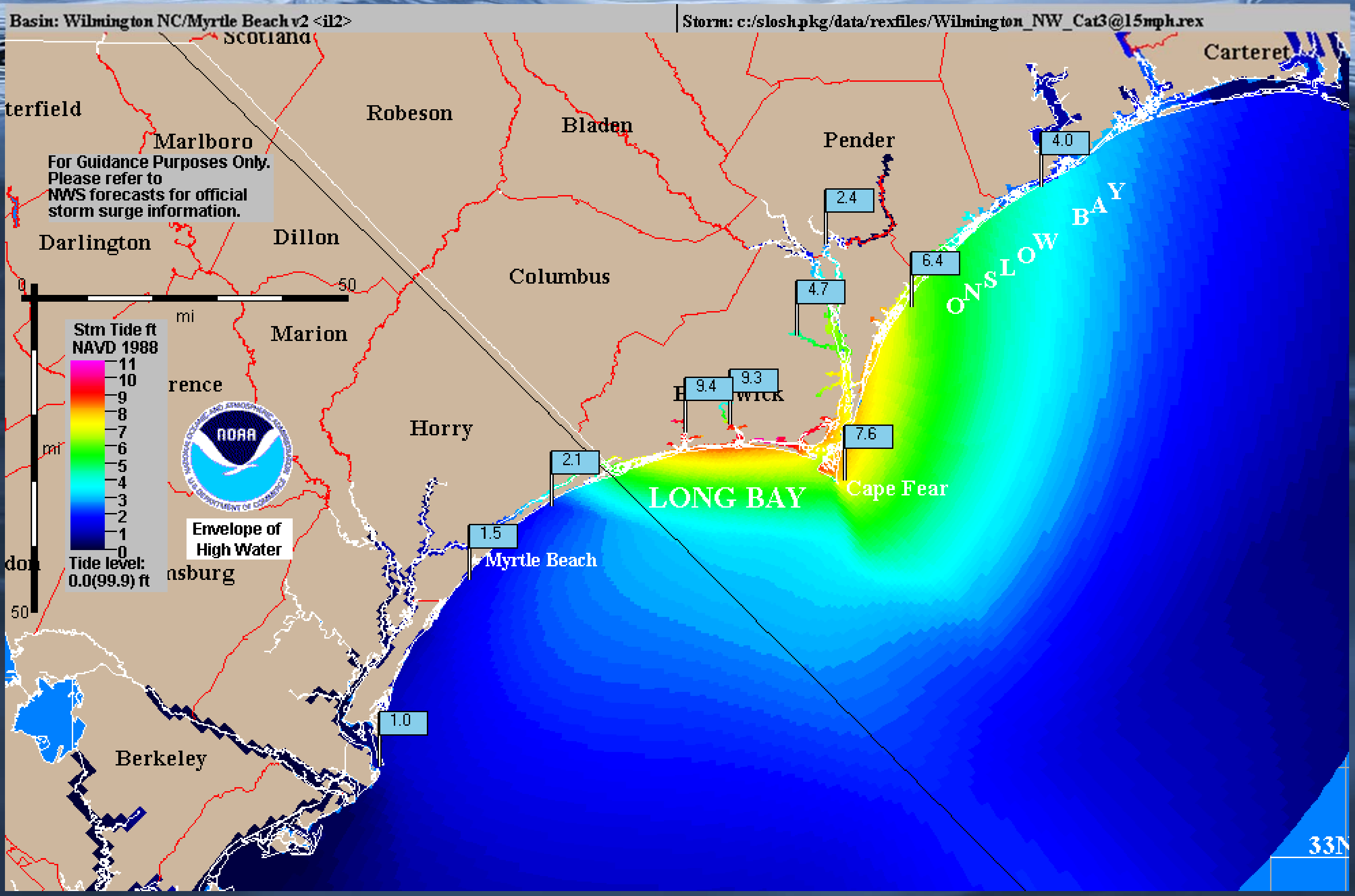


Size (Radius of Max Winds)

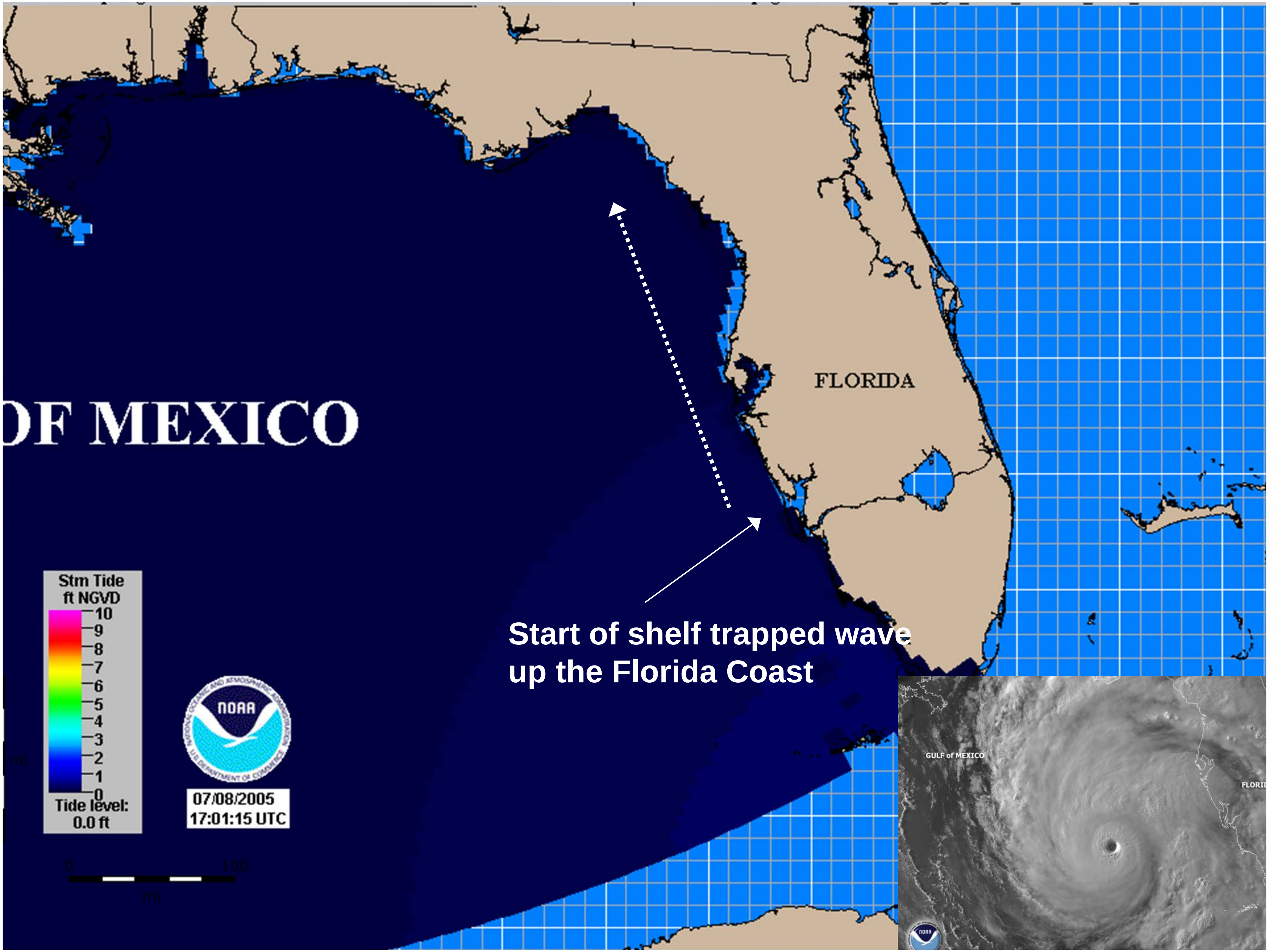


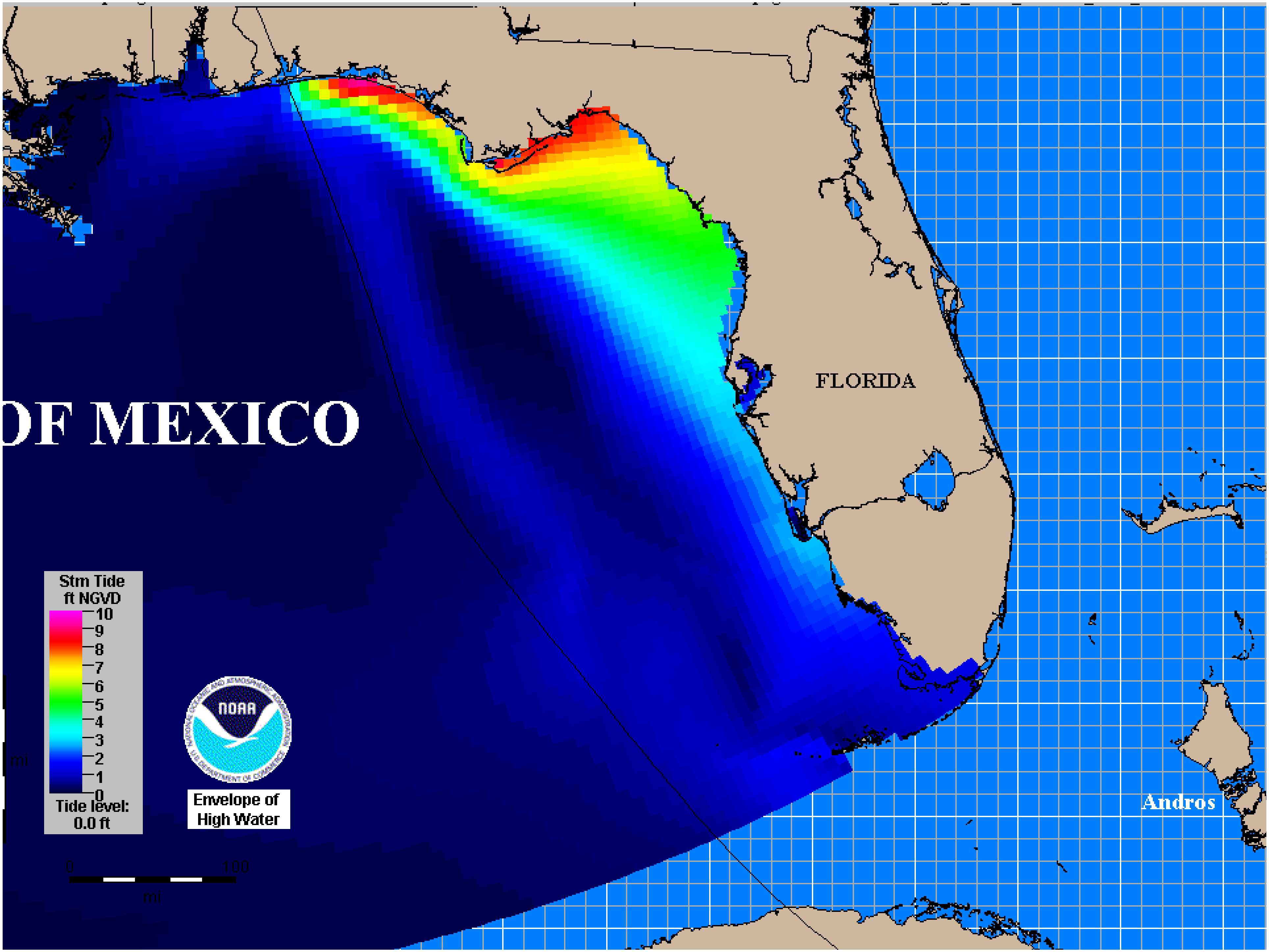
Angle of Approach

NNW Motion

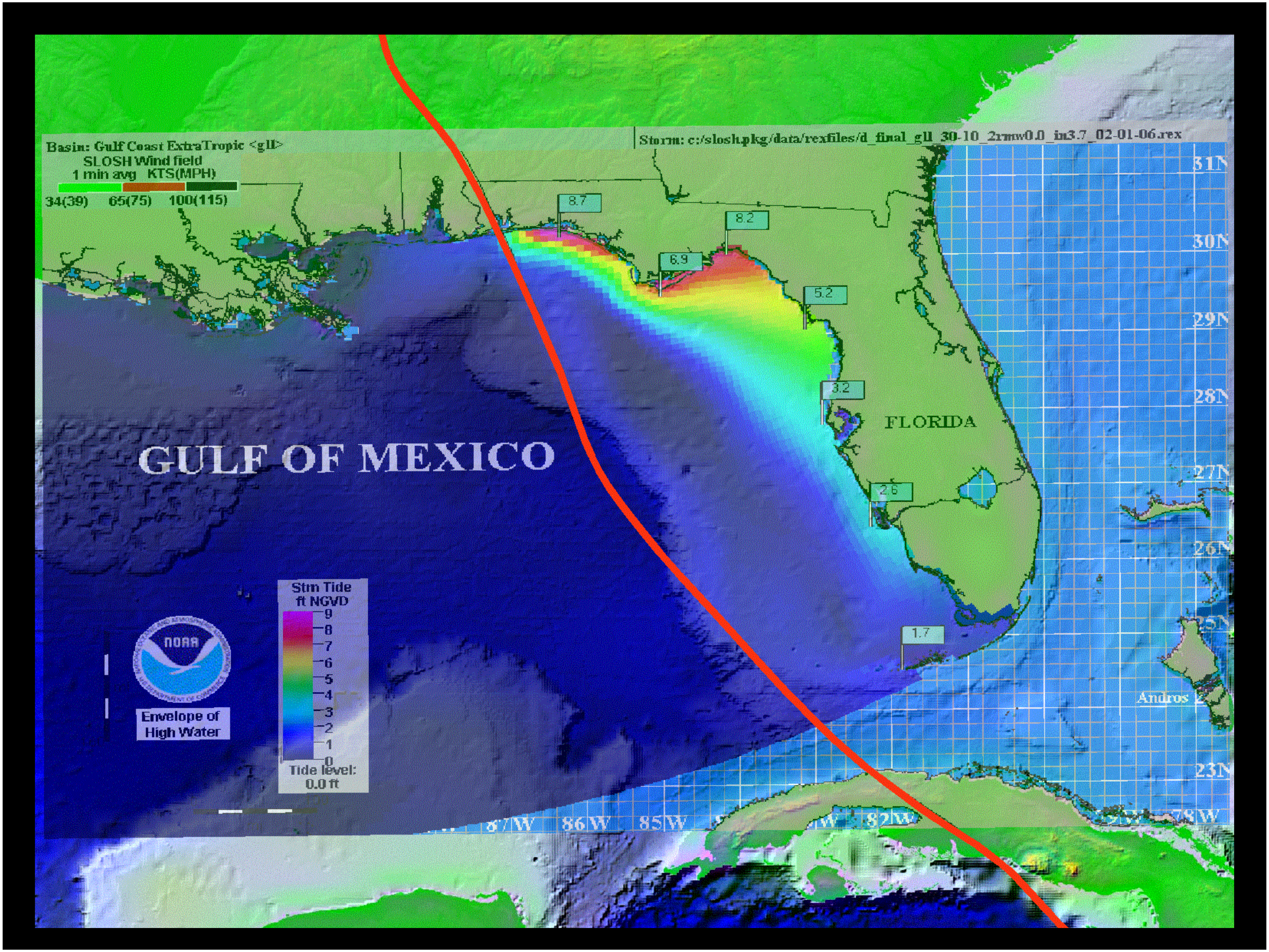


Width and Slope of Shelf


FLORIDA
OF MEXICO
Start of shelf trapped wave
up the Florida Coast
Stm Tide
ft NGVD
10
9
8
7
6
5
4
3
2
1
0
Tide level:
0.0 ft
NOAA
07/08/2005
17:01:15 UTC
GULF of MEXICO

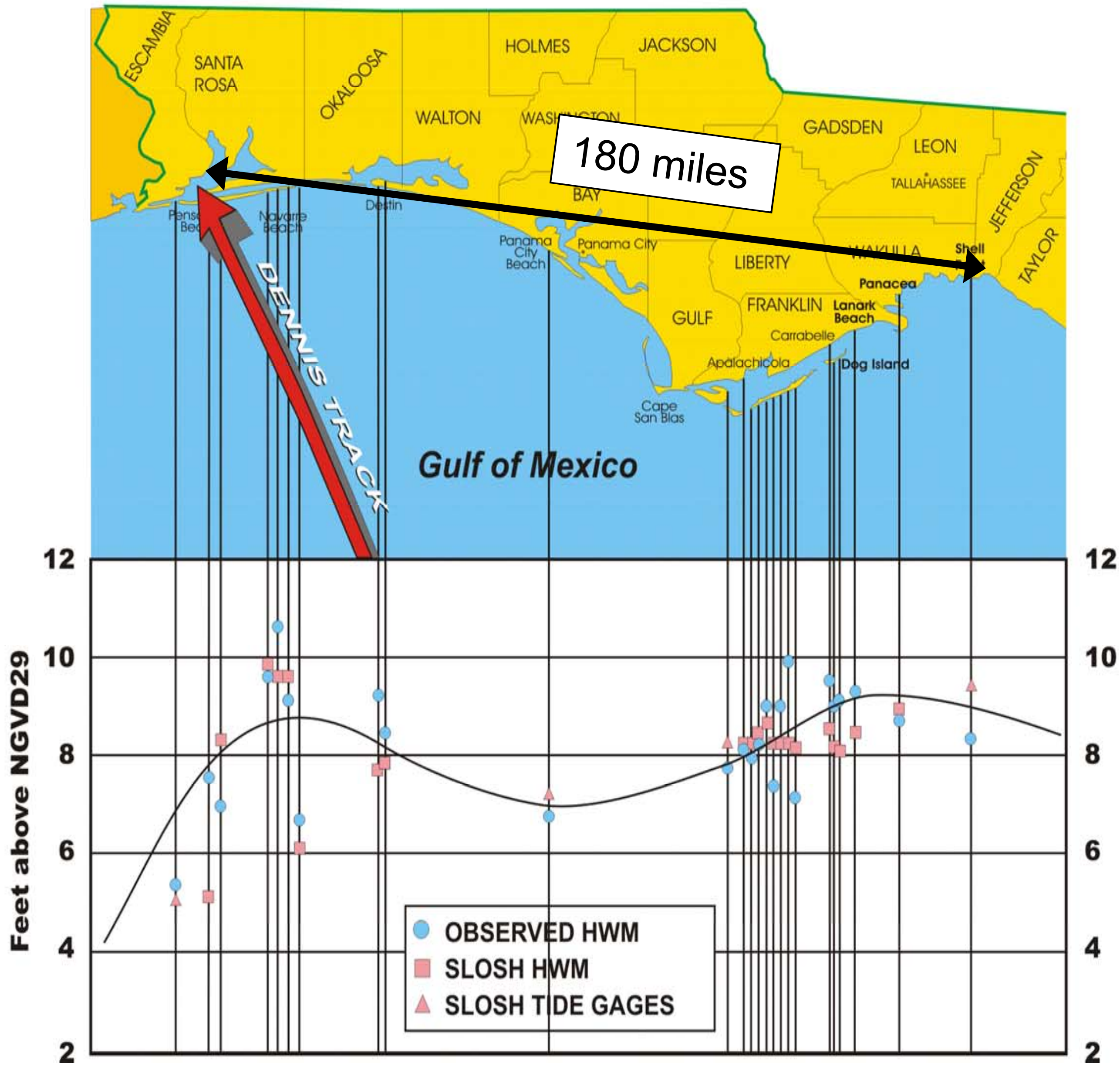


FLORIDA
OF MEXICO
Stm Tide
ft NGVD
10
9
8
7
6
5
4
3
2
1
0
Tide level:
0.0 ft
Envelope of
High Water
0
100
mi
Andros

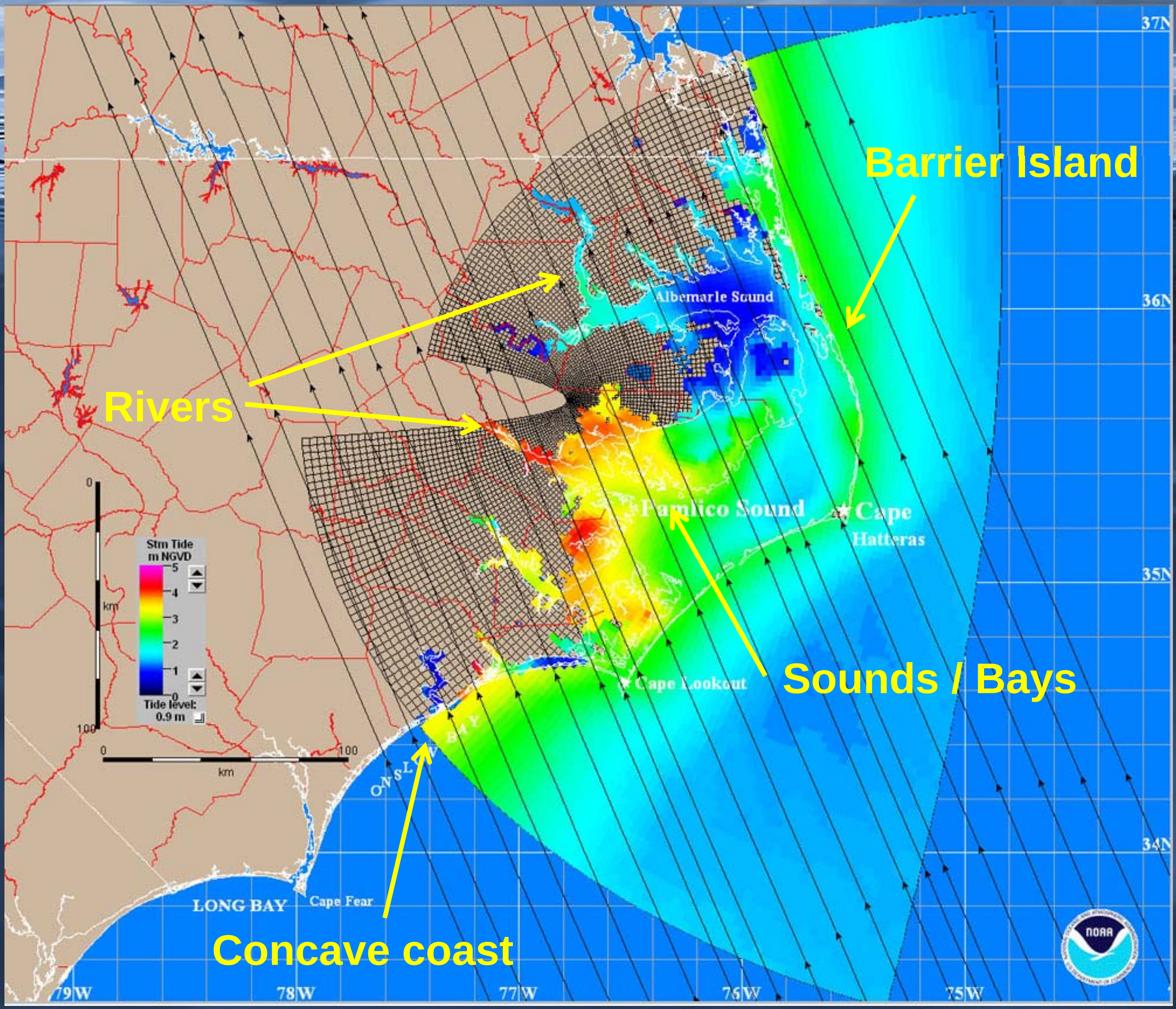


Basin: Gulf Coast ExtraTropic <gll>
SLOSH Wind field
1 min avg KTS(MPH)
34(39) 65(75) 100(115)
Storm: c:/slosh.pkg/data/rexfiles/d_final_gll_30-10_2rmw0.0_in3.7_02-01-06.rex
31N
30N
29N
28N
27N
26N
23N
8.7
8.2
6.9
5.2
3.2
2.6
1.7
FLORIDA
GULF OF MEXICO
Andros
Stm Tide
ft NGVD
9
8
7
6
5
4
3
2
1
0
Tide level:
0.0 ft
Envelope of
High Water
87W
86W
85W
82W
78W

OBSERVED VERSUS SLOSH MODEL CALCULATED SHORELINE STORM SURGE PROFILES FOR HURRICANE DENNIS (2005)



Local Features



Observing and Measuring Storm Surge

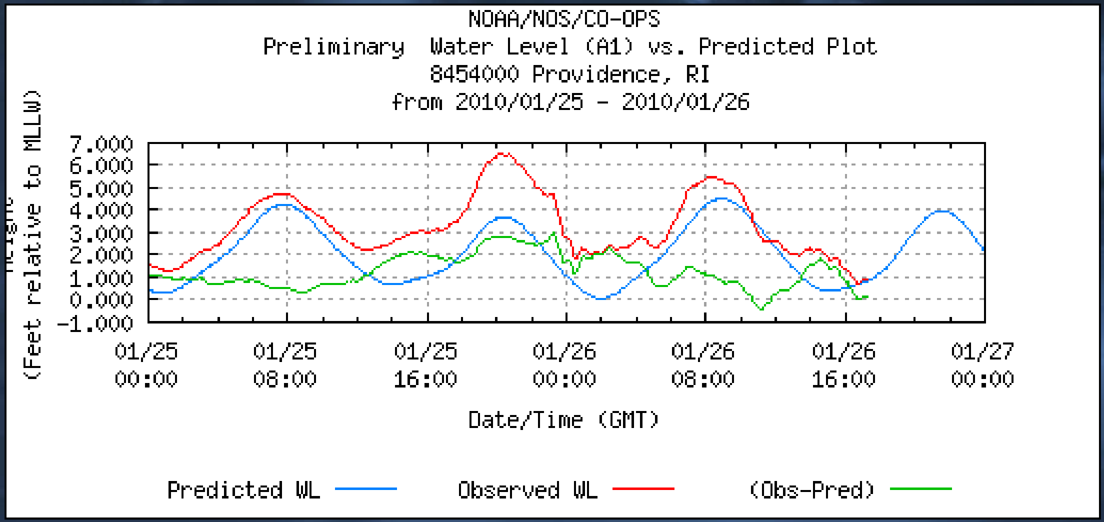
- Tide stations (NOAA)
  - Still water
  - Traditionally most reliable
  - Limited stations
  - Stations often fail at height of event
- High water marks (FEMA/USGS)
  - Perishable
  - Traditionally best method for capturing highest surge
  - Subjective and often include impacts of wave runup/setup
- Pressure Sensors (USGS)
  - Relatively new method
  - Deployed in advance of storm at expected location of highest surge
  - Can contain effects of waves

NOS Water Level Stations

- A network of 175 long-term, continuously operating water-level stations throughout the U.S.
- Expanded over time in response to increasing national and local needs.
- Serve as foundation for NOAA's tide prediction products

NOS Water Level Stations

- http://tidesonline.nos.noaa.gov
- http://tidesandcurrents.noaa.gov

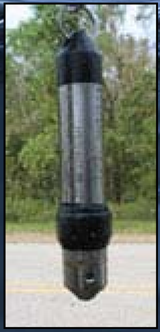


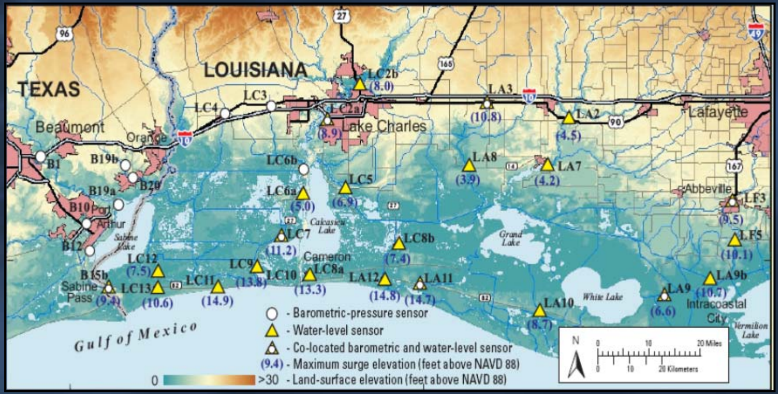
High Water Marks

- Lines found on trees and structures marking the highest elevation (peak) of the water surface for a flood event, created by foam, seed, or other debris
- Survey crews deployed after storm to locate and record reliable HWMs
- GPS methods used to determine location for coastal HWMs, which are then mapped on a vertical datum such as NAVD88
- Generally include effects of wave action/wave runup and only a small percentage of HWMs represent still water (storm surge)

USGS Pressure Sensors

- Temporary water-level and barometric-pressure sensors
- Installed right before cyclone landfall
- Provide information about storm surge duration, times of surge arrival and retreat, and maximum depths





Surge Data Issues

- Instrument failures during event
  - Incomplete data or data does not capture height of event
- Different reference levels (what the heck is the difference between sea level, MLLW, NGVD29, NAVD88, etc.?)
  - Complicated conversion methods
- Different or even unknown error characteristics
  - Incompatible data sources
- Data measuring different things
  - Stillwater versus wave runup

Next…

- What is a vertical datum and why should I care?

- What is the SLOSH model?

- What kind of storm surge products are available?

- How does NHC forecast storm surge?