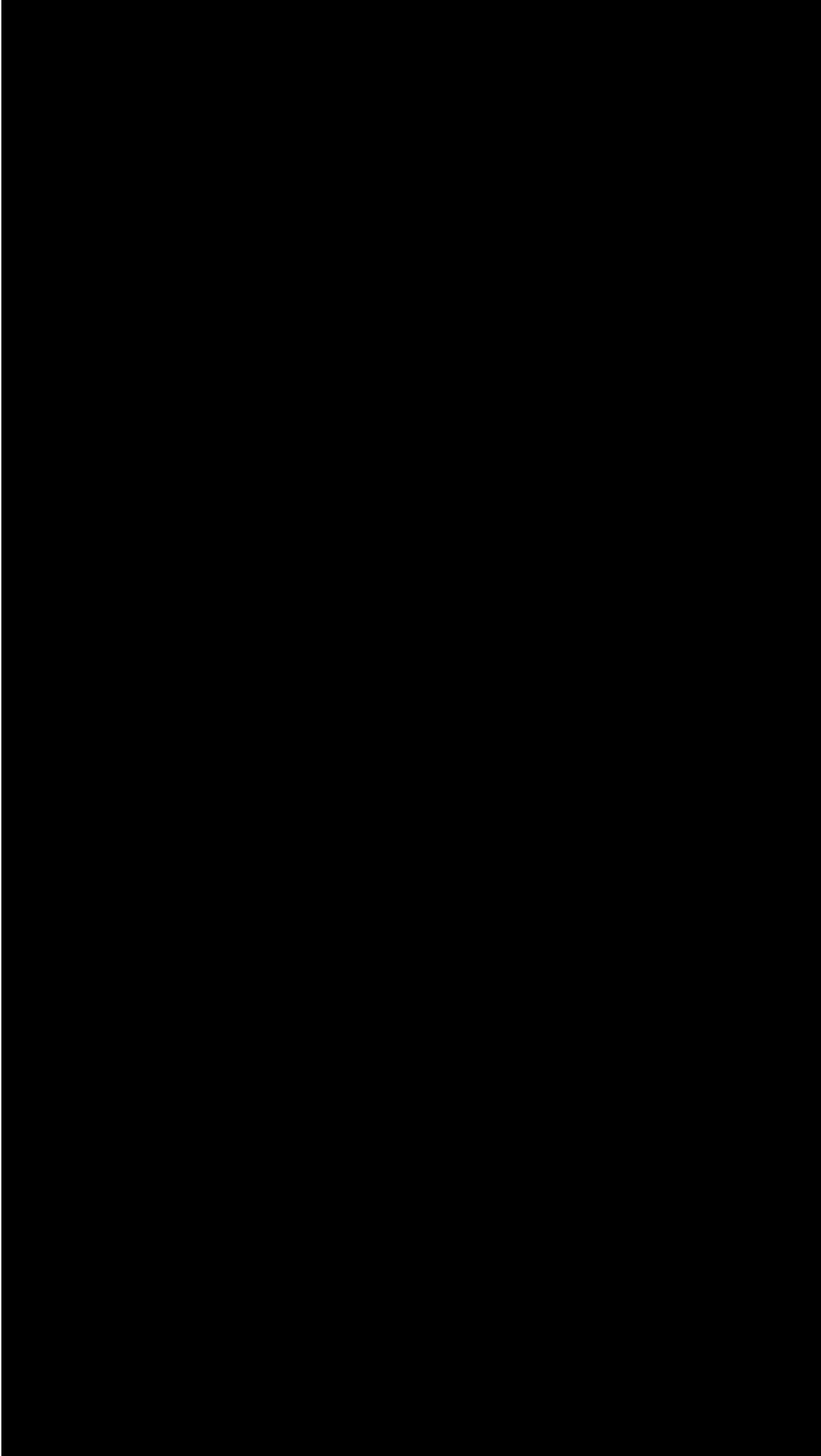


Introduction to Storm Surge



Robbie Berg and John Cangialosi - Hurricane Specialist
Jamie Rhome - Storm Surge Team Lead





Hurricane Katrina (2005) – Mississippi

1200 deaths, \$108 billion damage



Hurricane Sandy (2012) – Northeast U.S.

73 deaths, \$65 billion damage



Hurricane Ike (2008) - Bolivar Peninsula, Texas

20 deaths, \$29.5 billion



Unit Outline

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



Hurricane Ike Inundation Depth

This map illustrates the inundation depth of Hurricane Ike across the coastal regions of Texas and Louisiana. The map uses a color-coded system to represent different levels of flooding, with red indicating the deepest inundation (> 10 feet) and yellow indicating shallower depths (6-8 feet). The map also shows the drainage network, county boundaries, and the state boundary between Texas and Louisiana. A thick black line indicates the track of Hurricane Ike, showing its path from the Gulf of Mexico into the Texas coast. The map includes labels for various counties and parishes, as well as major water bodies like Galveston Bay, White Lake, and Vermilion Bay. A legend in the top left corner provides the key for the inundation depths and other map features. A scale bar and a north arrow are located in the bottom right corner.

Legend:

- Drainage Network
- County Boundary
- State Boundary
- Inundation Depth (ft)
- No Inundation
- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

Map Labels:

- TEXAS
- LOUISIANA
- Liberty County
- Jefferson County
- Orange County
- Calcasieu Parish
- Jefferson Davis Parish
- Vermilion Parish
- Iberia Parish
- Chambers County
- Harris County
- Galveston County
- Brazoria County
- Galveston Bay
- East Bay
- West Bay
- White Lake
- Vermilion Bay
- Gulf of Mexico

Ike's track

DATA SOURCES:
Inundation Layers (TX) - HCFCD
Inundation Layers (LA) - NWS

NOTES:
Inundation extent and depth estimates are based on elevations derived from November 2001 LIDAR, 2006 NOAA LIDAR and Vintage 2004 LIDAR data. The data used in the analysis of the storm surge were provided by FEMA, LSU Sea Grant, Harris County Flood Control District, Galveston County, USGS, NOAA and Calcasieu Parish.

20FEB2009

1 inch equals 15 miles

0 15 30
Miles

N
S
E
W

Harris County Flood Control District

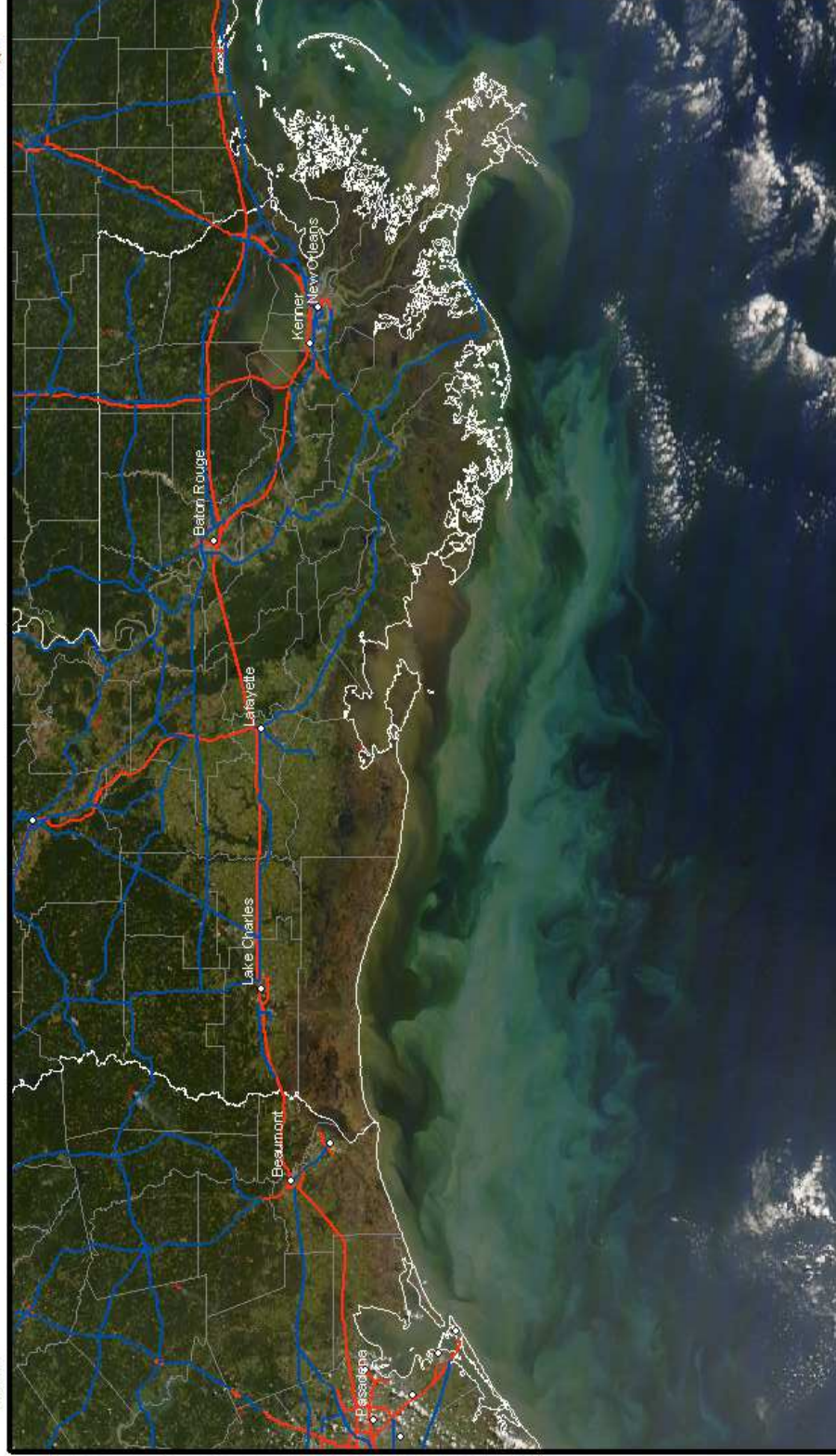
The Harris County Flood Control District makes no claim as to the accuracy or correctness of the data represented on this map. Appropriate use of this data is the sole responsibility of the user.

C:\Open\GIS\work_directory\UKEN\undation\Maps\kleinun_extended\area\depth_11x17.pdf

The Harris County Flood Control District makes no claim as to the accuracy or correctness of the data represented on this map. Appropriate use of this data is the sole responsibility of the user.



Dying Vegetation due to Salt Water Intrusion



The brown region along the coast indicates dying vegetation due to Salt Water intrusion. 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



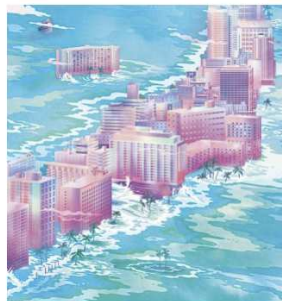
THE SIEGE OF MIAMI

As temperatures climb, so, too, will sea levels.

BY ELIZABETH KOLBERT



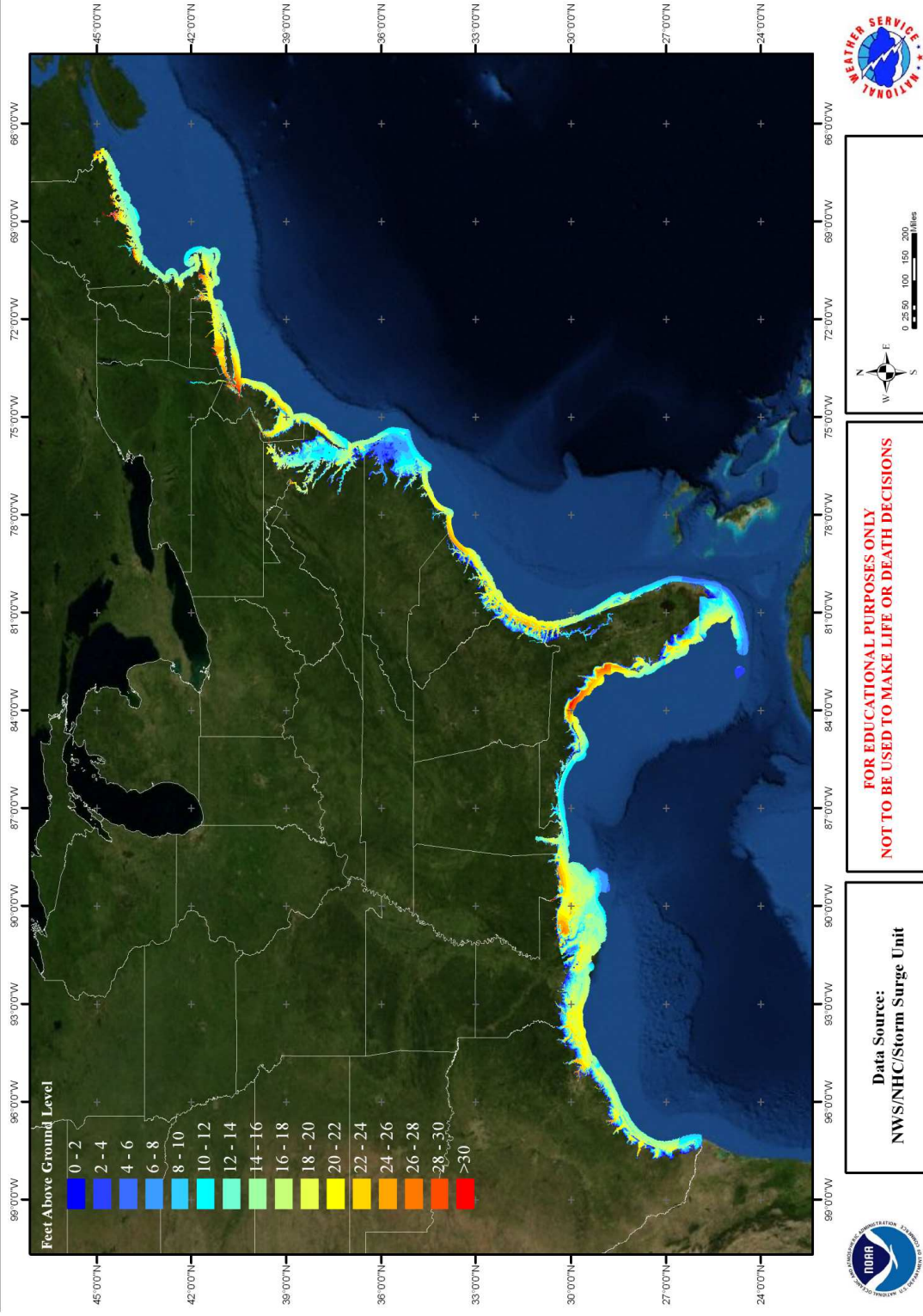
The city of Miami Beach floods on such a predictable basis that if, out of curiosity or sheer perversity, a person wants to she can plan a visit to coincide with an inundation. Knowing the tides would be high around the time of the “super blood moon,” in late September, I arranged to meet up with Hal Wanless, the chairman of the University of Miami’s geological-sciences department. Wanless, who is seventy-three, has spent nearly half a century studying how South Florida came into being. From this, he’s concluded that



In the Miami area, the daily high-water mark has been rising almost an inch a year.

- 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

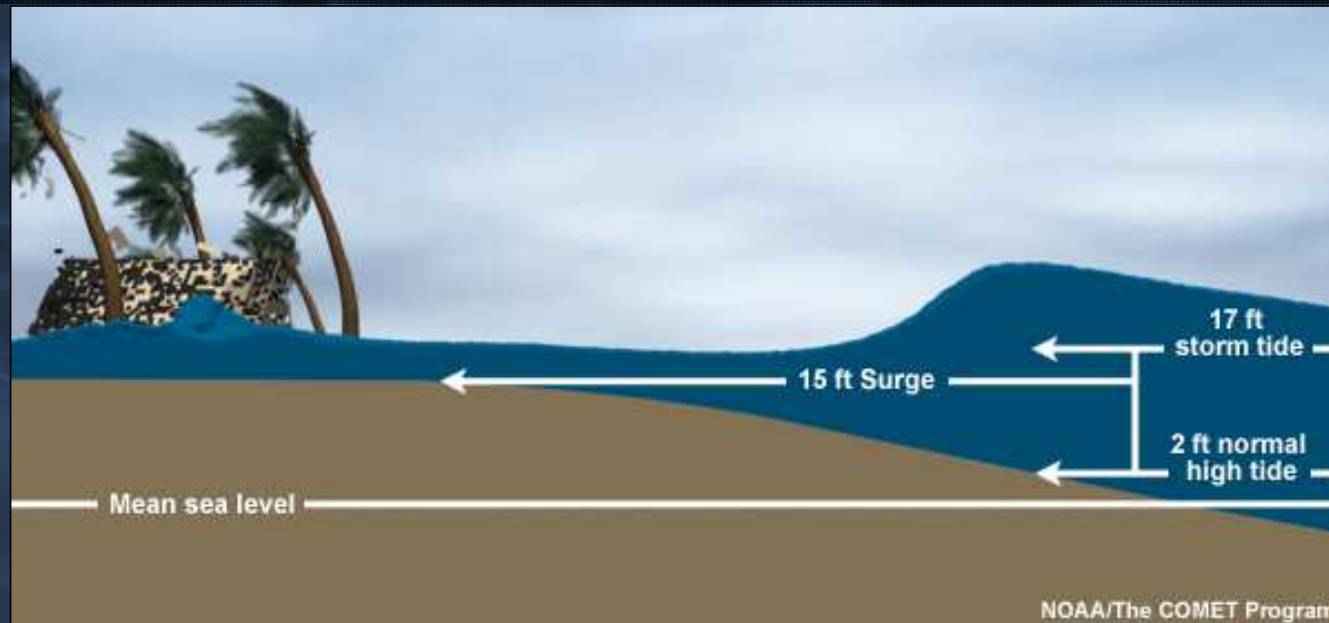
Storm Surge Vulnerability: Category 4 Hurricane



What is Storm Surge?

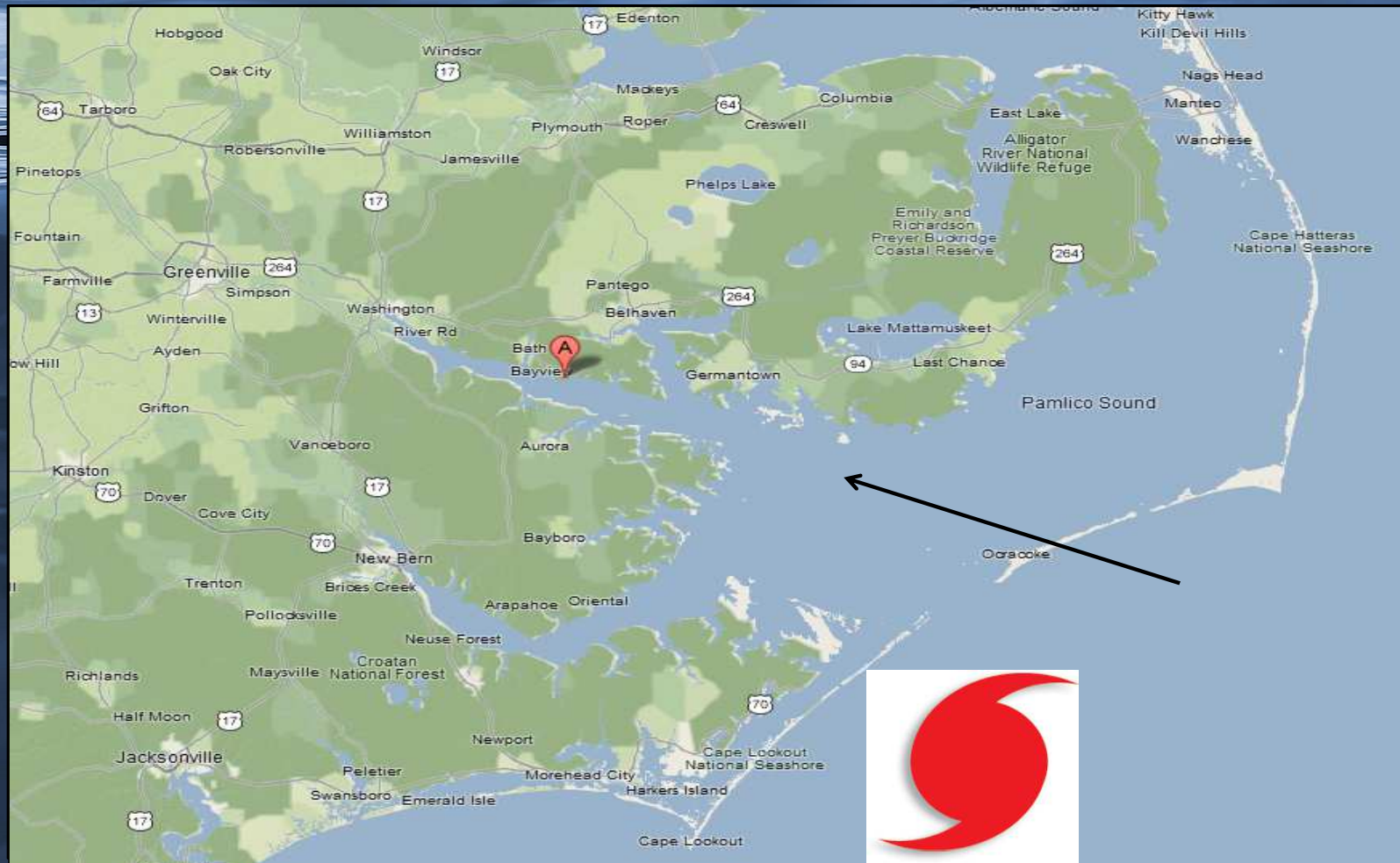
STORM SURGE is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

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



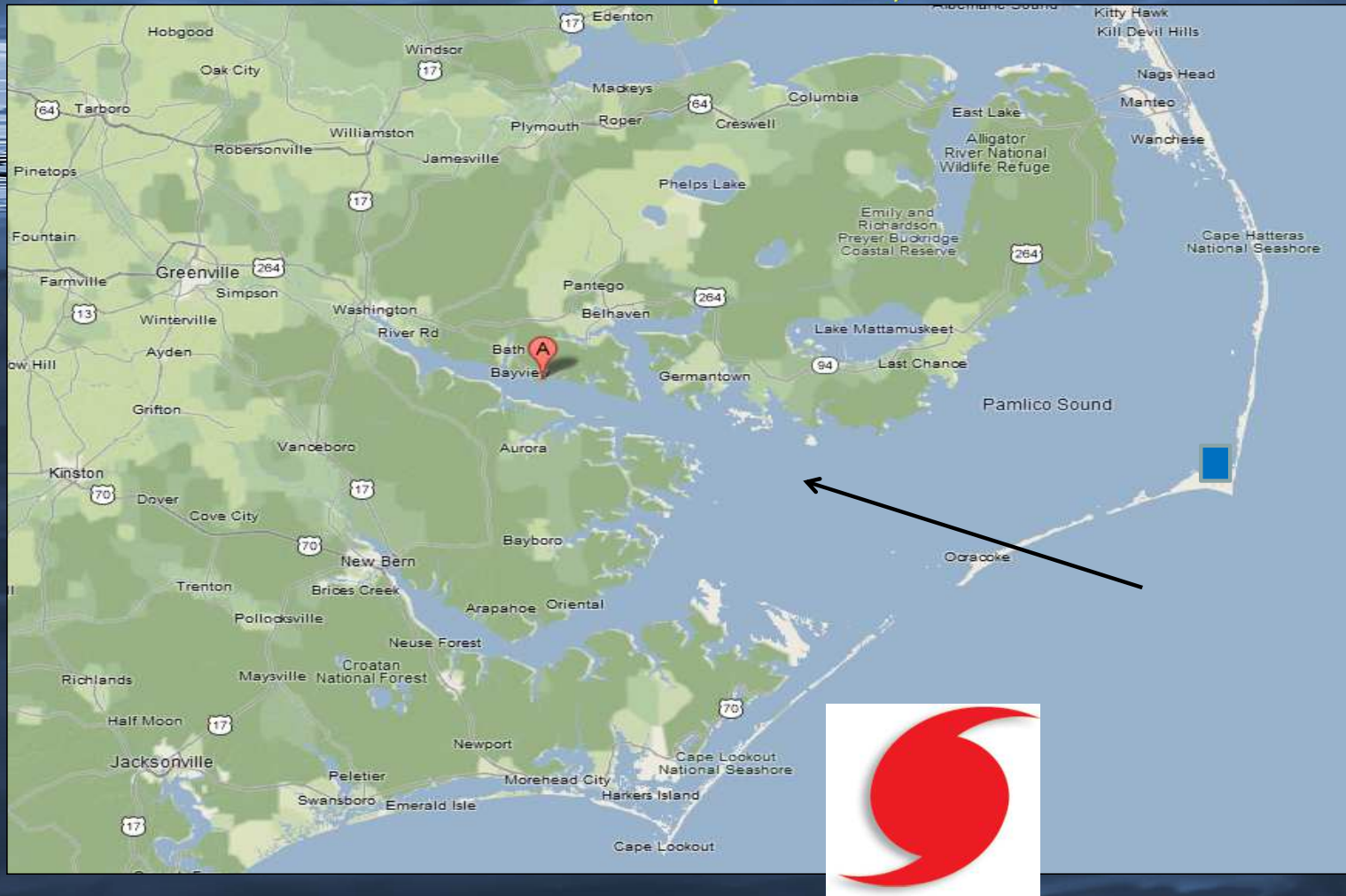
Storm Surge from Hurricane Irene

Rumley Marsh on the Pamlico River in North Carolina



Low Water from Hurricane Irene

Pamlico Sound at Cape Hatteras, NC



Storm Surge from Tropical Storm Debby

Bayshore Blvd., Tampa, FL



Storm Surge from Hurricane Sandy

Alphabet City (East Village), Manhattan, NY



8th St./Ave. C, Manhattan, NY
(YouTube/Kevin Barnett)

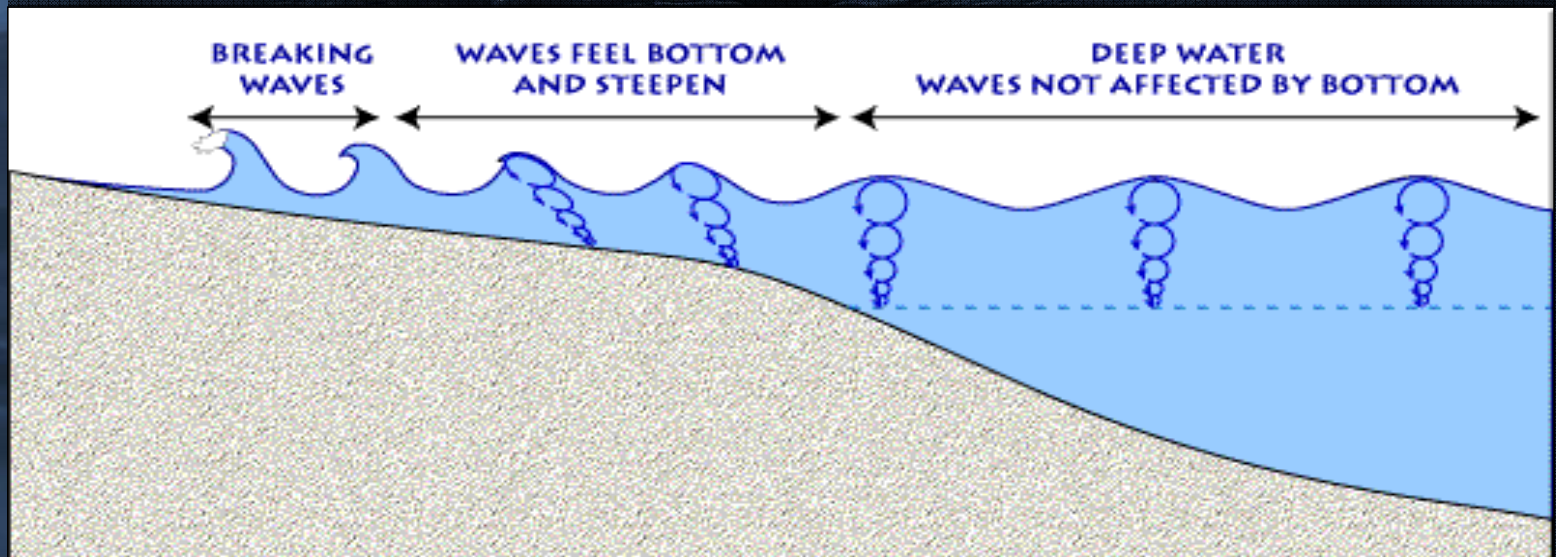
Hurricane Ike – Bolivar peninsula, TX



Courtesy of:
Mark Sudduth
Hurricanetrack.com

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

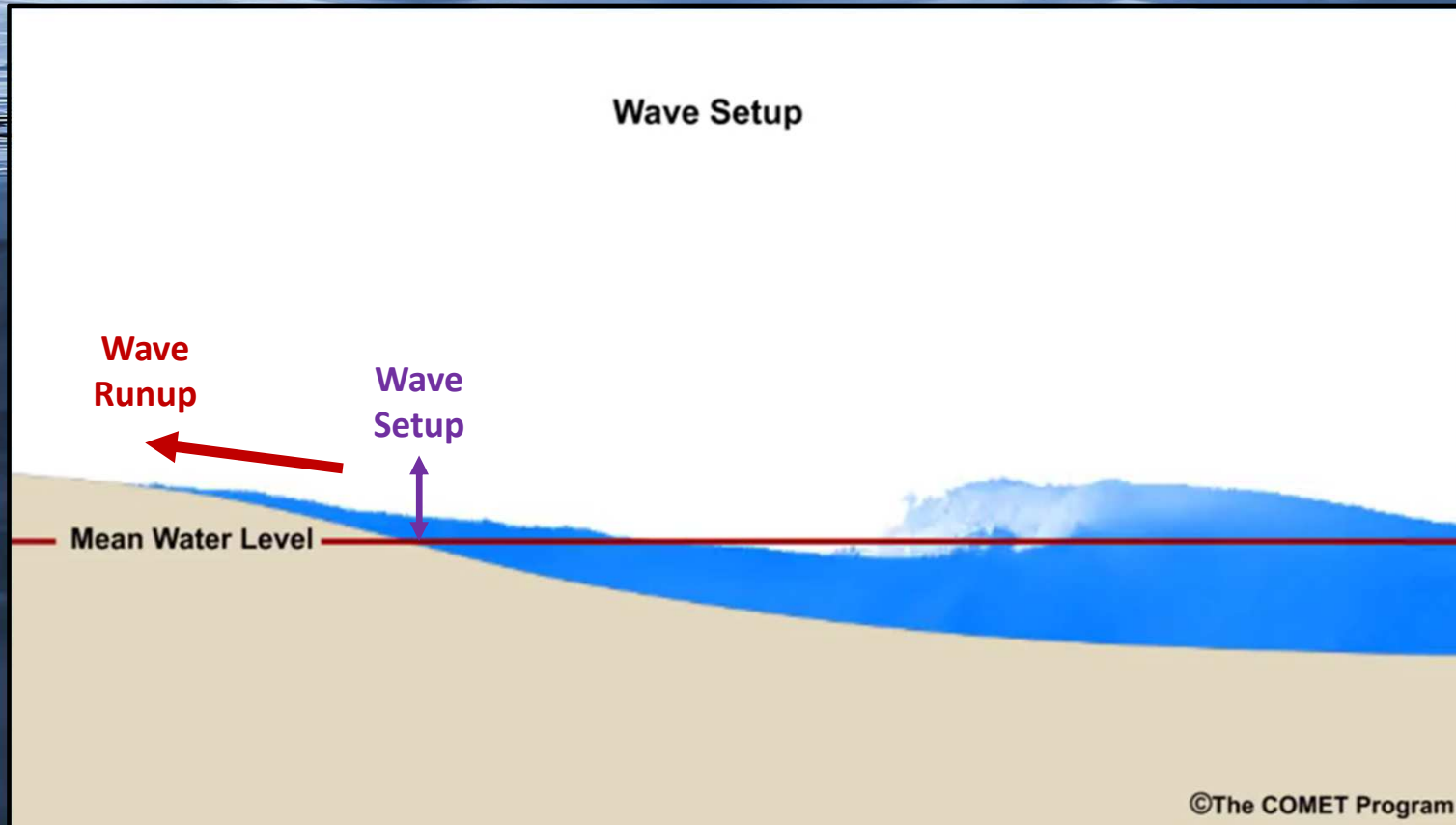


Alphapure Design Studio

navbar placeholder

-1-

Wave Runup and Setup



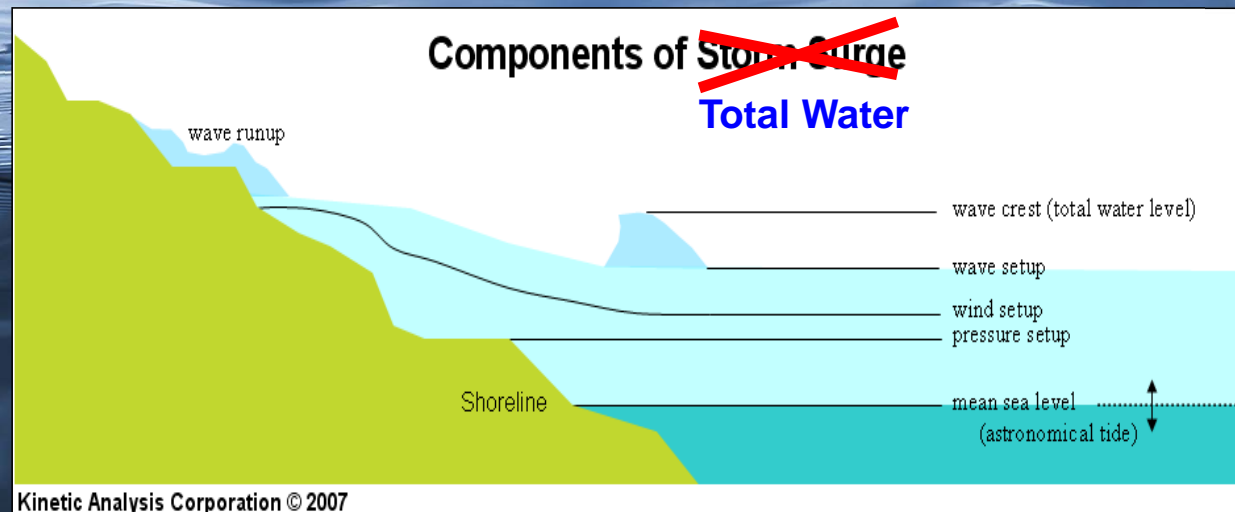
Freshwater Input



- 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		Winds (mph)	Surge	Damage
	Millibars	Inches			
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)**

← **SANDY (1)**

ISAAC (1)

← **CHARLEY (4)**

No Such Thing as “Just a Tropical Storm”

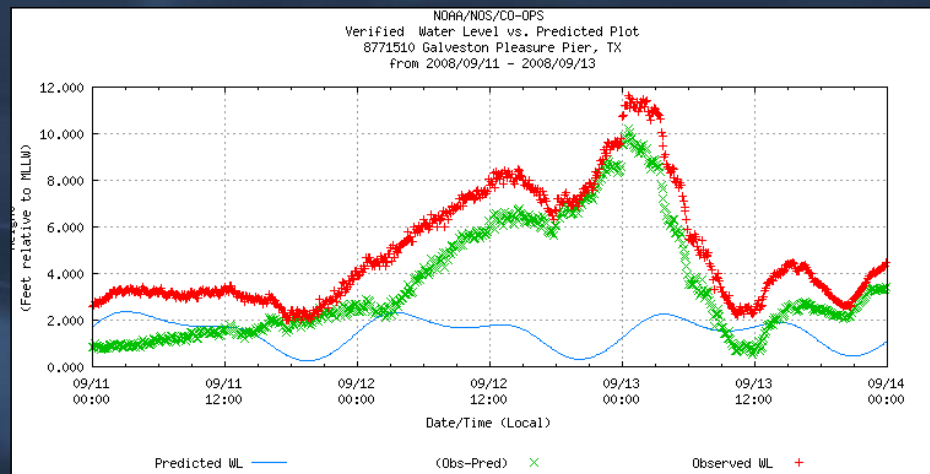


Louisiana State Rd. 23 near Myrtle Grove
Tropical Storm Lee (2011)

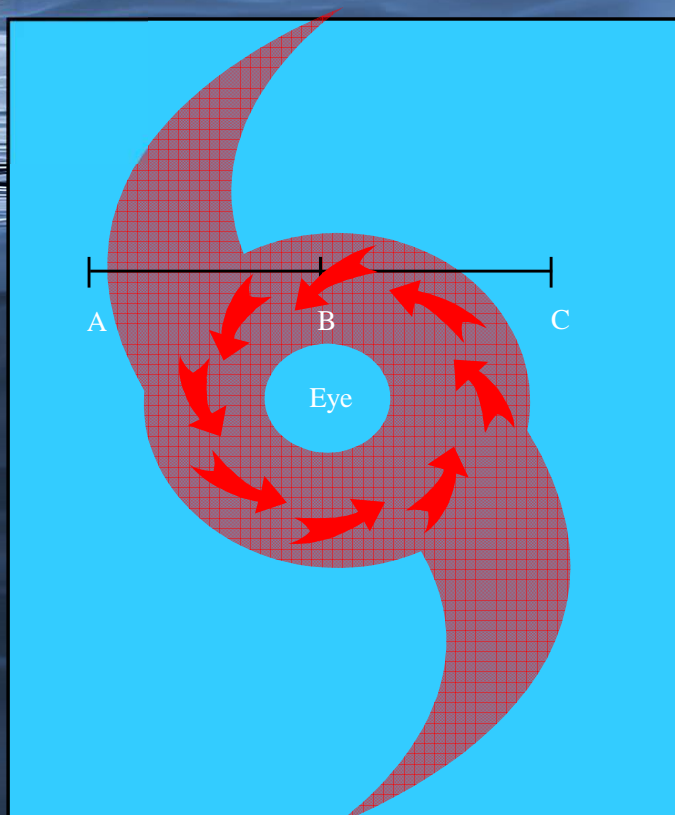


Galveston

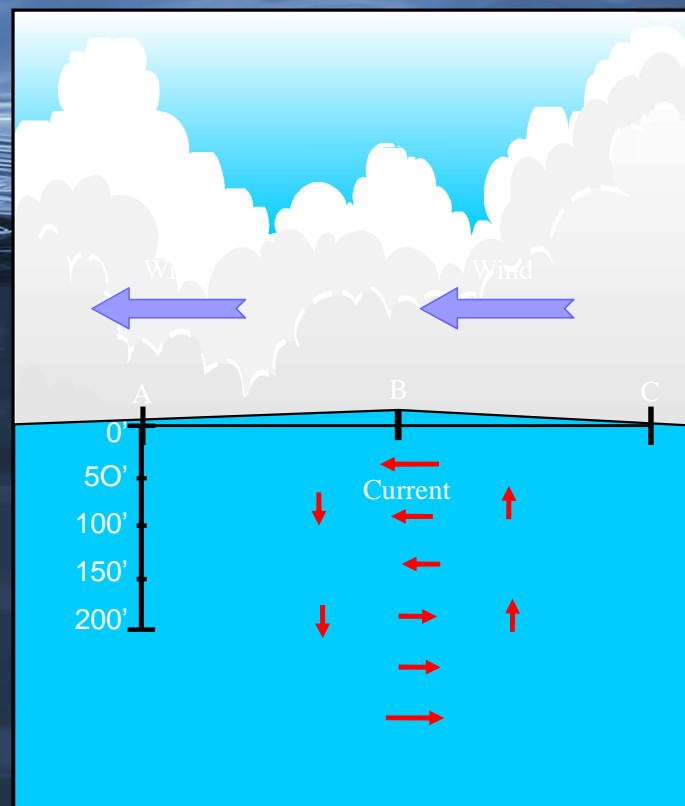
Day before Ike arrived



Deep Water



a. Top view of Sea Surface

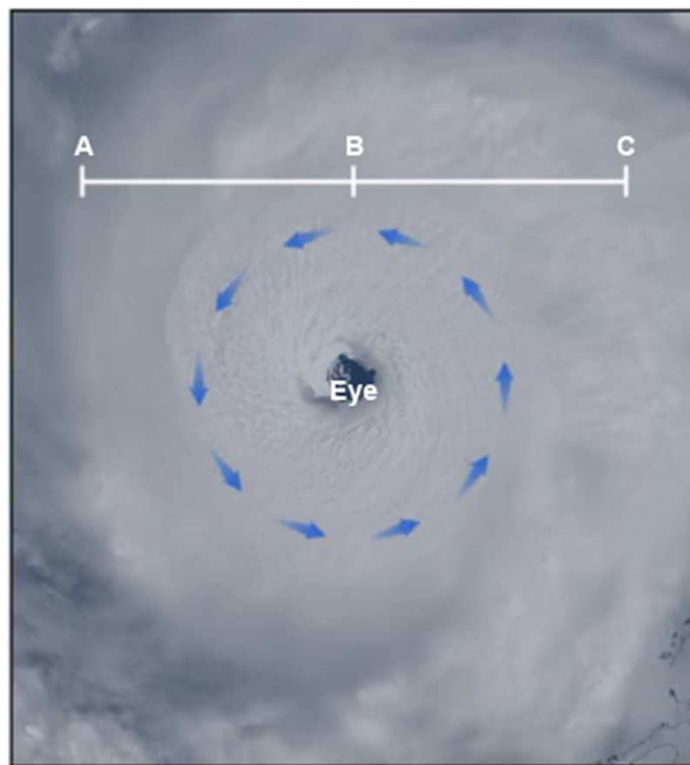


b. Side view of Cross Section "ABC"

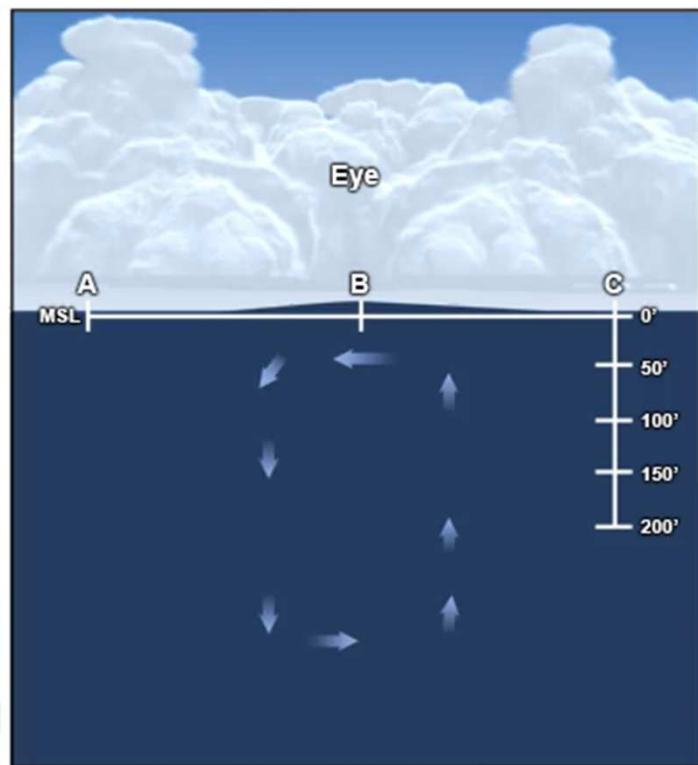


From Deep Water to Shallow Water

Top View of Sea Surface

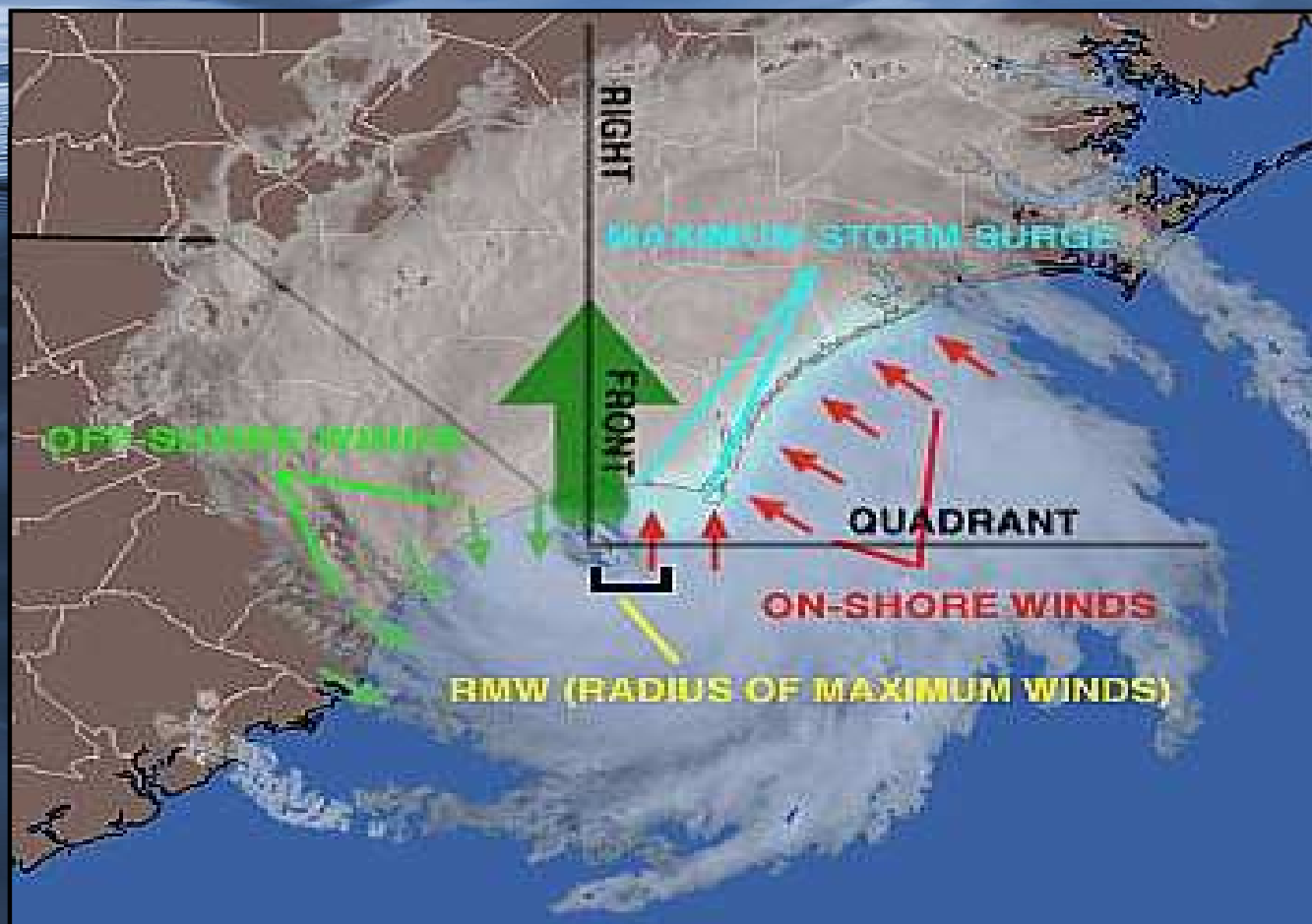


Side View of Cross Section "ABC"



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Understanding Surge

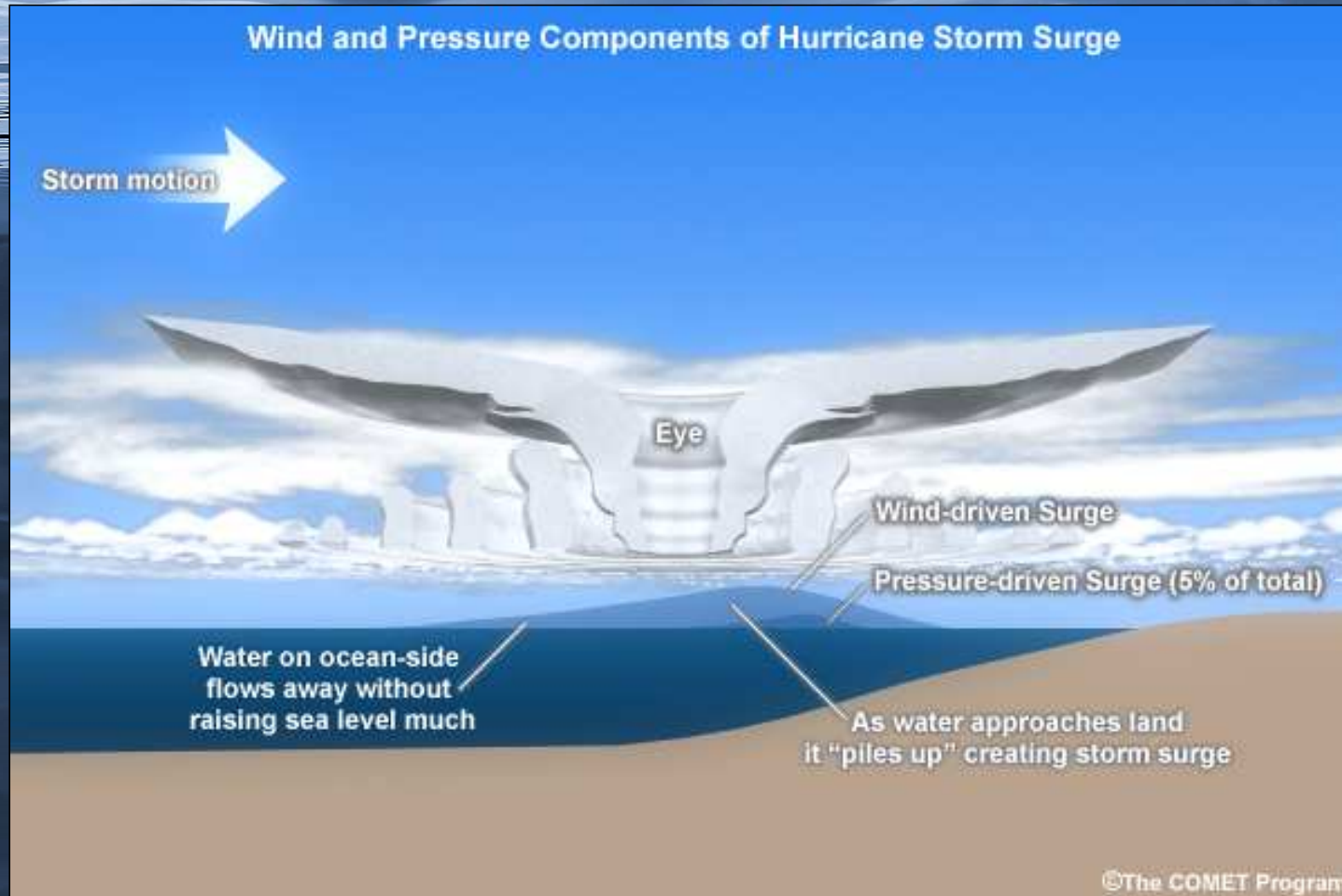


Factors Affecting Storm Surge

- 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

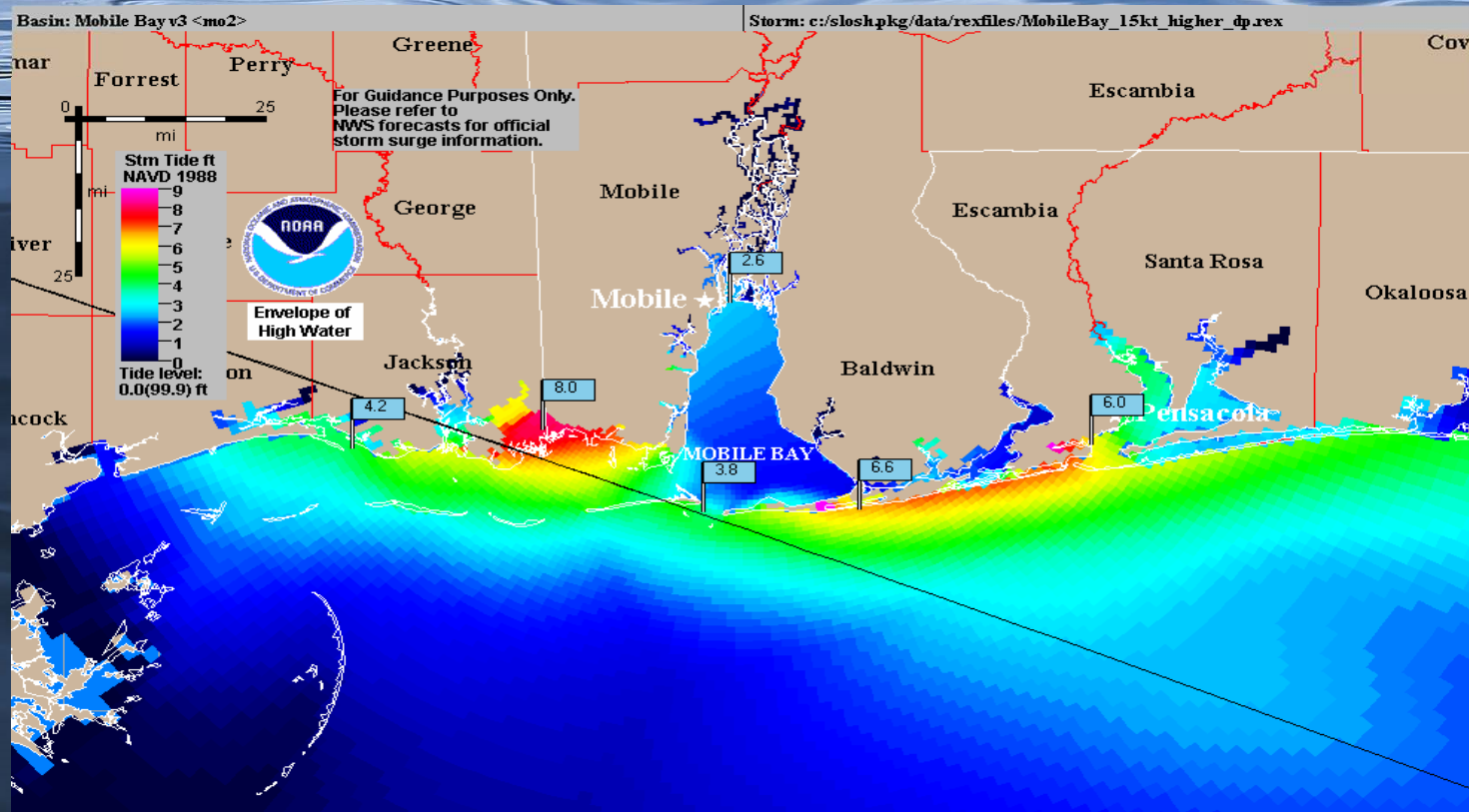


Effects of Low Pressure

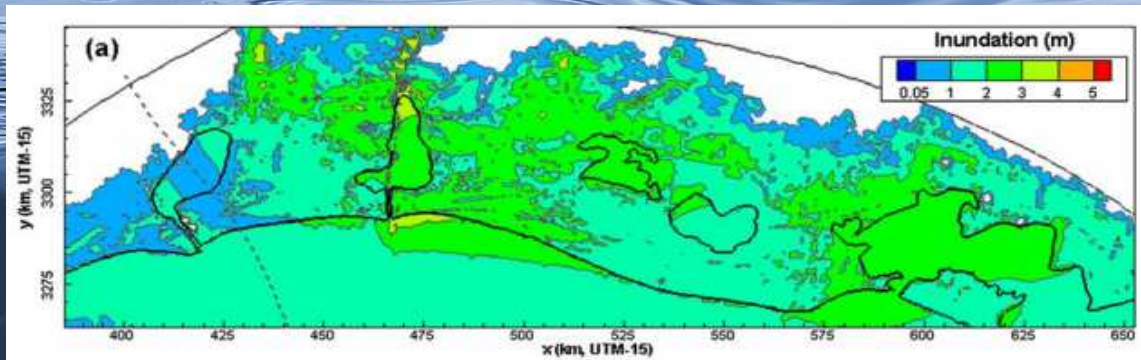


Intensity (Wind Speed)

15 mph stronger

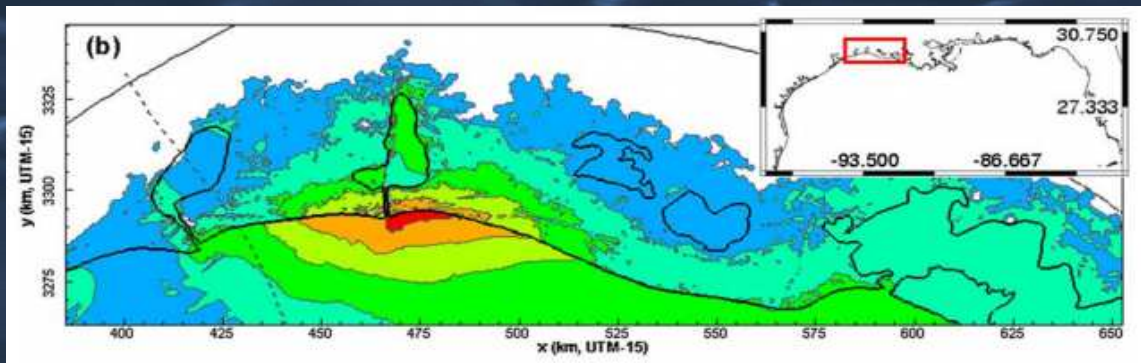


Forward Speed



Slow Speed (5 mph)

- More inland penetration



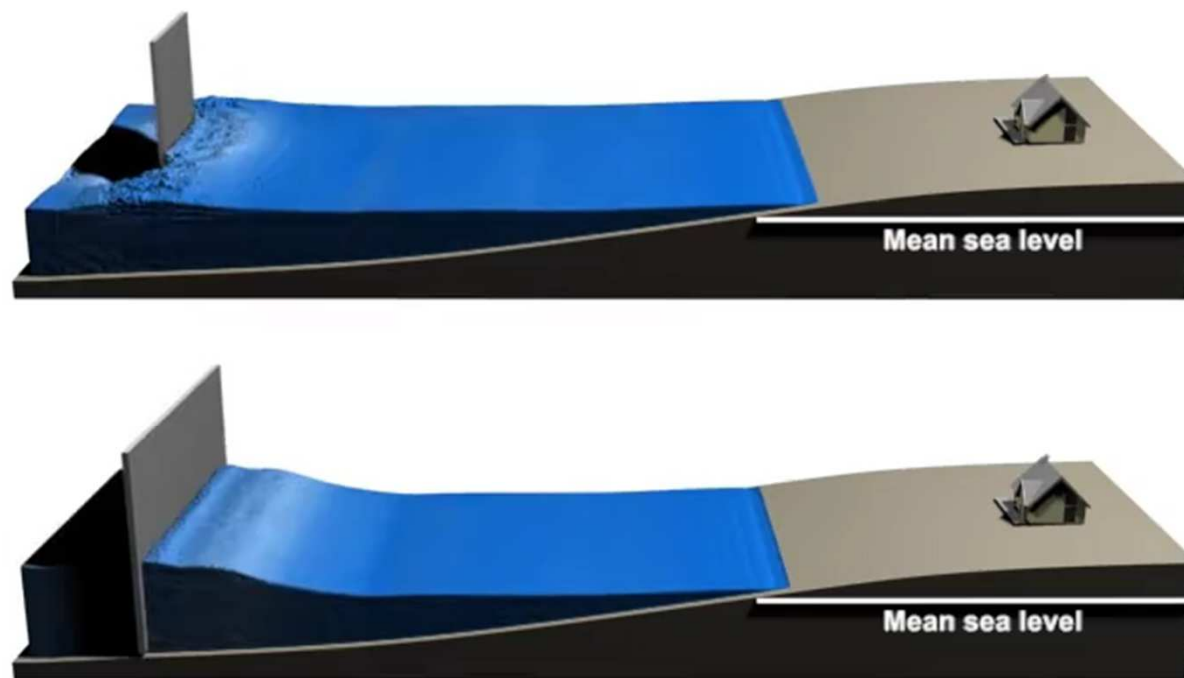
Fast Speed (25 mph)

- Higher maximum

Rego, J. L., and C. Li (2009). Forward speed of a hurricane. *Geophysical Research Letters*, 36.

Size

(Radius of Max Winds)

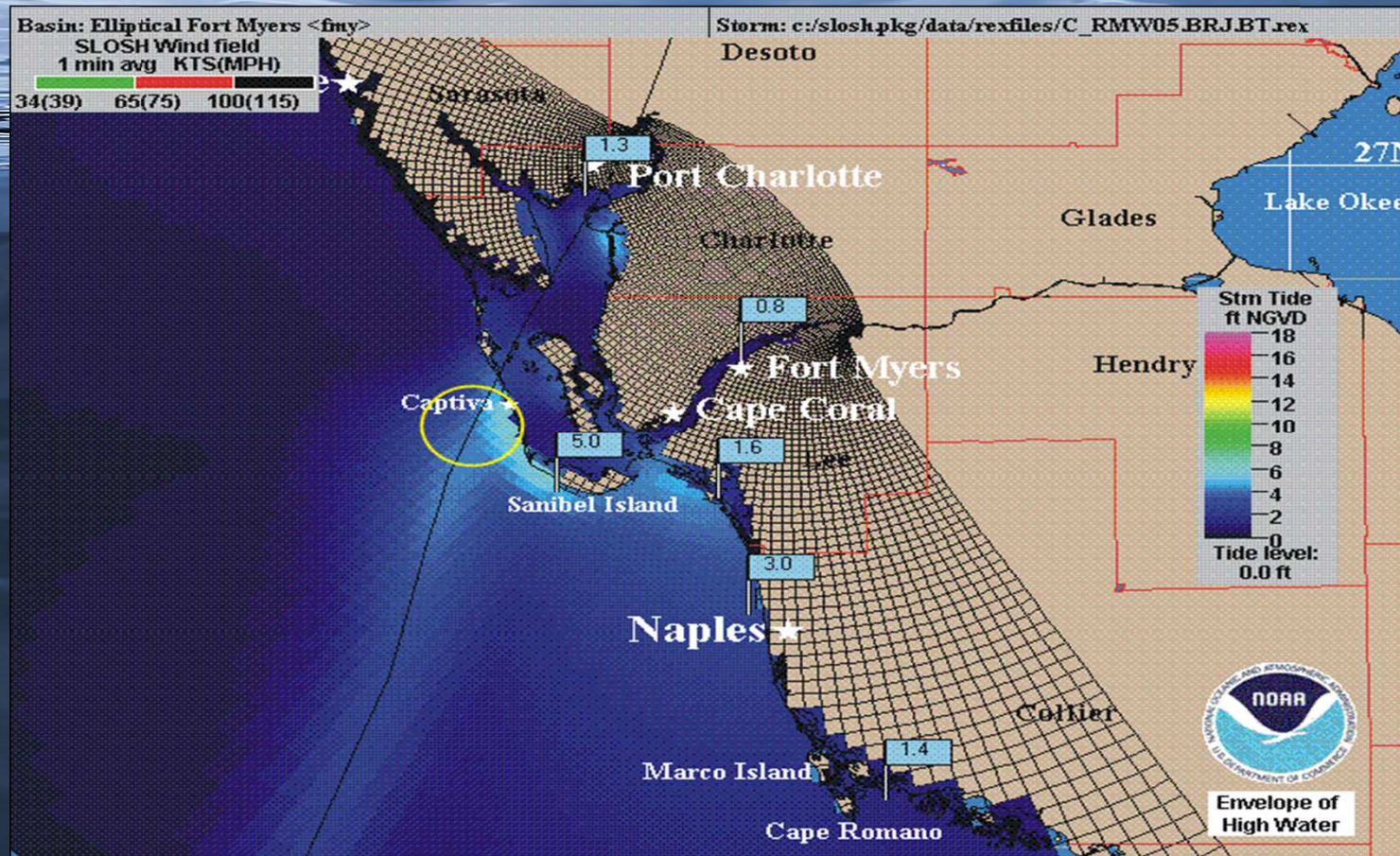


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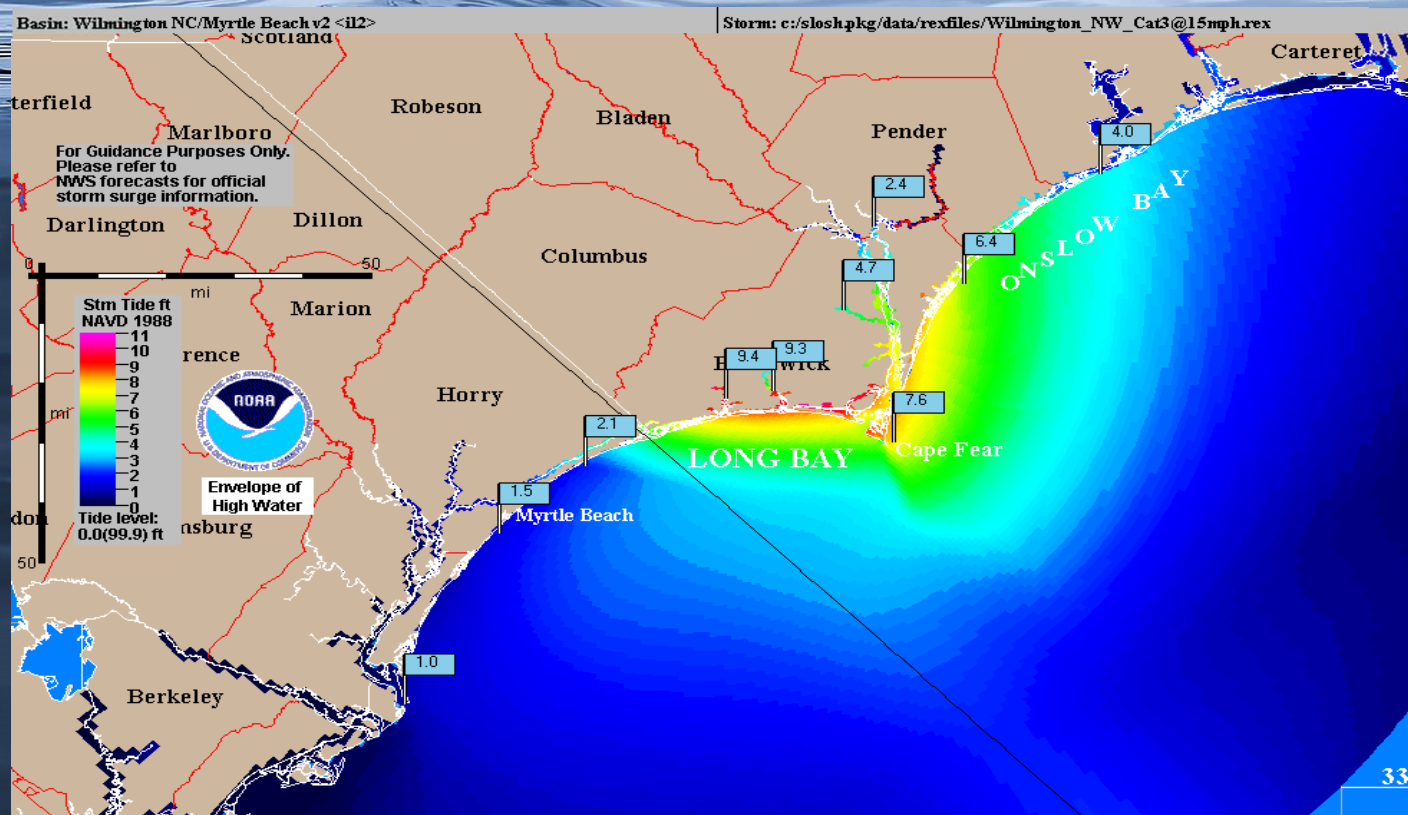
Size

(Radius of Max Winds)

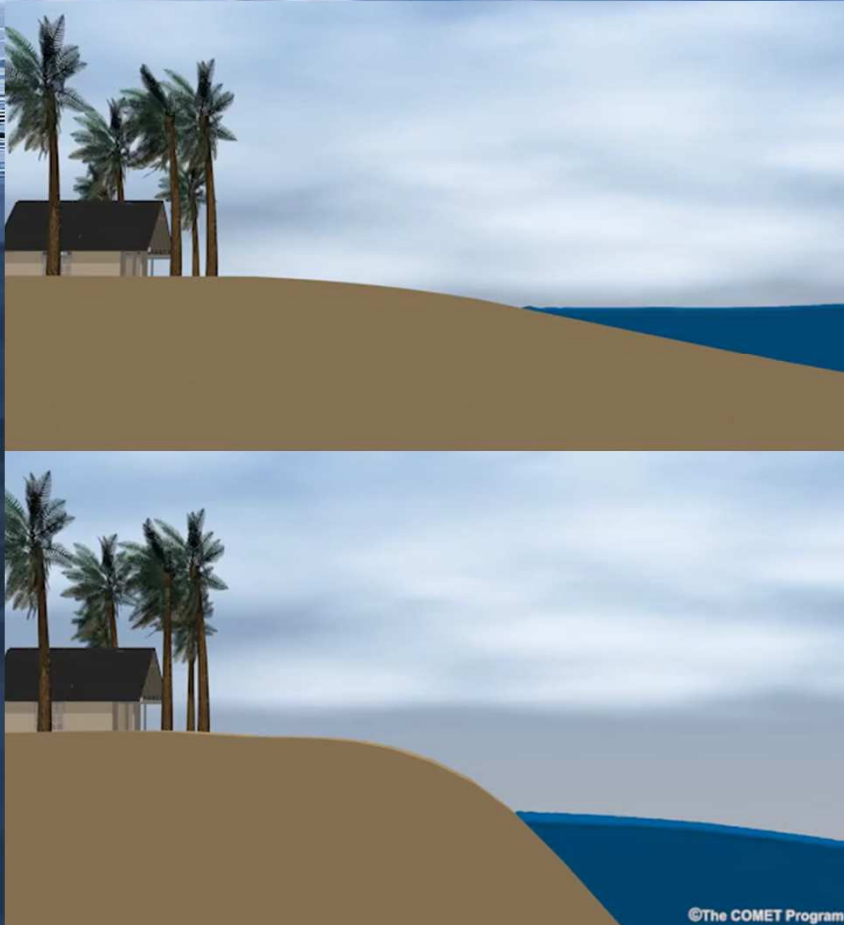


Angle of Approach

NNW Motion



Width and Slope of Shelf

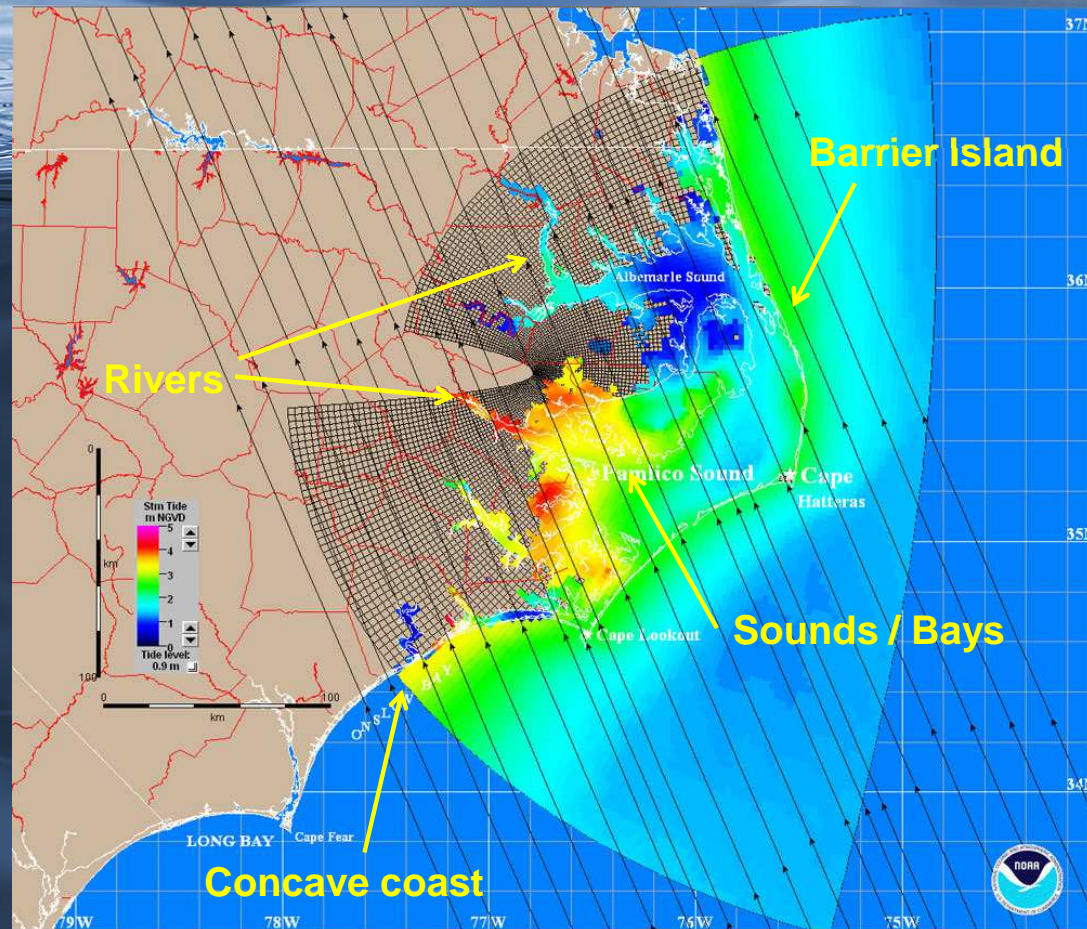


Wide shelf/
gentle slope

Narrow shelf/
sharp slope



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



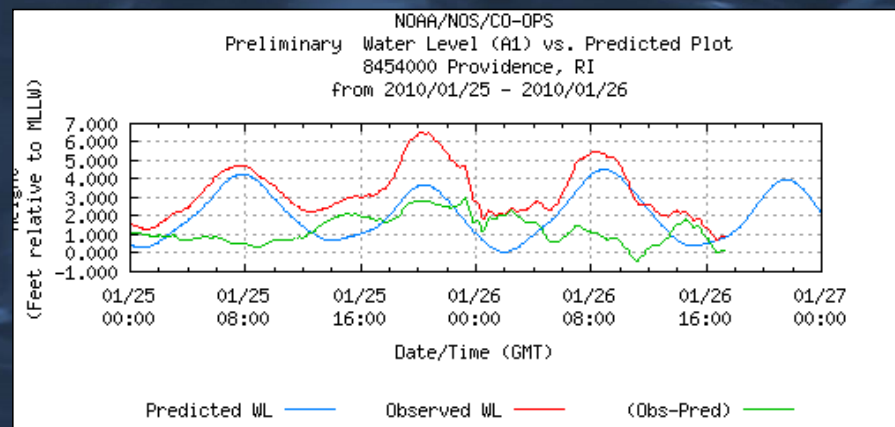
NOS Water Level Stations

- A network of 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



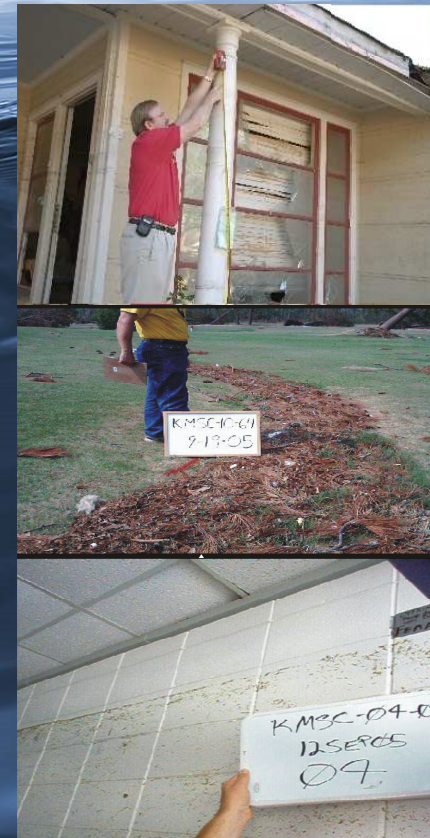
NOS Water Level Stations

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



High Water Marks

- Lines found marking the highest elevation (peak) of the water surface for a flood event
- Two types:
 - Lines found on trees and structures
 - Foam, seed, debris lines marking furthest extent
- Survey crews deployed after storm to locate and record reliable HWMs
- Generally include effects of wave action/wave runup and only a small percentage of HWMs represent still water (storm surge)



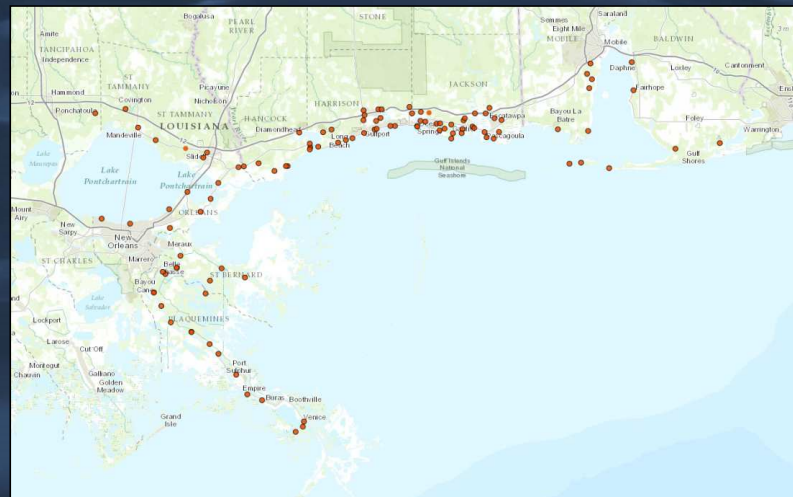
High Water Mark

Hoboken, New Jersey (Sandy)



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

