STORM SURGE

An Introduction to Storm Surge and Storm Surge Forecasting

Presented By: Cody Fritz
National Hurricane Center
Storm Surge Unit

WMO RA-IV Workshop on Hurricane Forecasting and Warnings
March 03, 2022

OUTLINE

- Introduction to Storm Surge
  - Who is vulnerable?
  - What is Storm Surge?
  - What factors affect Storm Surge?
- Forecasting Storm Surge and Storm Surge Products
  - SLOSH
  - Ensemble Guidance
- CIFDP-C Demonstration Project

OUTLINE

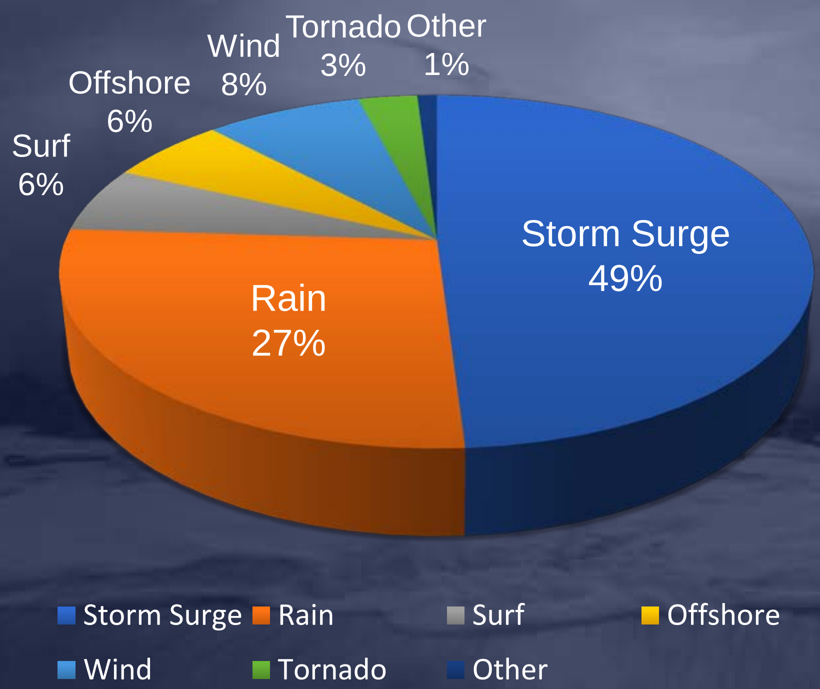
- Introduction to Storm Surge
  - Who is vulnerable?
  - What is Storm Surge?
  - What factors affect Storm Surge?

- Forecasting Storm Surge and Storm Surge Products
  - SLOSH
  - Ensemble Guidance

- CIFDP-C Demonstration Project

The Danger of Storm Surge

2,544 Fatalities From 1963–2012



- Almost 50% the deaths are due to storm surge
- Over 80% of deaths are due to water
- Wind causes less than 10% of deaths

Edward N. Rappaport, 2014: Fatalities in the United States from Atlantic Tropical Cyclones: New Data and Interpretation. Bull. Amer. Meteor. Soc., 95, 341–346.

Hurricane Ike (2008) - Bolivar Peninsula, Texas

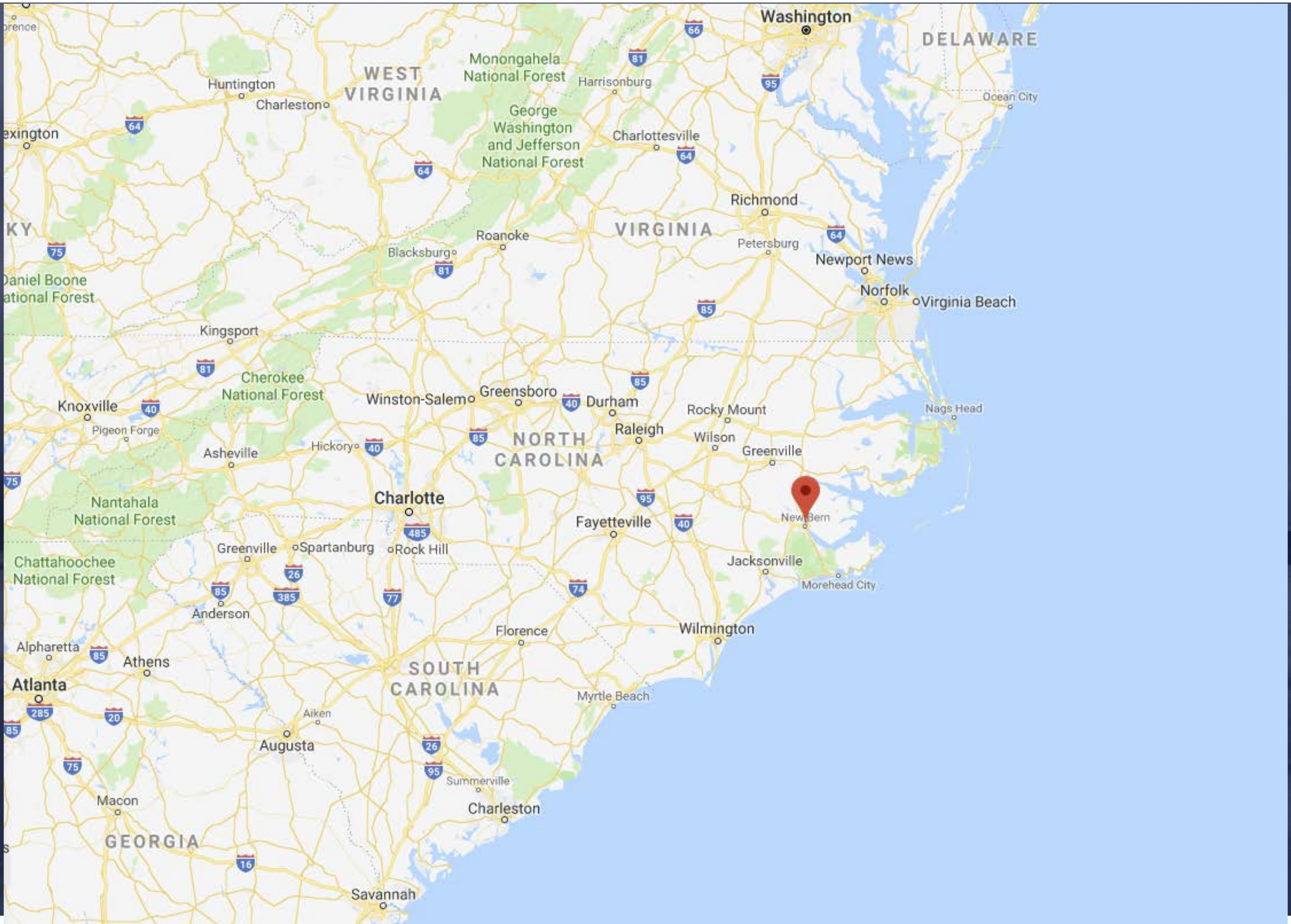
House of David and Kimberly King

Myth or Fact?

I live miles from the beach, so storm surge is not my problem.

Myth

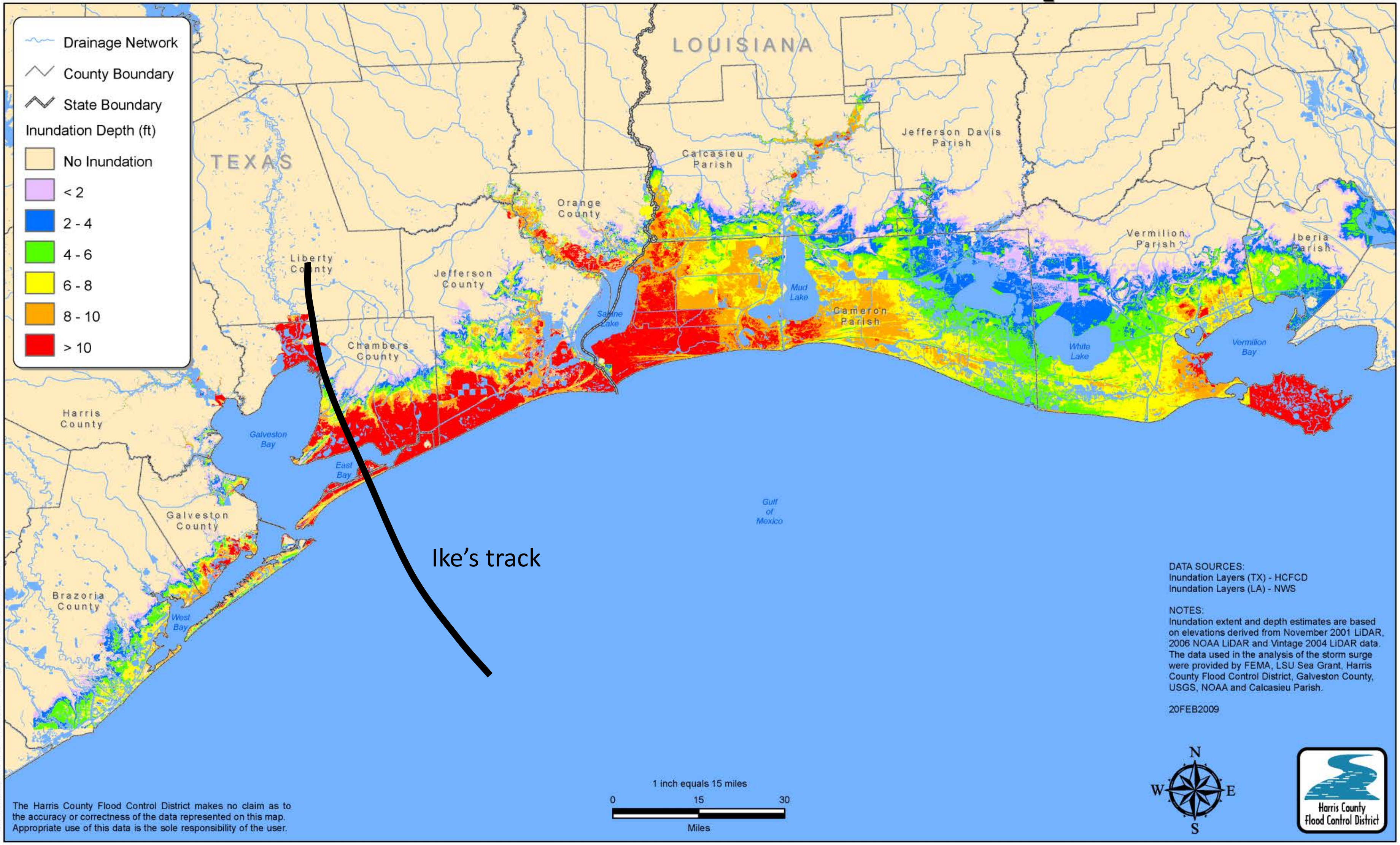
New Bern, NC – Hurricane Florence



New Bern, NC – Hurricane Florence

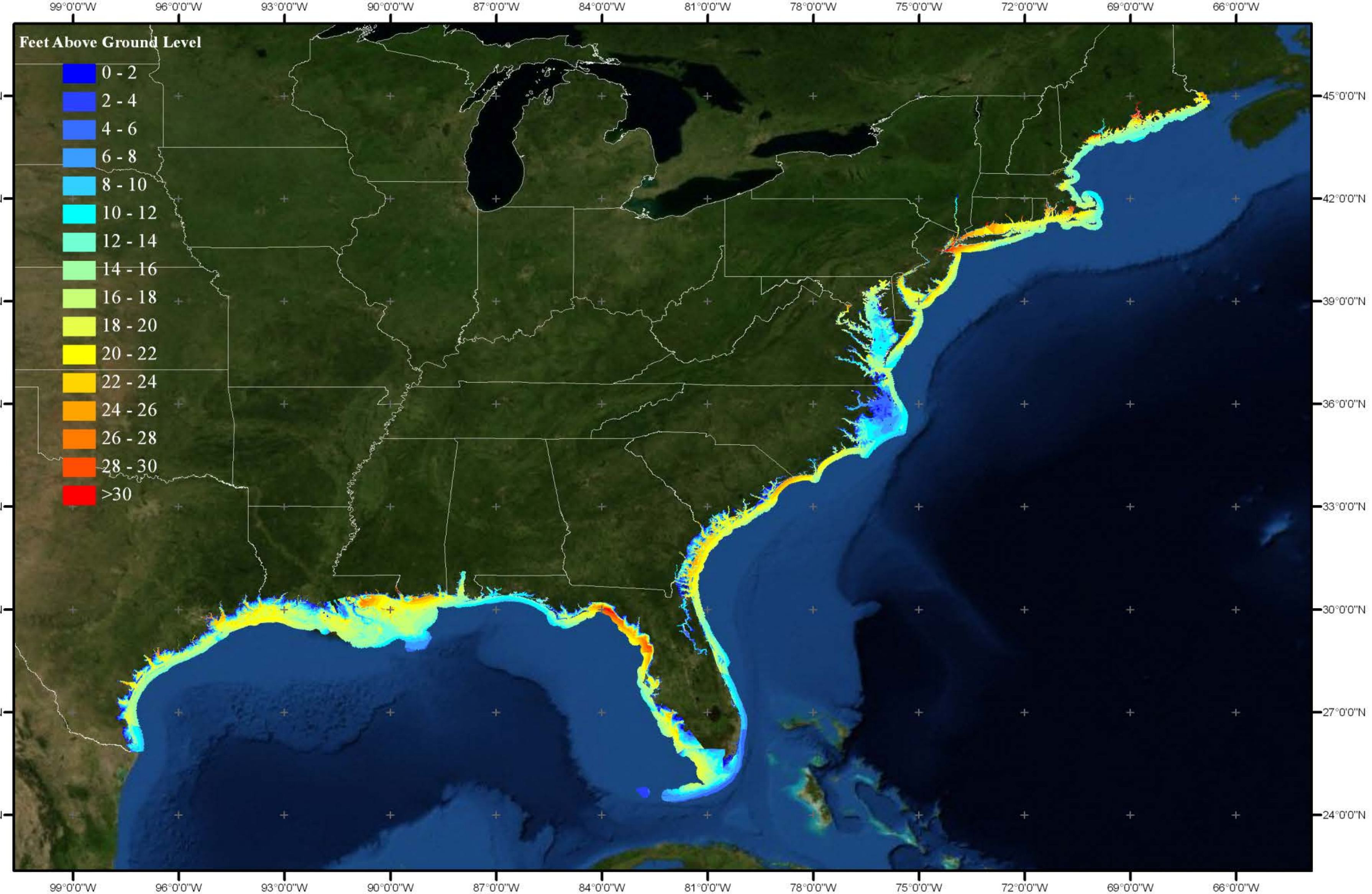
New Bern, NC – Hurricane Florence

Hurricane Ike Inundation Depth



Are some areas more vulnerable to storm surge than others?

Storm Surge Vulnerability: Category 4 Hurricane



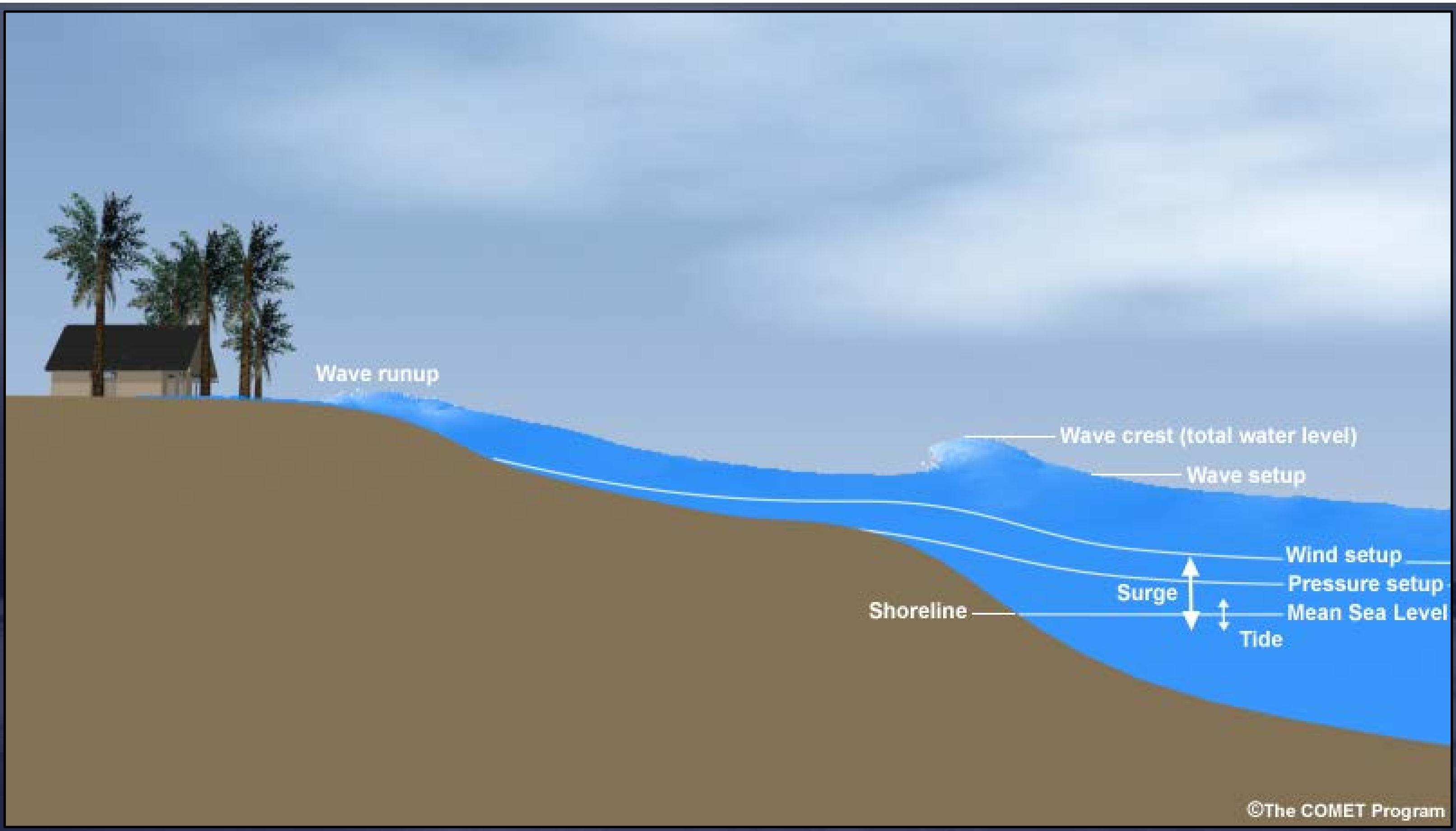
Data Source:
NWS/NHC/Storm Surge Unit

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

What is storm surge and how does it work?

Total Water

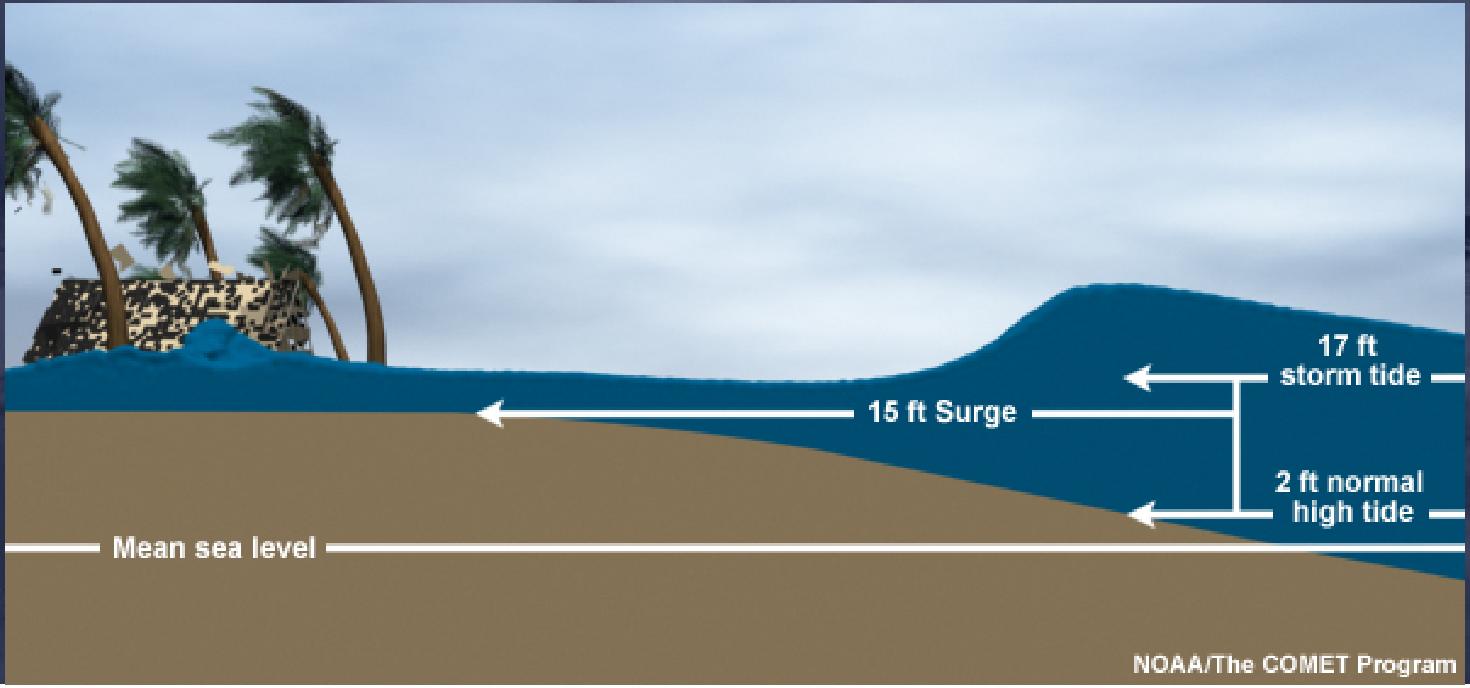


Total water level = Storm surge + Tides + Wave setup + Freshwater

What are Storm Surge and Storm Tide?

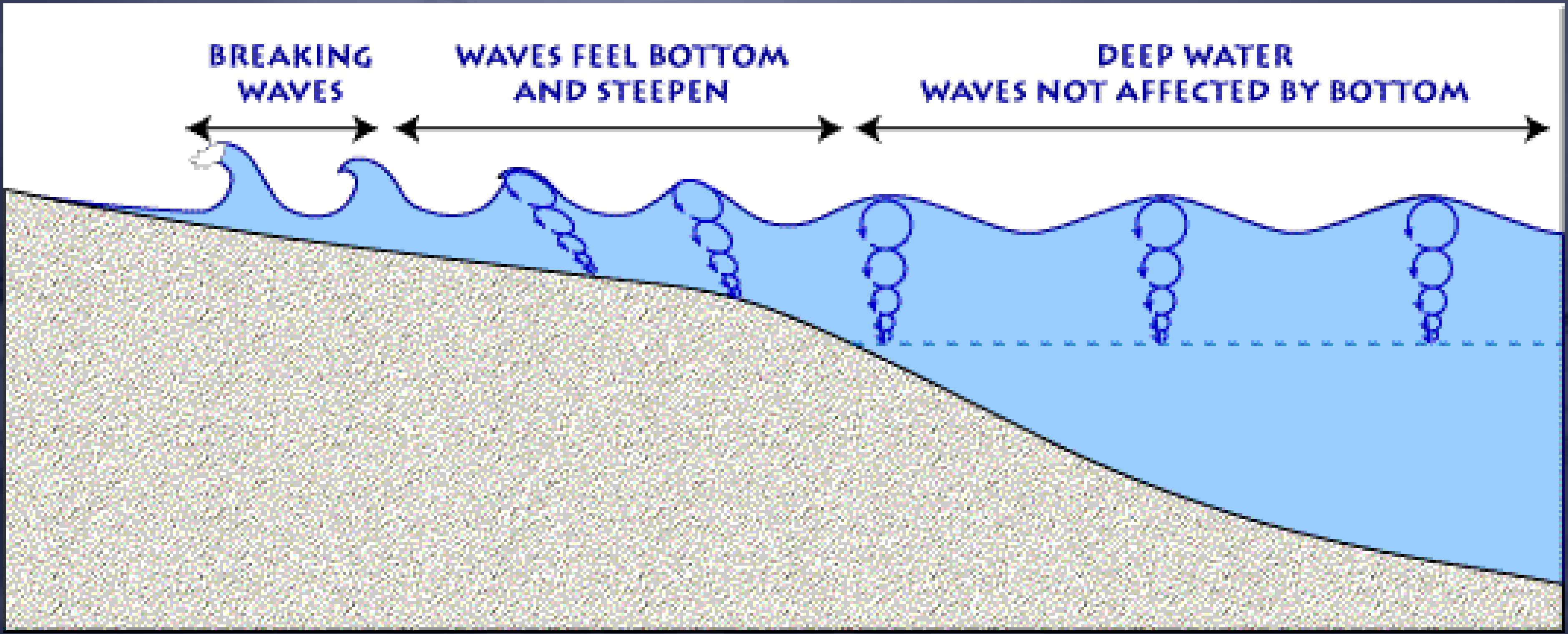
STORM SURGE is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

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

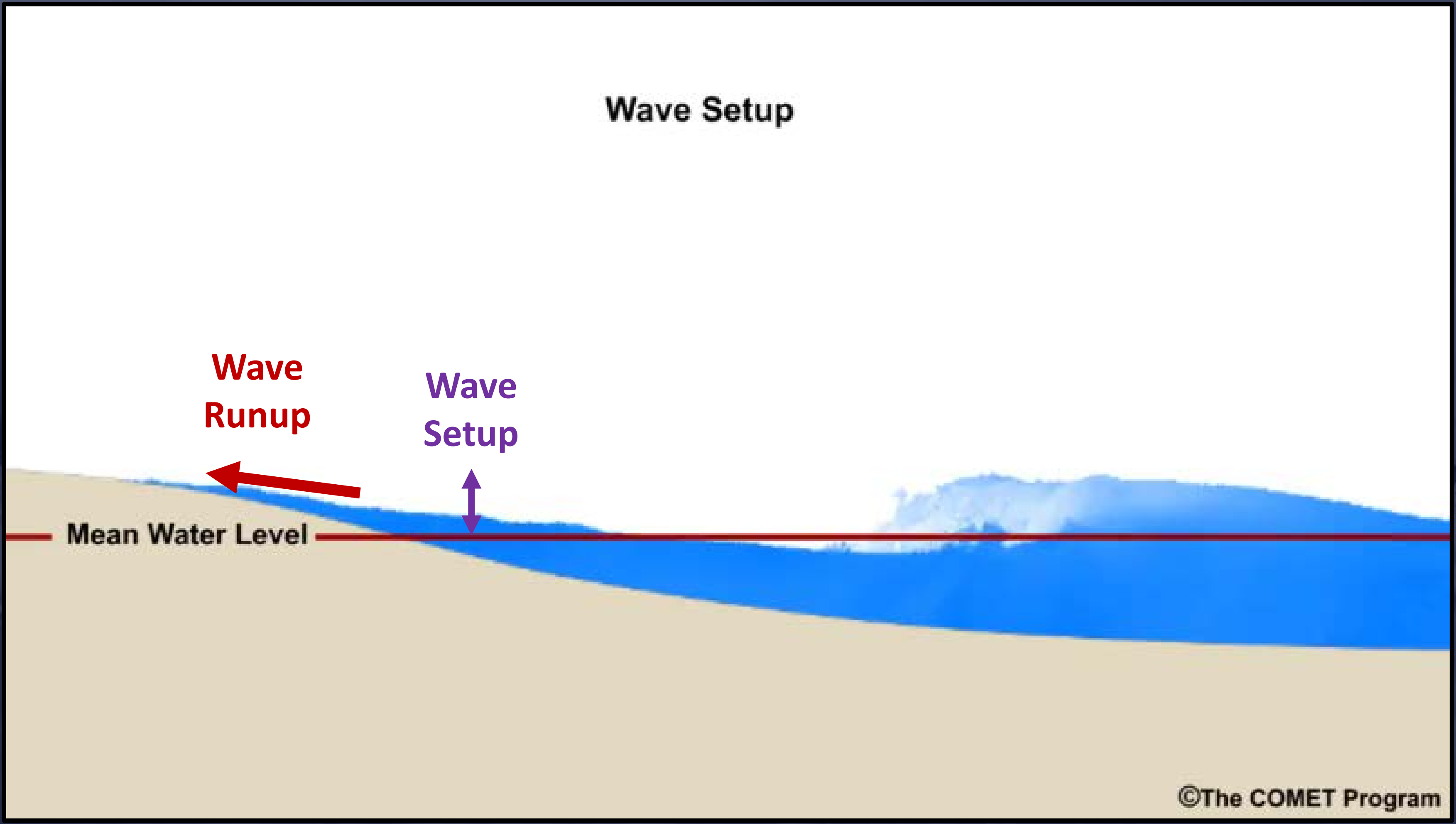


What about Waves?

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



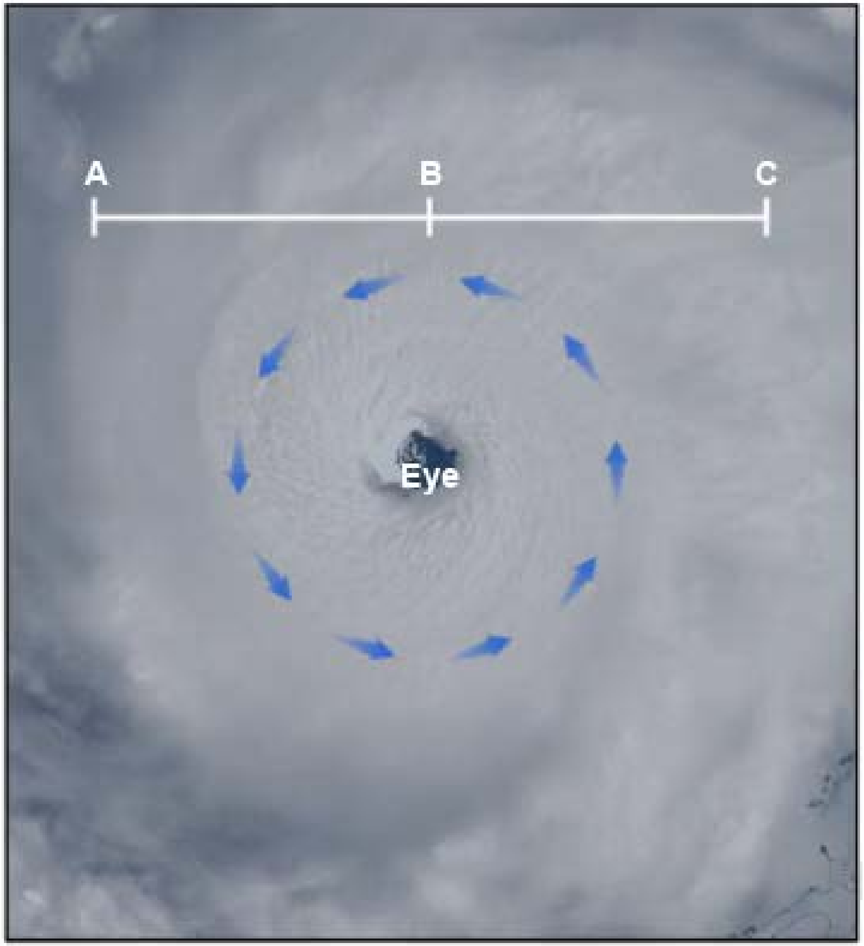
Wave Runup and Setup

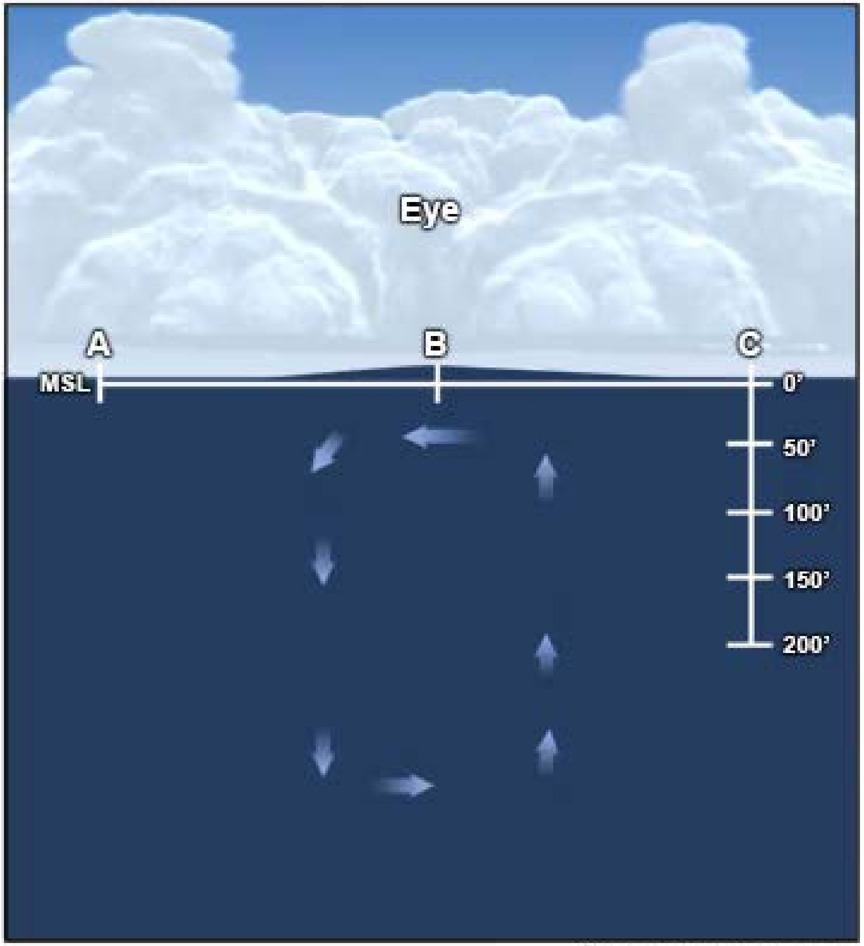


Freshwater Input

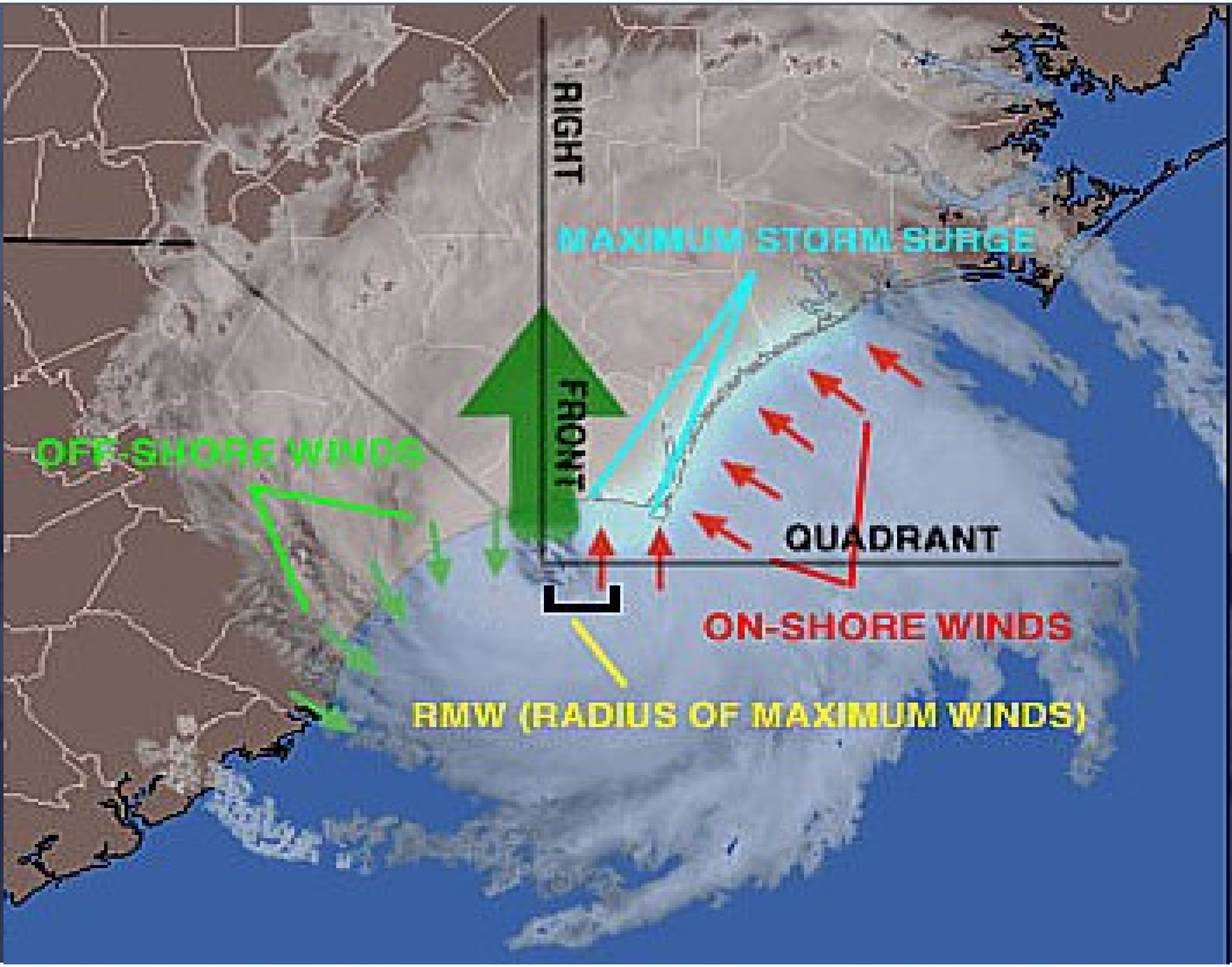
- River input, esp. into bays and sounds
  - Mississippi River discharges 200,000 – 700,000 cubic feet per second
- Rivers

From Deep Water to Shallow Water



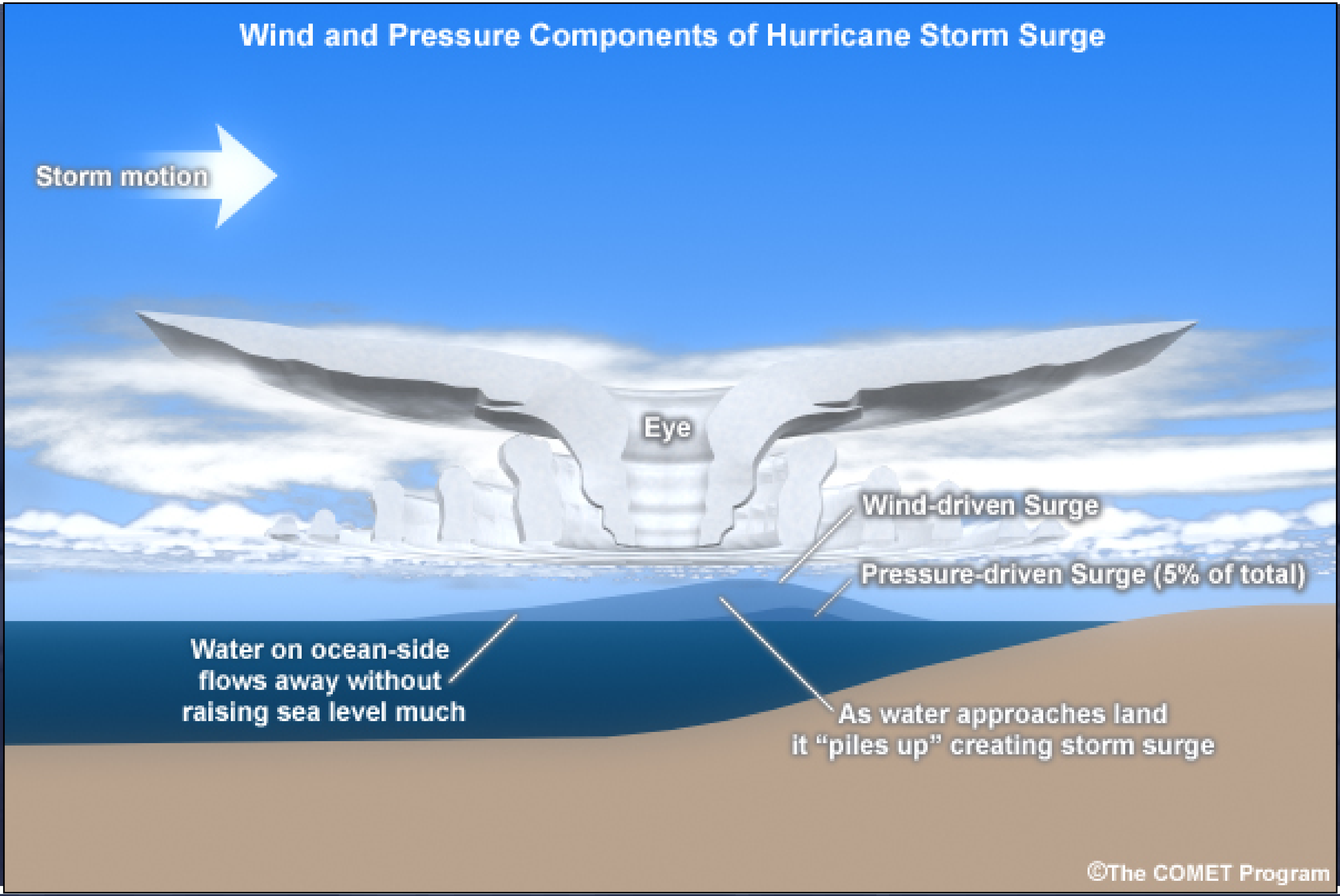


Understanding Surge



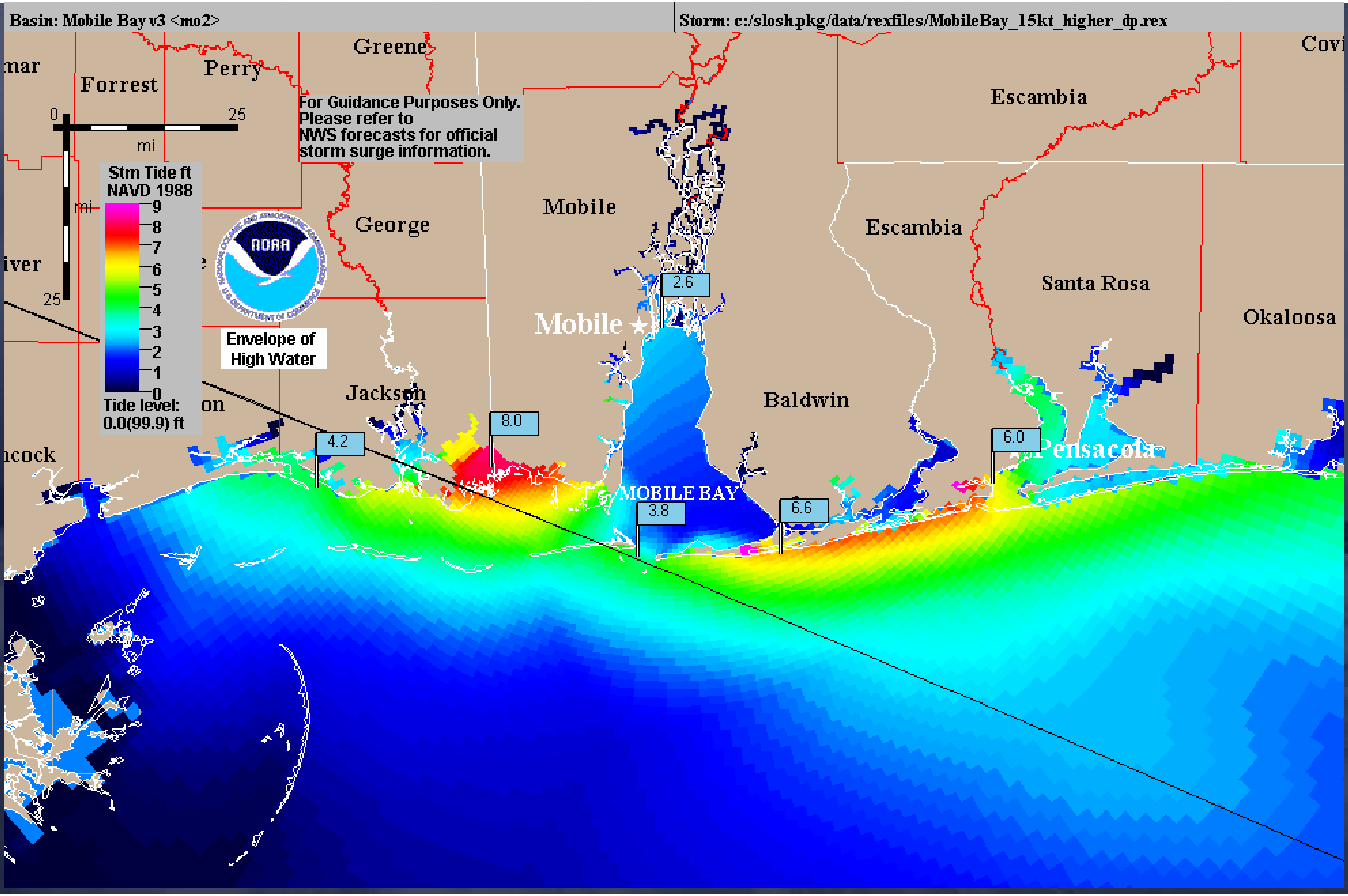
What are the factors that affect storm surge?

Effects of Low Pressure

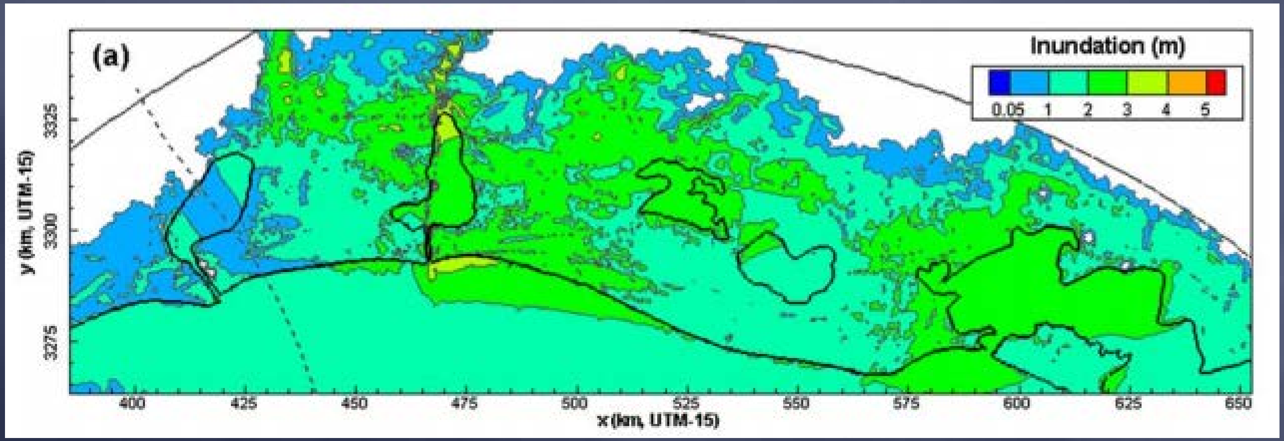


Intensity (Wind Speed)

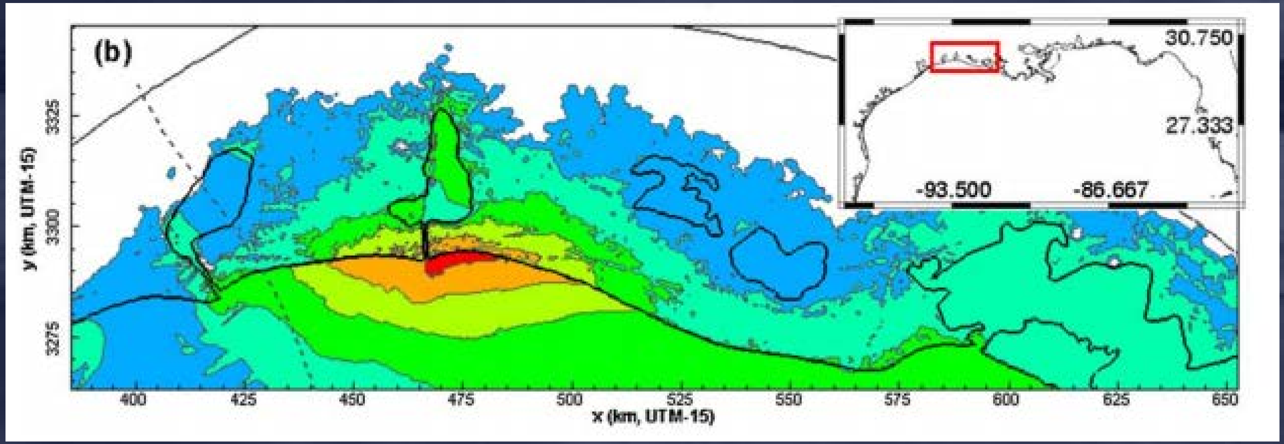
15 mph stronger



Forward Speed



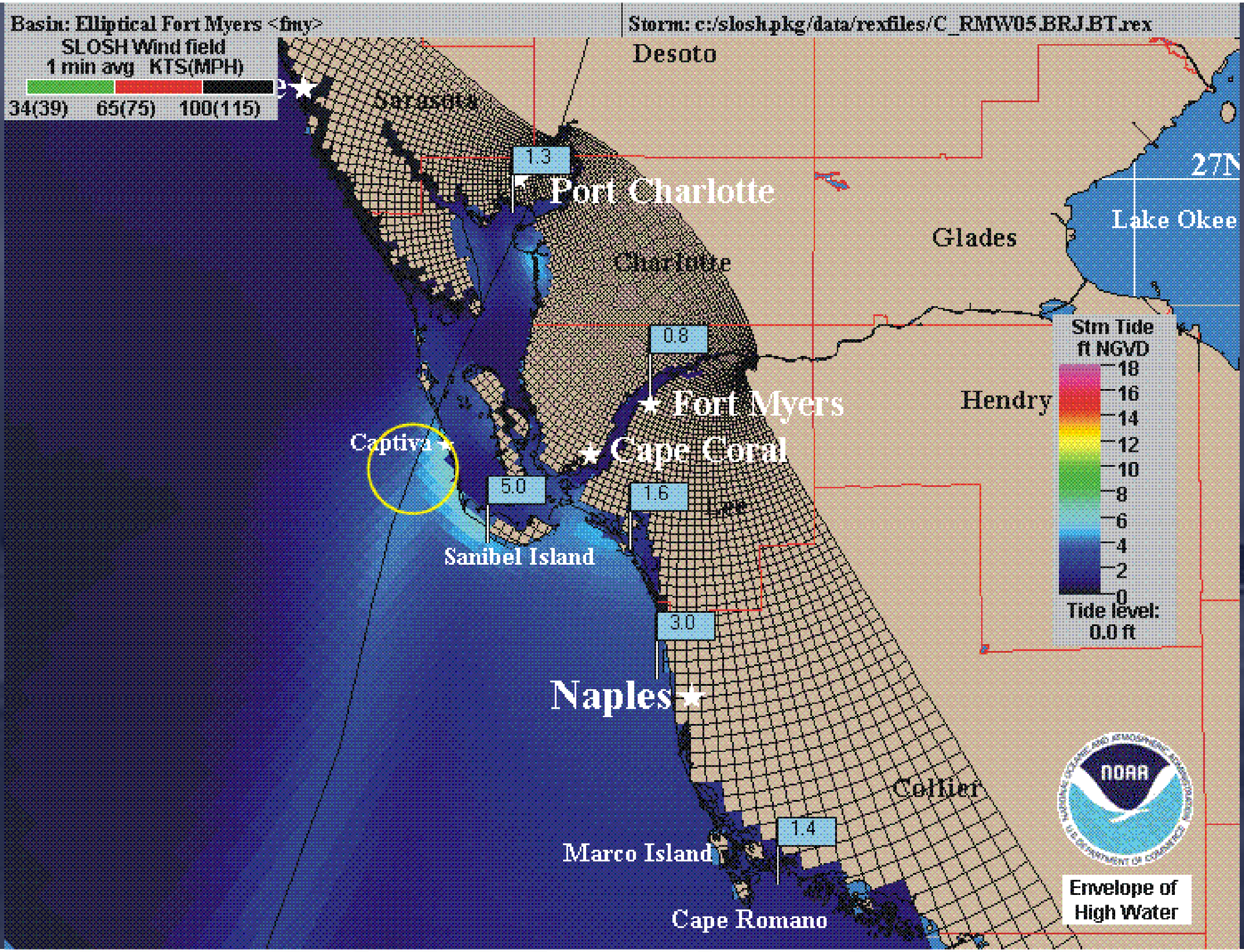
Slow Speed (5 mph)
- More inland penetration



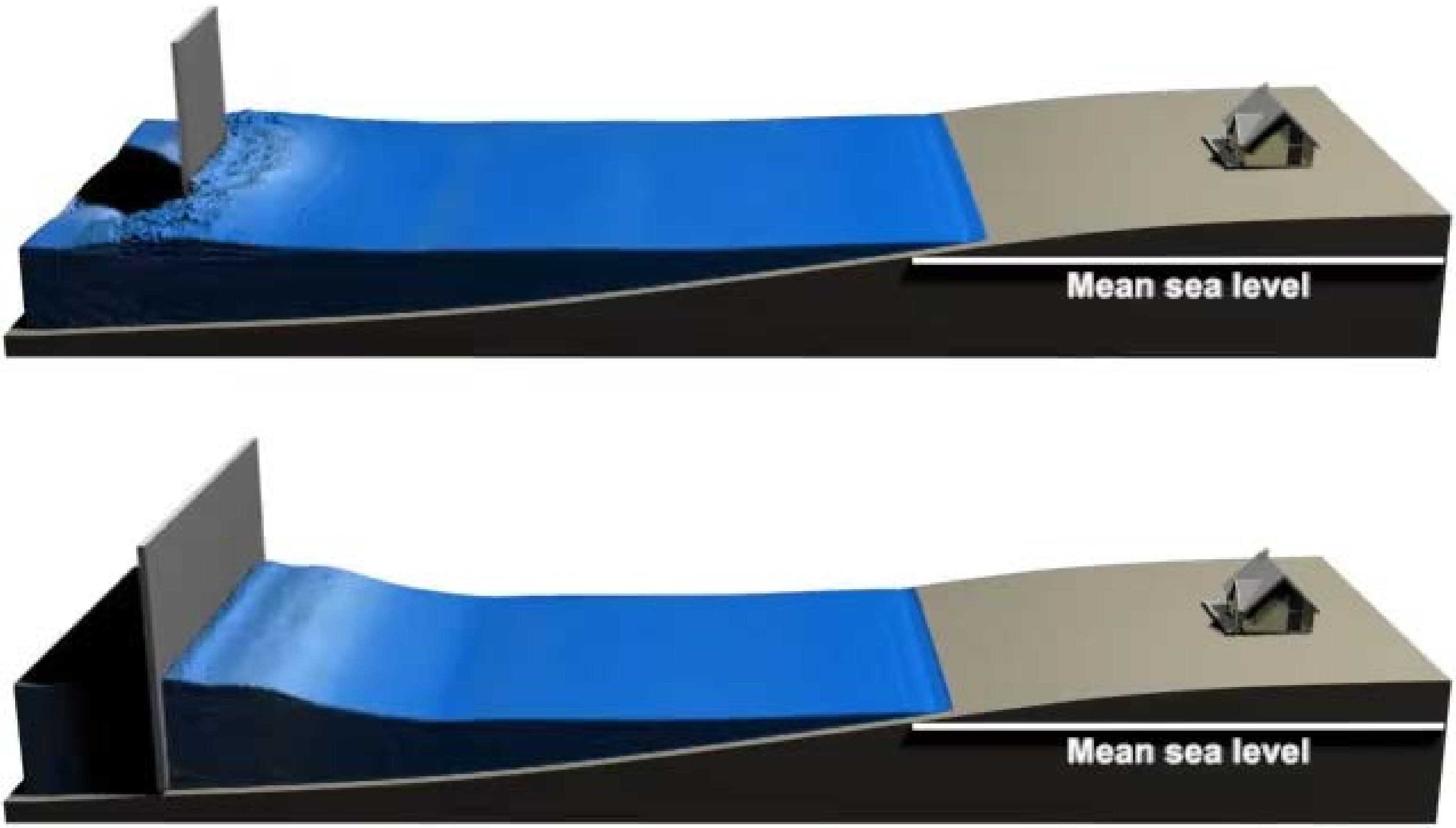
Fast Speed (25 mph)
- Higher maximum

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

Size
(Radius of Max Winds)

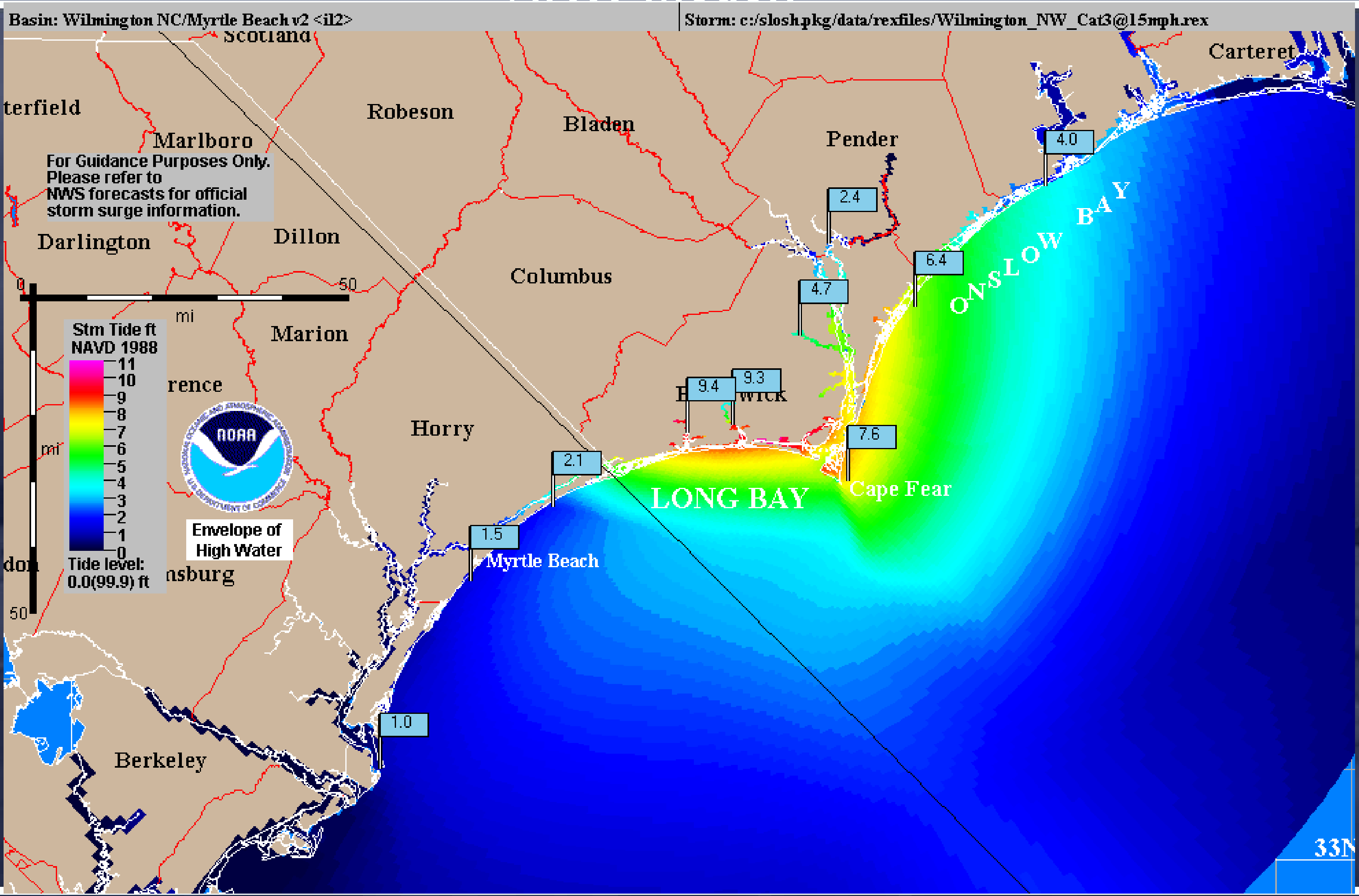


Size
(Radius of Max Winds)

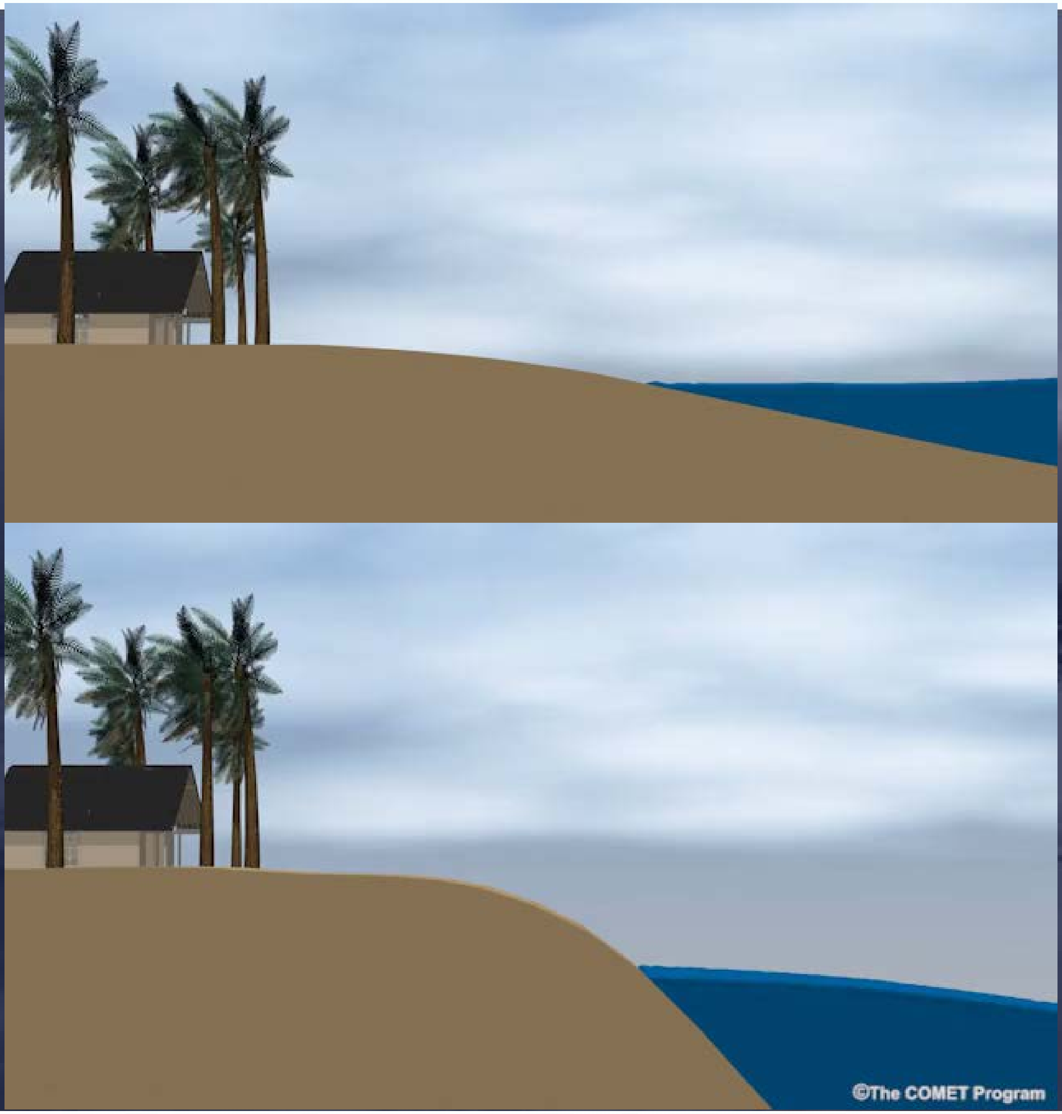


Angle of Approach

NNW Motion



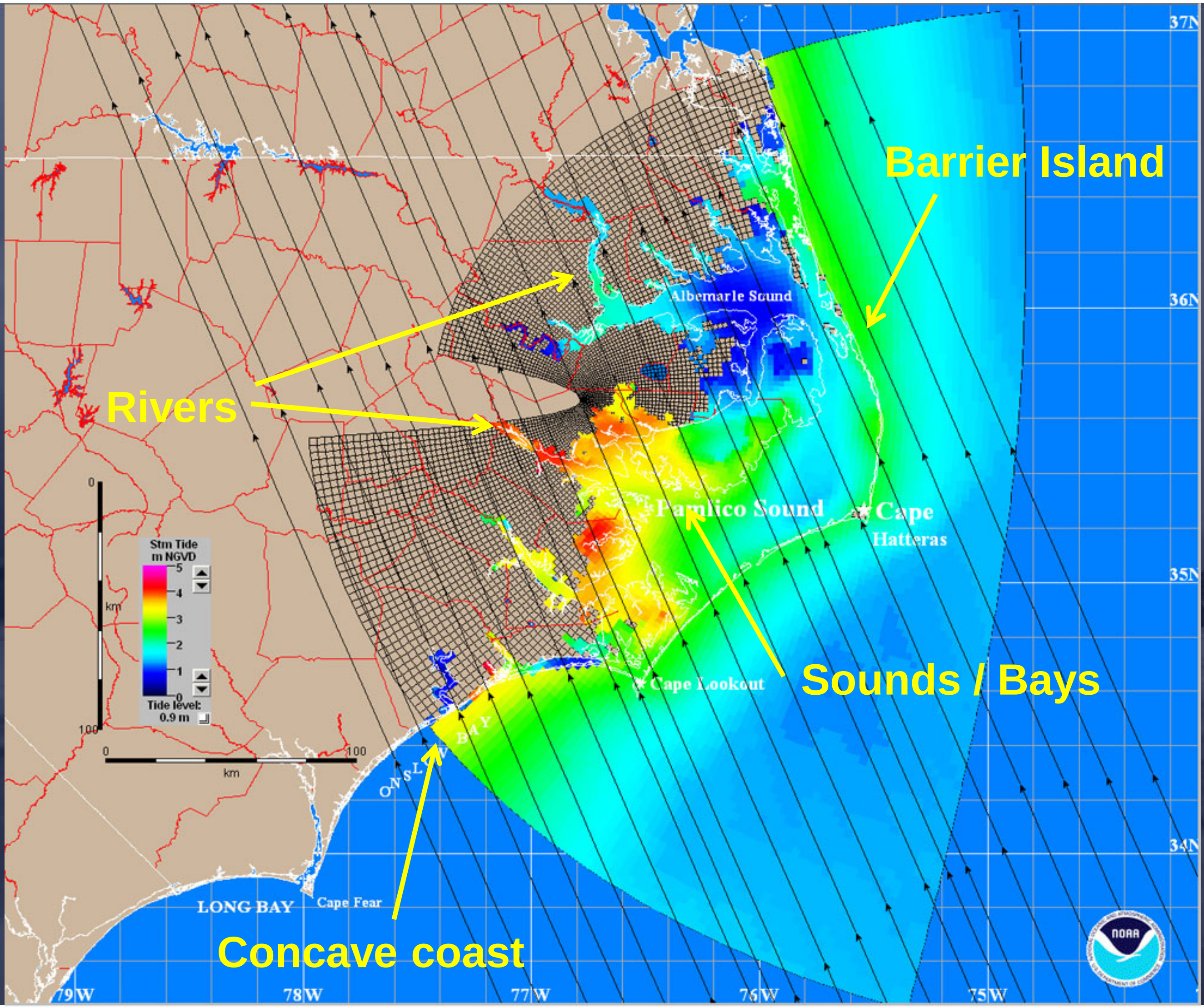
Width and Slope of Shelf



Wide shelf/gentle slope

Narrow shelf/sharp slope

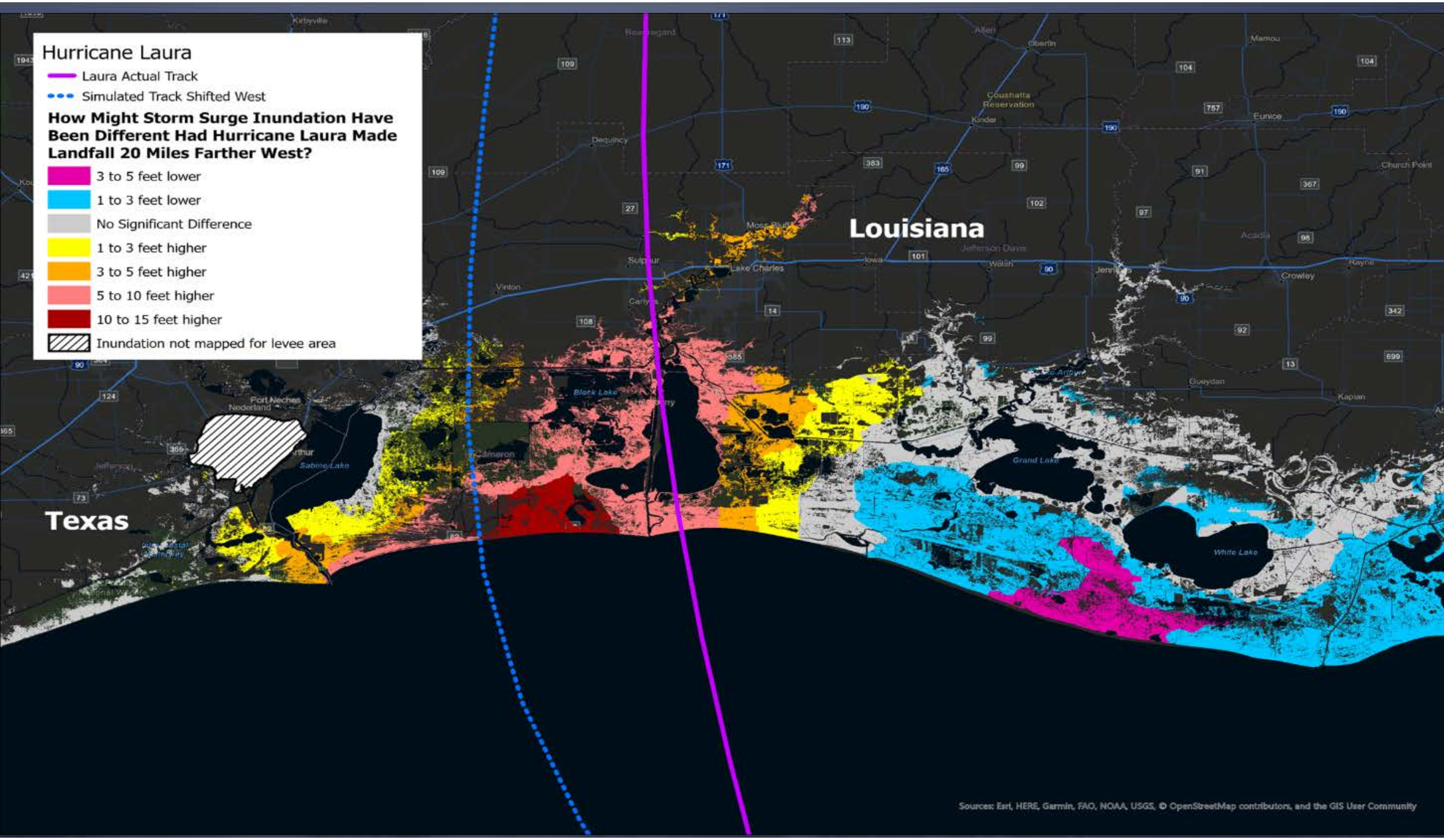
Local Features



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

Factors Affecting Storm Surge

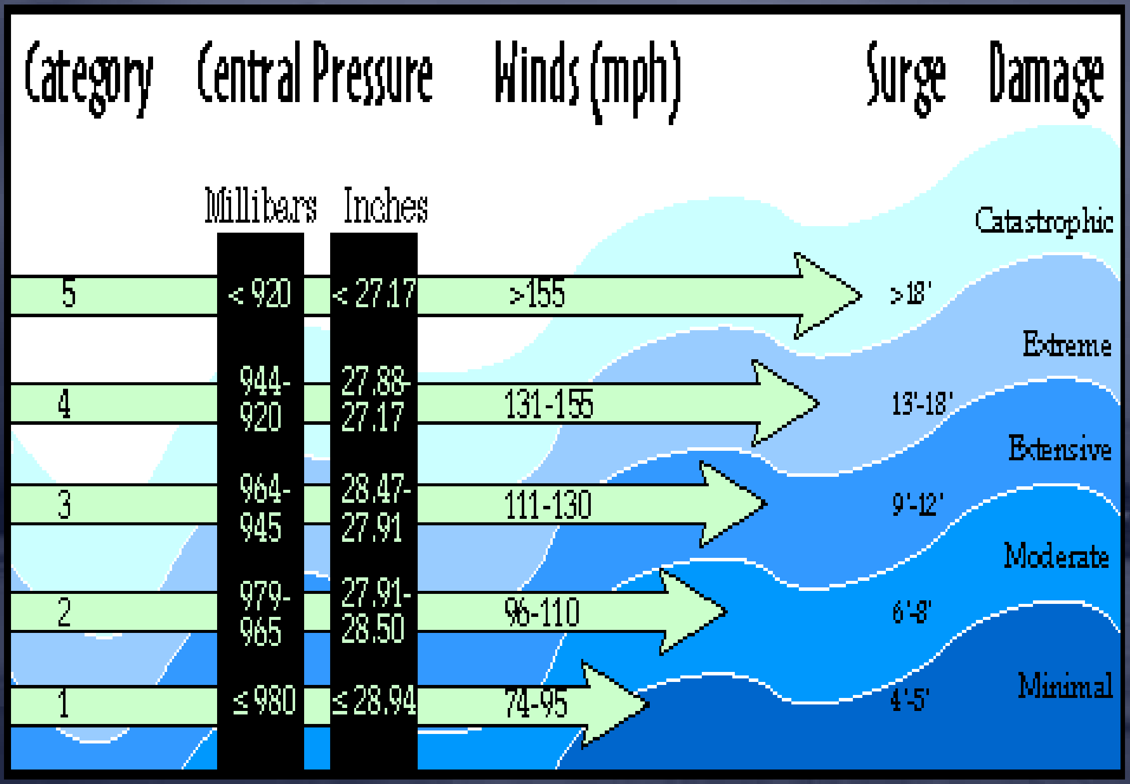


Myth or Fact?

Category 4 hurricanes always produce more storm surge than Category 1 hurricanes?

Myth

No More Surge in the Saffir-Simpson Scale!



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)

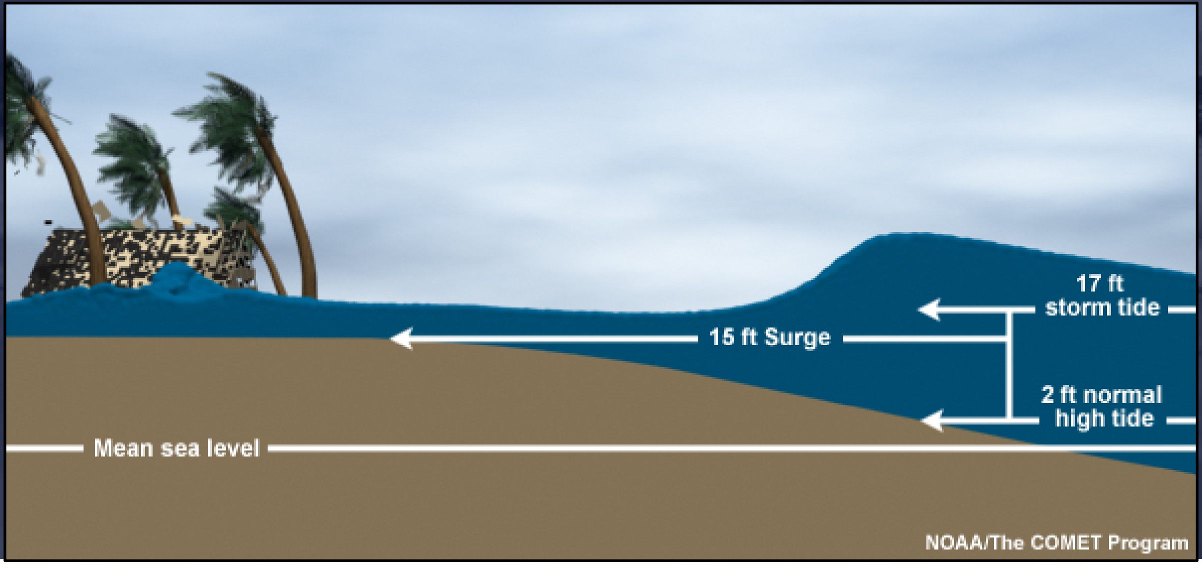
OUTLINE

- Introduction to Storm Surge
  - Who is vulnerable?
  - What is Storm Surge?
  - What factors affect Storm Surge?
- Forecasting Storm Surge and Storm Surge Products
  - SLOSH
  - Ensemble Guidance
- CIFDP-C Demonstration Project

SLOSH

- **Sea, Lake, and Overland Surges from Hurricanes**

- **A computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights (and winds) resulting from historical, hypothetical, or predicted hurricanes**



SLOSH
Strengths and Limitations

- SLOSH does include:
  - Flow through barriers/gaps/passes
  - Deep passes between bodies of water
  - Inland inundation (wet/dry cell)
  - Overtopping of barrier systems, levees, and roads
  - Coastal reflection (coastally trapped Kelvin waves)
  - Astronomical tide
  - Wave setup in U.S. island states and territories

- SLOSH does not include:
  - Wave run-up (efforts underway)
  - Normal river flow and rain

Storm Surge Products

Pre-Computed

Available outside US

MEOWs

Maximum Envelopes Of Water

MOMs

Maximum Of the MEOWs

Real-Time

Not Available outside US

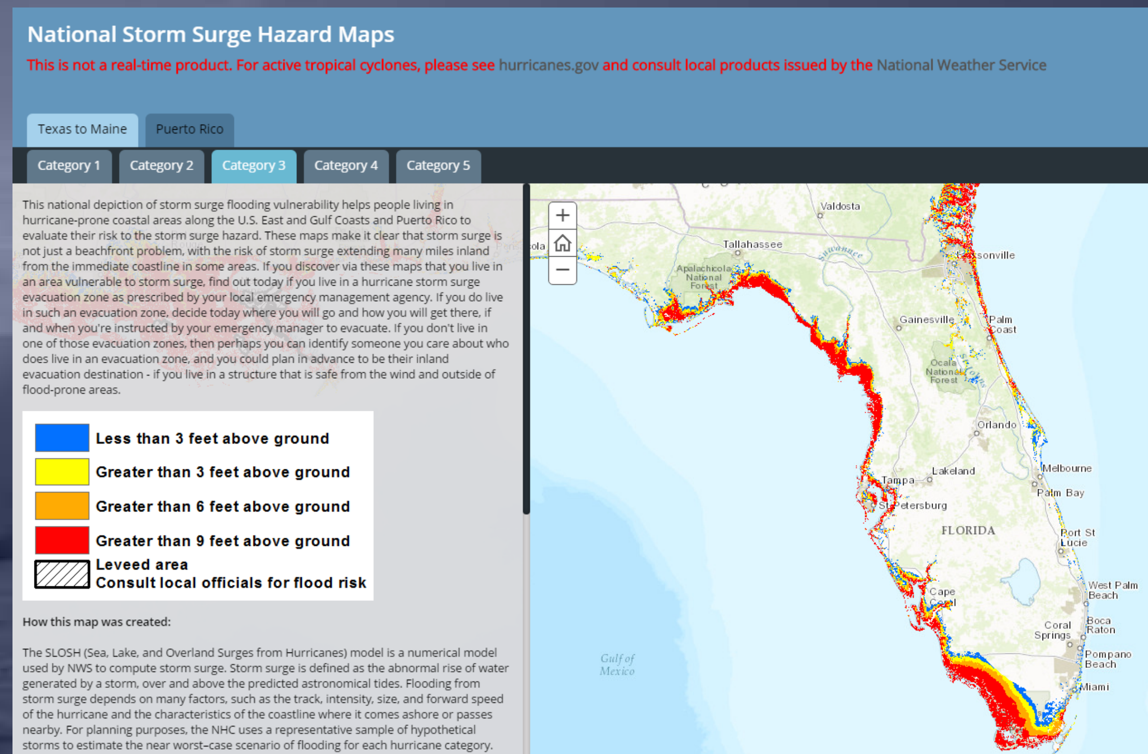
Probabilistic Storm Surge (P-Surge)

Potential Storm Surge Flooding Graphic

Storm Surge Watch/Warning

National SLOSH MOM and Risk Analysis

- About 7.4 million people vulnerable to storm surge
- Roughly 4,600 miles of evacuation route becomes inundated or cut off
- Almost 3.9 million housing units vulnerable to surge



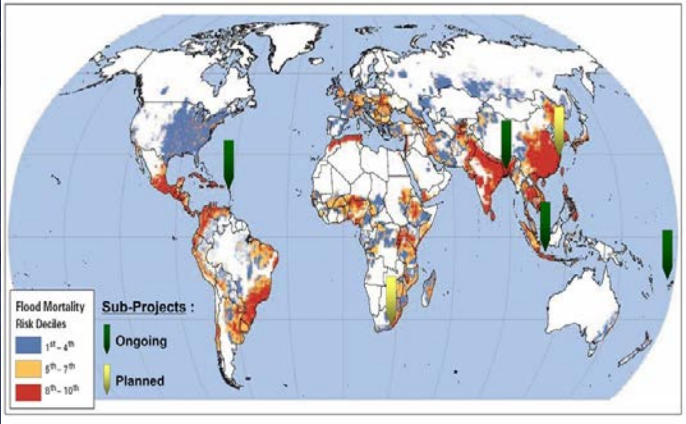
Zachry, B. C., W. J. Booth, J. R. Rhome, and T. M. Sharon, 2015: A National View of Storm Surge Risk and Inundation. J Wea. Climate Soc., 7(2), 109-117

OUTLINE

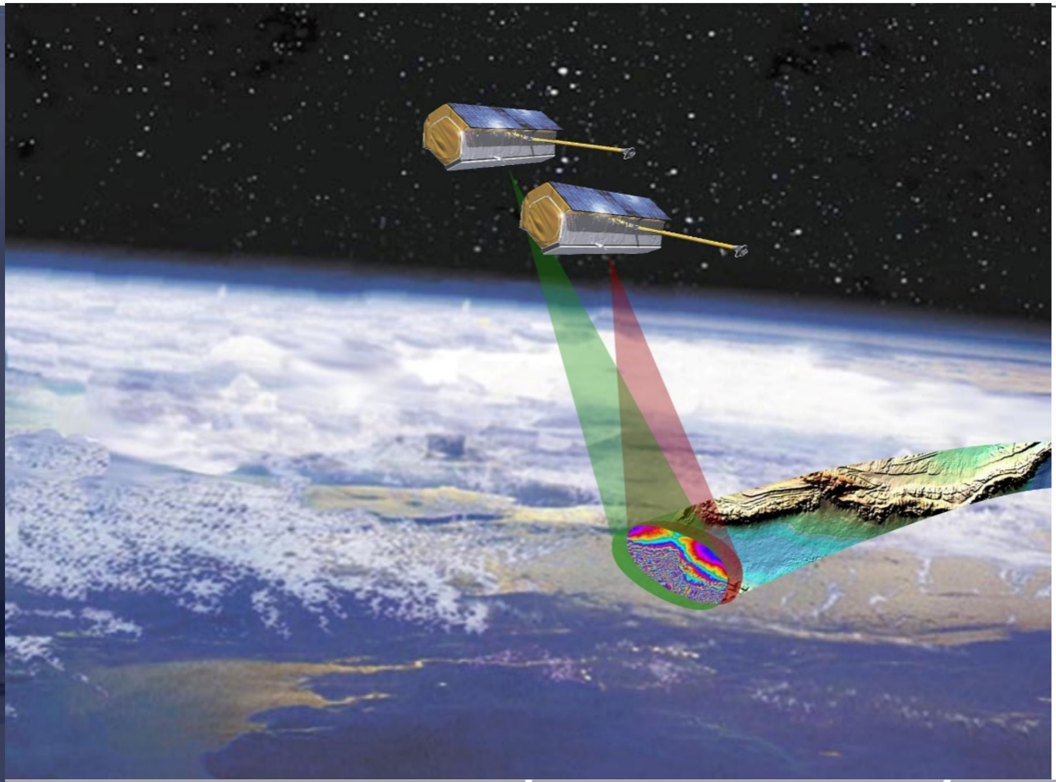
- Introduction to Storm Surge
  - Who is vulnerable?
  - What is Storm Surge?
  - What factors affect Storm Surge?
- Forecasting Storm Surge and Storm Surge Products
  - SLOSH
  - Ensemble Guidance
- CIFDP-C Demonstration Project

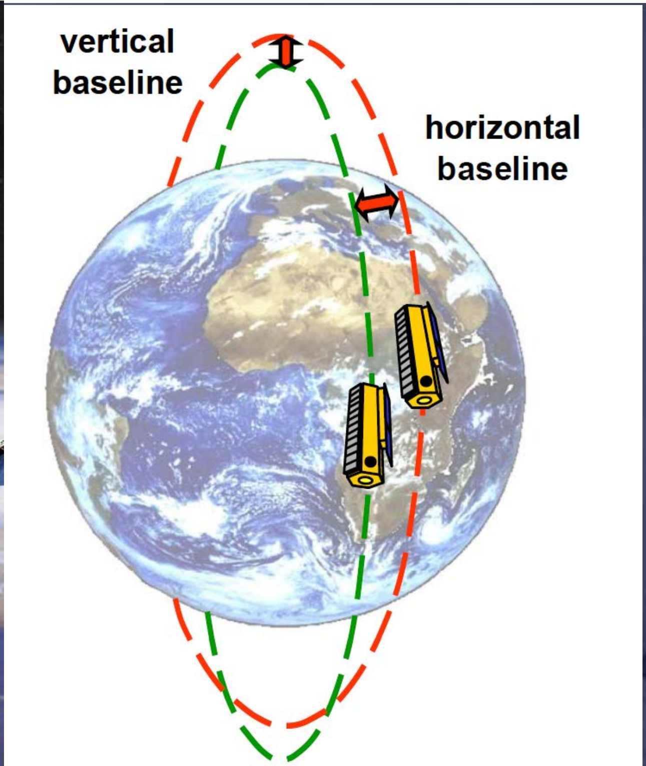
History of CIFDP-C

- At the 5th meeting of the CIFDP Program Steering Group (May 2014, Geneva), the previous Sub-Project for Dominican Republic (CIFDP-DR) was re-scoped for a Caribbean/regional approach and denoted CIFDP-C
- CIFDP-C was initially demonstrated and tested for the Dominican Republic and Haiti
- RSMC Miami provided the leading technical contribution, in collaboration with the PSG and other partners, which ensured the maximum synergies of regional and national efforts *and introduced a new direction to provide storm surge information to all other Caribbean countries*



TanDEM-X

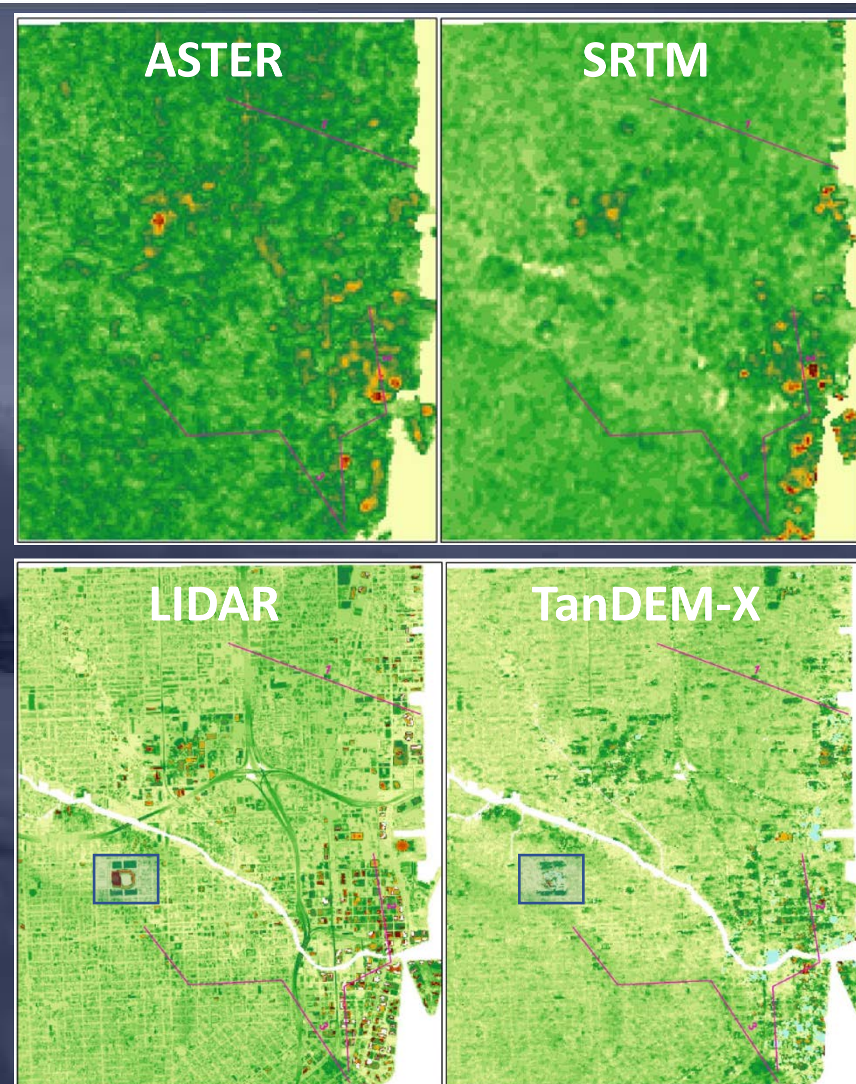




Requirements	Specification	DTED-2	TanDEM-X DEM
Relative Vertical Accuracy	90 % linear point-to-point error over a 1° by 1° cell	12 m (slope < 20 %) 15 m (slope > 20 %)	2 m (slope < 20 %) 4 m (slope > 20 %)
Absolute Vertical Accuracy	90 % linear error	18 m	10 m
Relative Horizontal Accuracy	90 % circular error	15 m	3 m
Absolute Horizontal Accuracy	90 % circular error	23 m	10 m
Spatial Resolution	Independent pixels	30 m (1 arc sec @ equator)	12 m (0,4 arc sec @ equator)

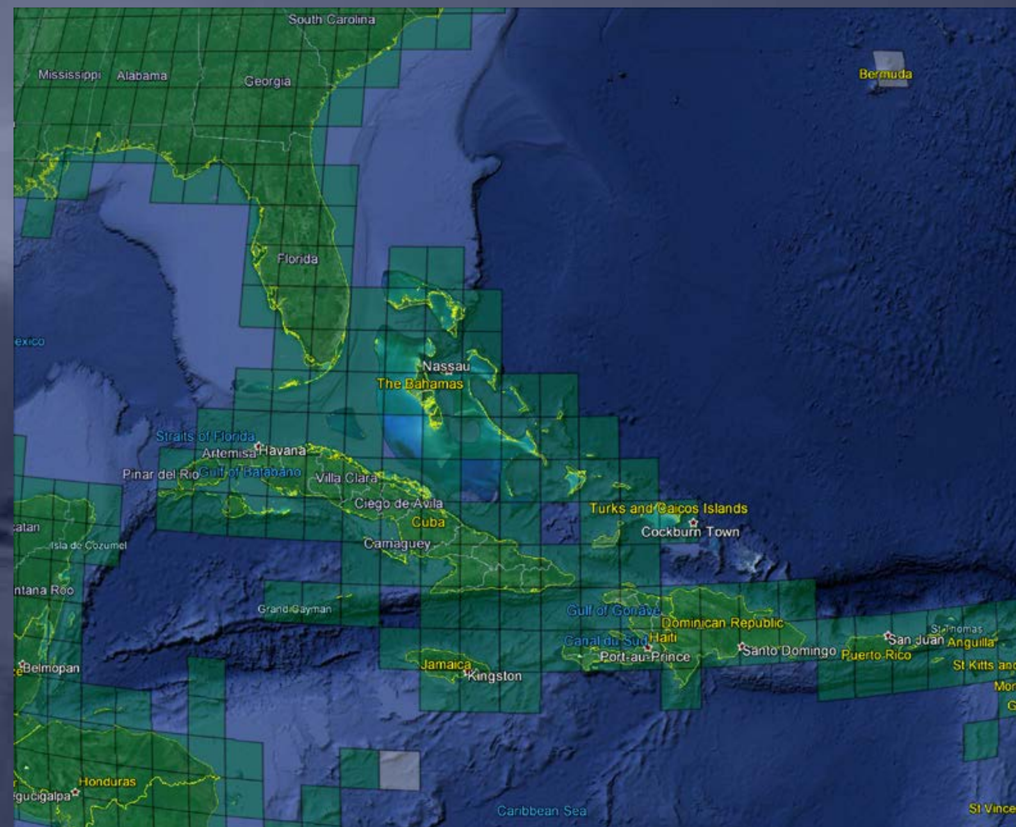
Topography Data Comparison: Miami, FL

Downtown Miami, FL



Data Availability

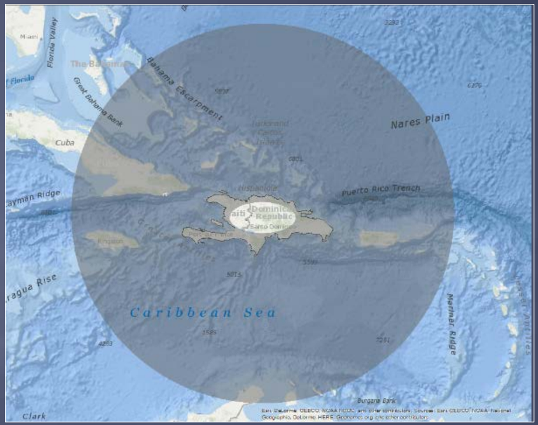
- Availability 2015
- Established an agreement with U.S. DOD for cost savings for CIFDP-C
- TANDEM-X DEMs not sharable per licensing agreement but final modeling results are

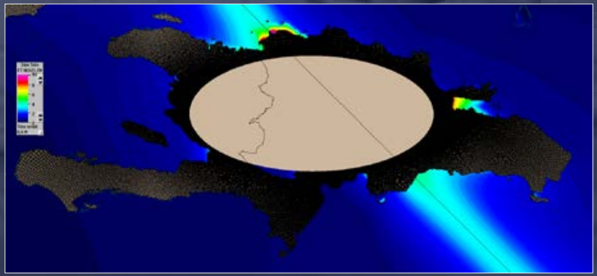


SLOSH + Waves Development

Coastal Inundation Forecasting Demonstration Project

- Implement a coupled storm surge and wave modeling system
  - SLOSH hydrodynamic model
  - Wave model recommended by IOOS modeling testbed (parametric)
- Develop products for planning, preparedness, and forecasting
  - SLOSH MOMs and MEOWs
- Provide specialized training programs on how to use the storm surge products for planning and preparedness





2^{nd} Gen (Parametric) Wave Model

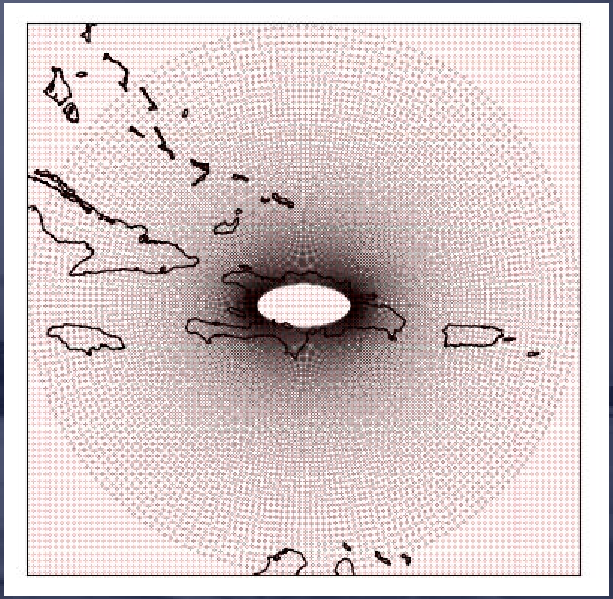
- An efficient parametric wave model to couple with SLOSH
- Parametric models that reduce full solution space N(t,x,y,σ,θ), to e.g. M(t,x,y) (Schwab et al. 1984).

$$\frac{\partial \vec{M}}{\partial t} + \vec{v} \cdot \nabla_{x,y} \vec{M} = \vec{\tau}_w$$

$$\vec{\tau}_w = 0.028 \rho_a D_f \left| \vec{U} - 0.83 C_p \right| \left(\vec{U} - 0.83 C_p \right)$$

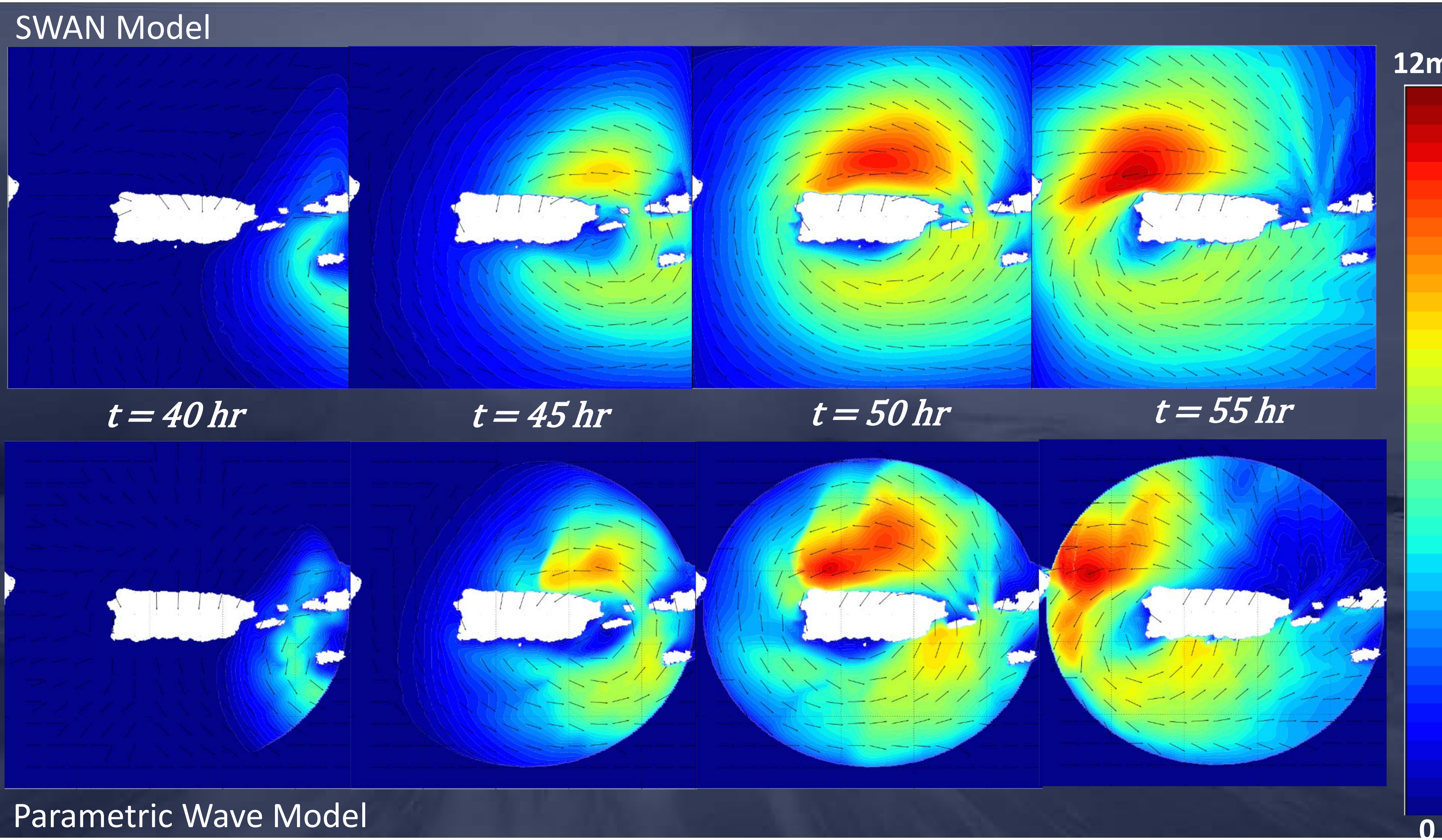
$$\sigma^2 = 6.23 \times 10^{-6} \left(\frac{f_p U}{g} \right)^{-10/3} \frac{U^4}{g^2}$$

- Simplified physics, but significantly cheaper than SWAN or WW3
- More suitable to couple with SLOSH

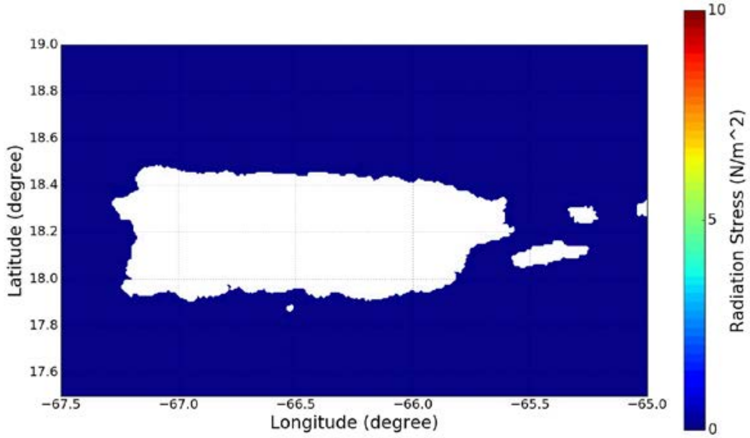


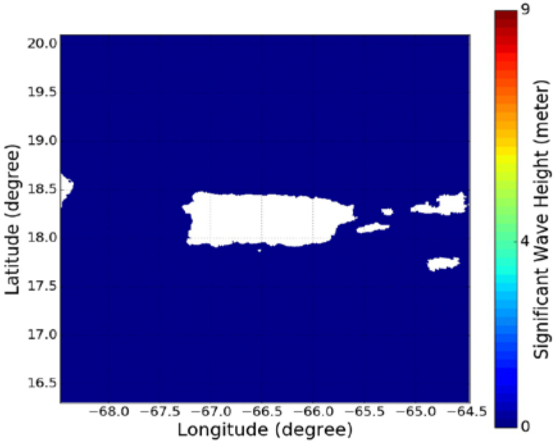
SLOSH basin and wave model grid mesh

Wave Height Comparison (Hurricane Georges, 1998)



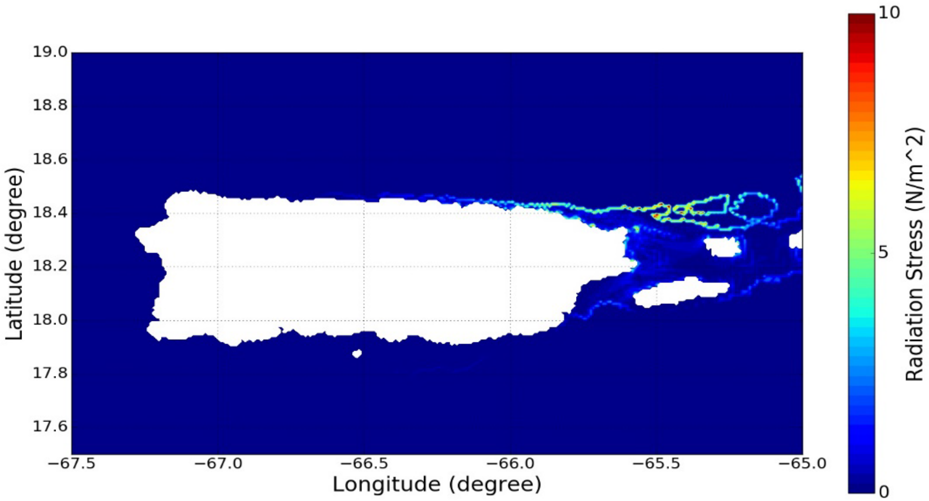
Coupled SLOSH + Waves

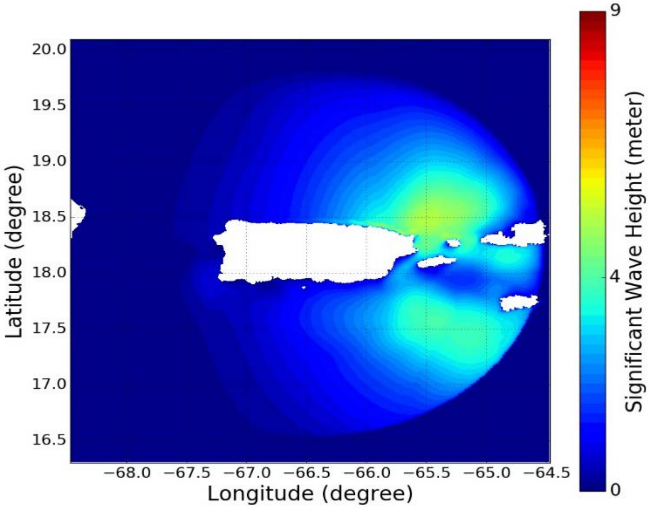




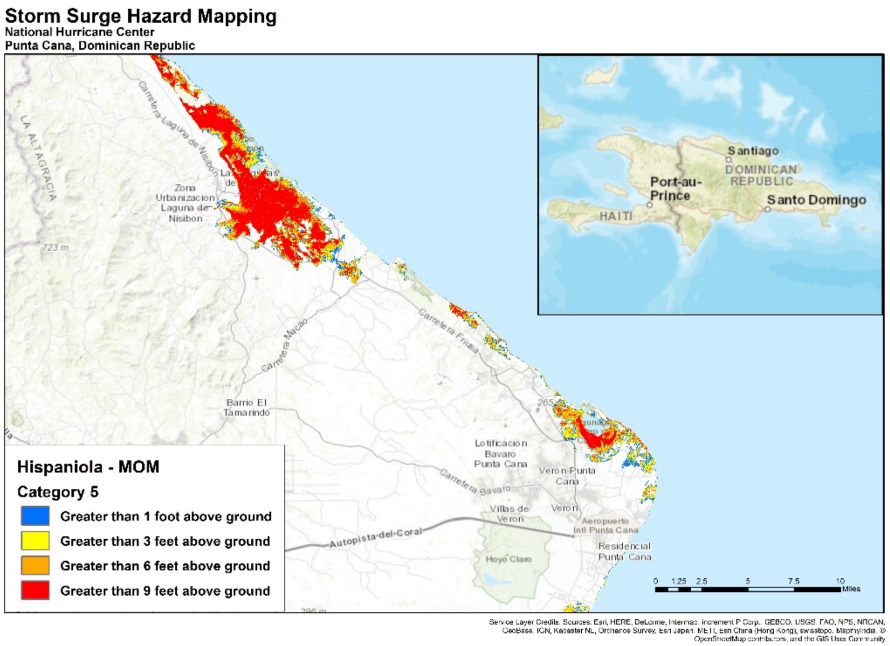
Wave Radiation Stress

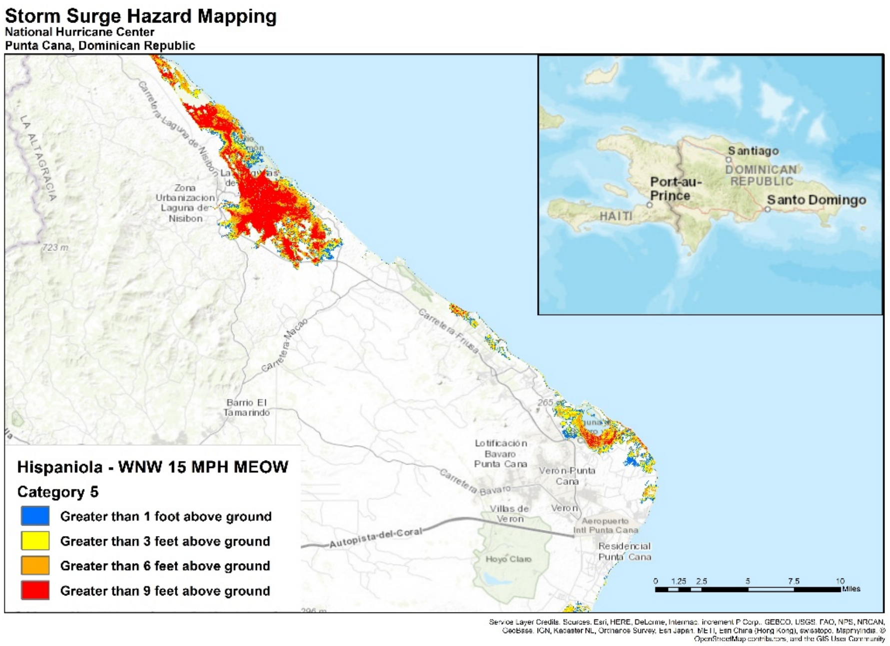
Significant Wave Height





Final Deliverable: High-Resolution Inundation Mapping



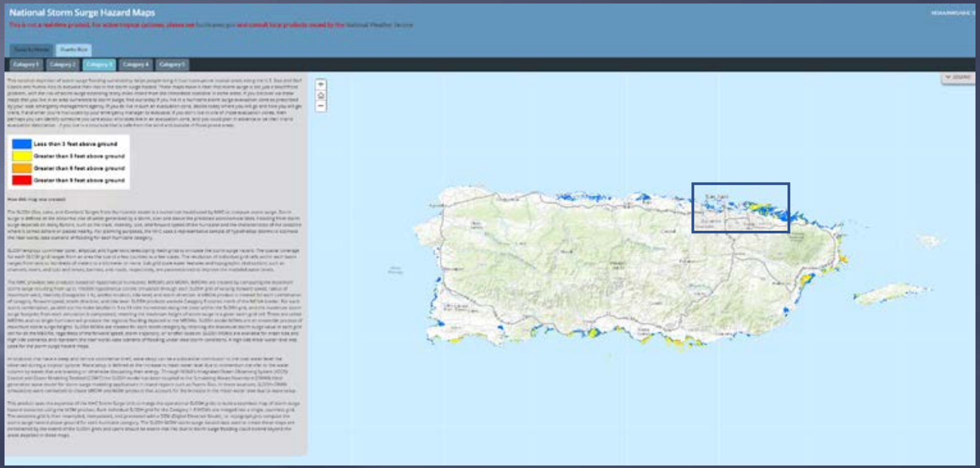


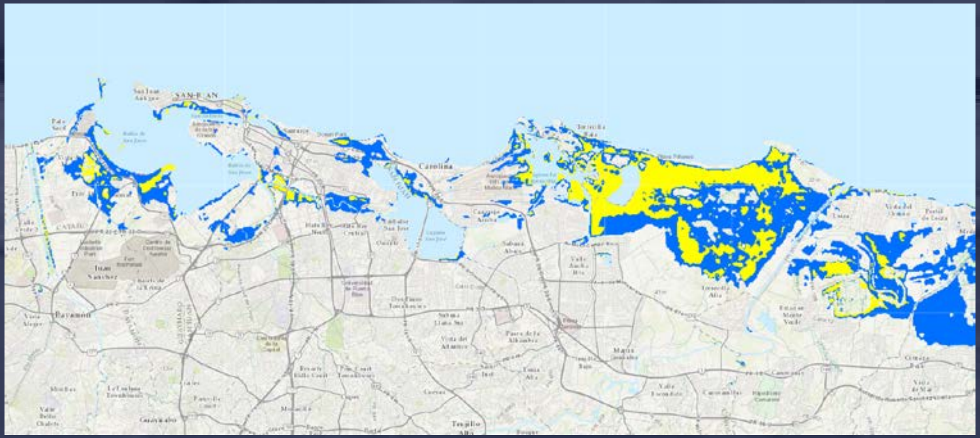
Bahamas Storm Surge Project Phases

Phase 0 2019-2020	Phase 1 2021	Phase 2 2022	Phase 3 2023	Phase 4 2024
Project Scoping and Preparation:	**Project Planning and Design:**	**System Development & Validation:**	**Postprocessing and Distribution:**	**System Integration and Training:**
Stakeholder meetings & workshop (Barbados)	Initial project design/setup	Final bathy/topo processing	MOMs/MEOW creation, QA/QC, post-processing, inundation mapping	System implementation, project evaluation, specialized training workshop
WRN/Storm Surge dual track established	Establish definitive National Agreement	Final SLOSH model configuration and testing.	Transmit GIS data and HVX integration	Fully deploy for hurricane season
	Data acquisition and processing	Develop specialized training needs & requirements	Test/evaluate for hurricane season	Project evaluation and recommended application to region (RA-IV)

Dissemination and Data Availability

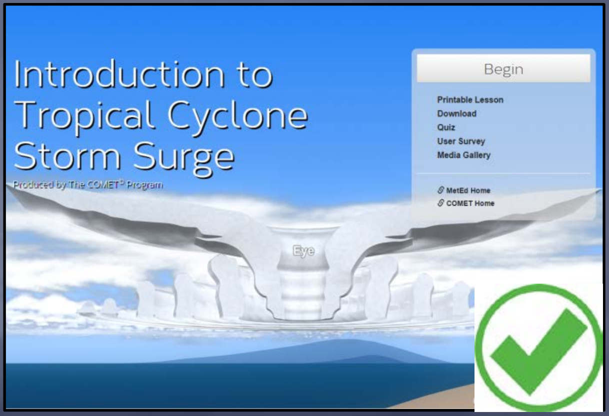
- MEOWs: GIS files provided to the Government of the Bahamas
- NHC will host the CIFDP-C MOMs on an online web portal for high-resolution inundation mapping
    - Provide GIS data
    - Map services

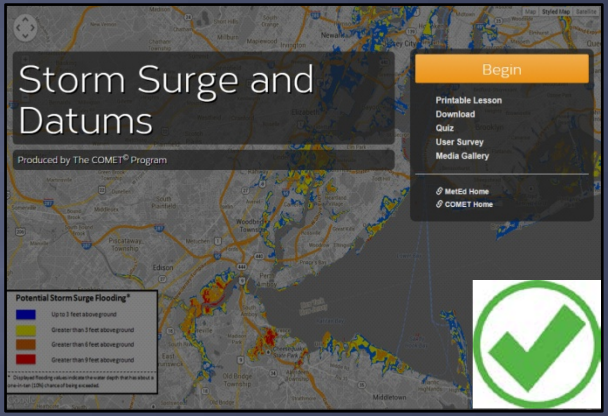




Existing Forecaster and Civil Defense Training Modules

Tropical Cyclone Forecast Uncertainty





Storm Surge Forecasting