STORM SURGE

Introduction to Storm Surge and Storm Surge Forecasting

Heather Nepaul – Storm Surge Specialist

STORM SURGE
Hurricane Ian

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

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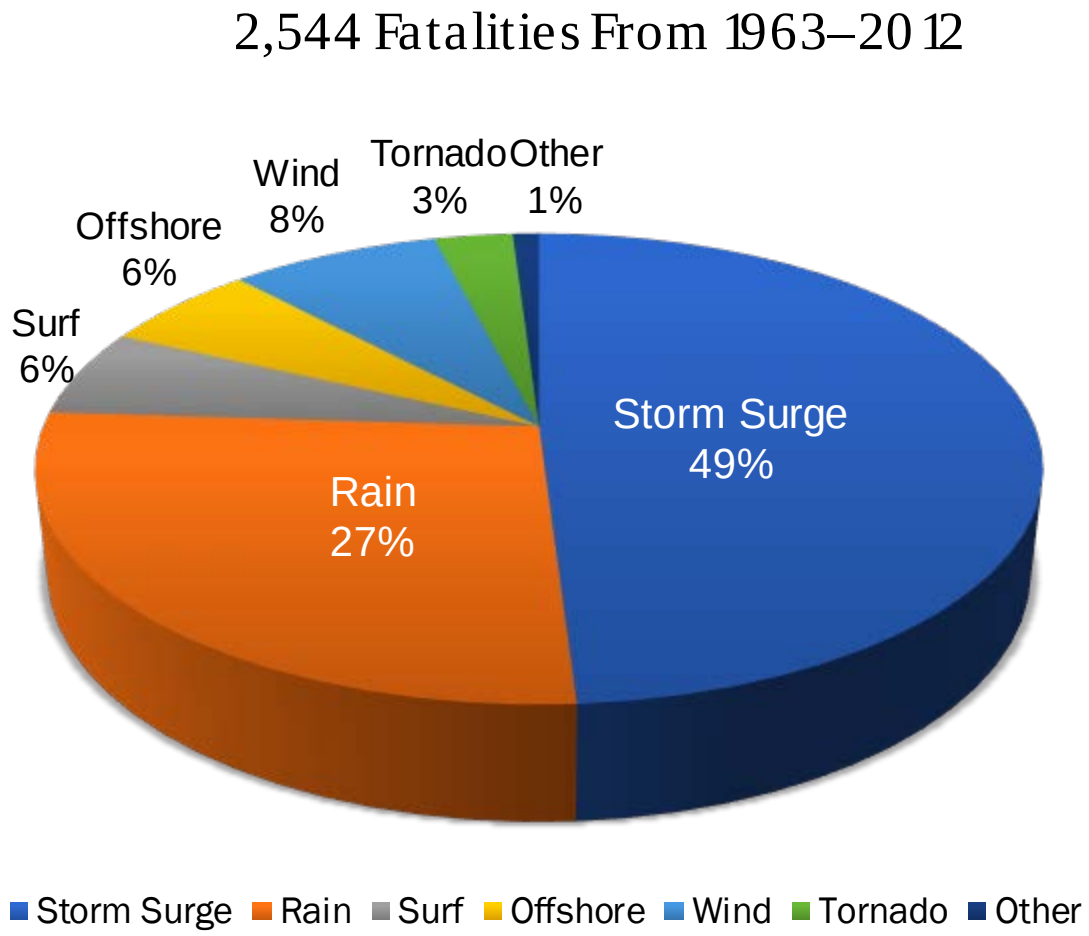
The Danger of Storm Surge



- 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.

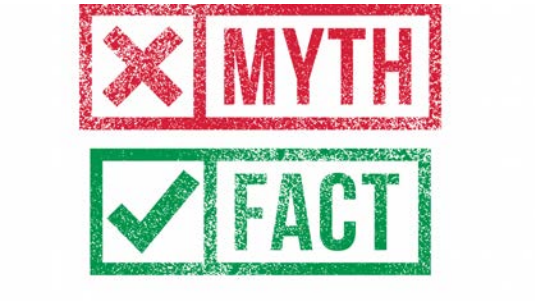
STORM SURGE IMPACTS
Waveland, Mississippi

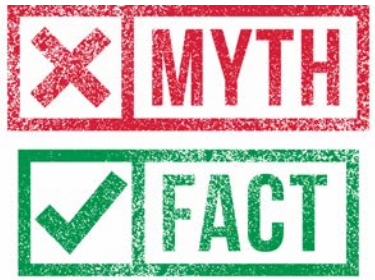
MYTH OR FACT?

Inland

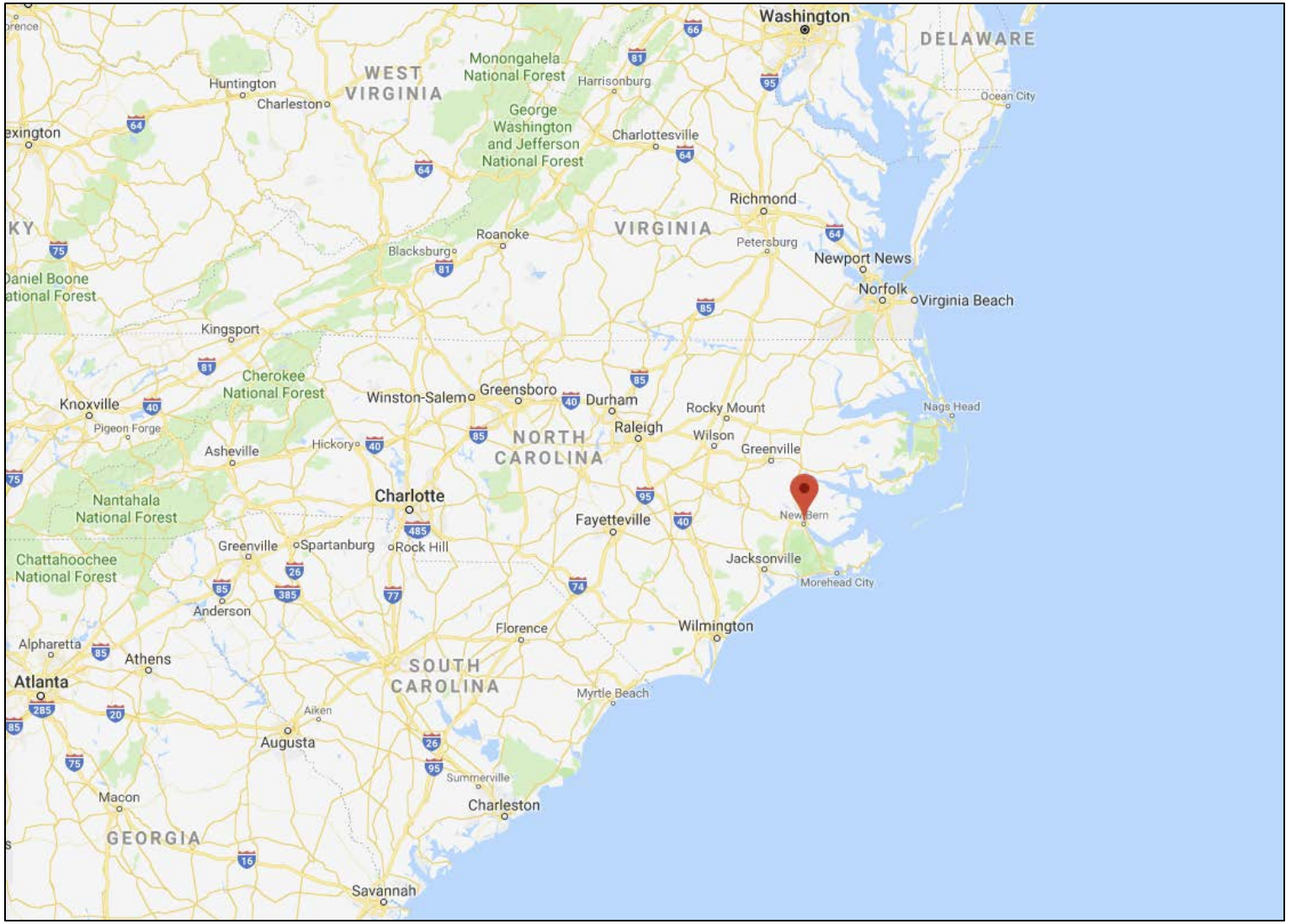
I live miles from the beach, so storm surge is not my problem.

Myth





New Bern, NC – Hurricane Florence



New Bern, NC – Hurricane Florence

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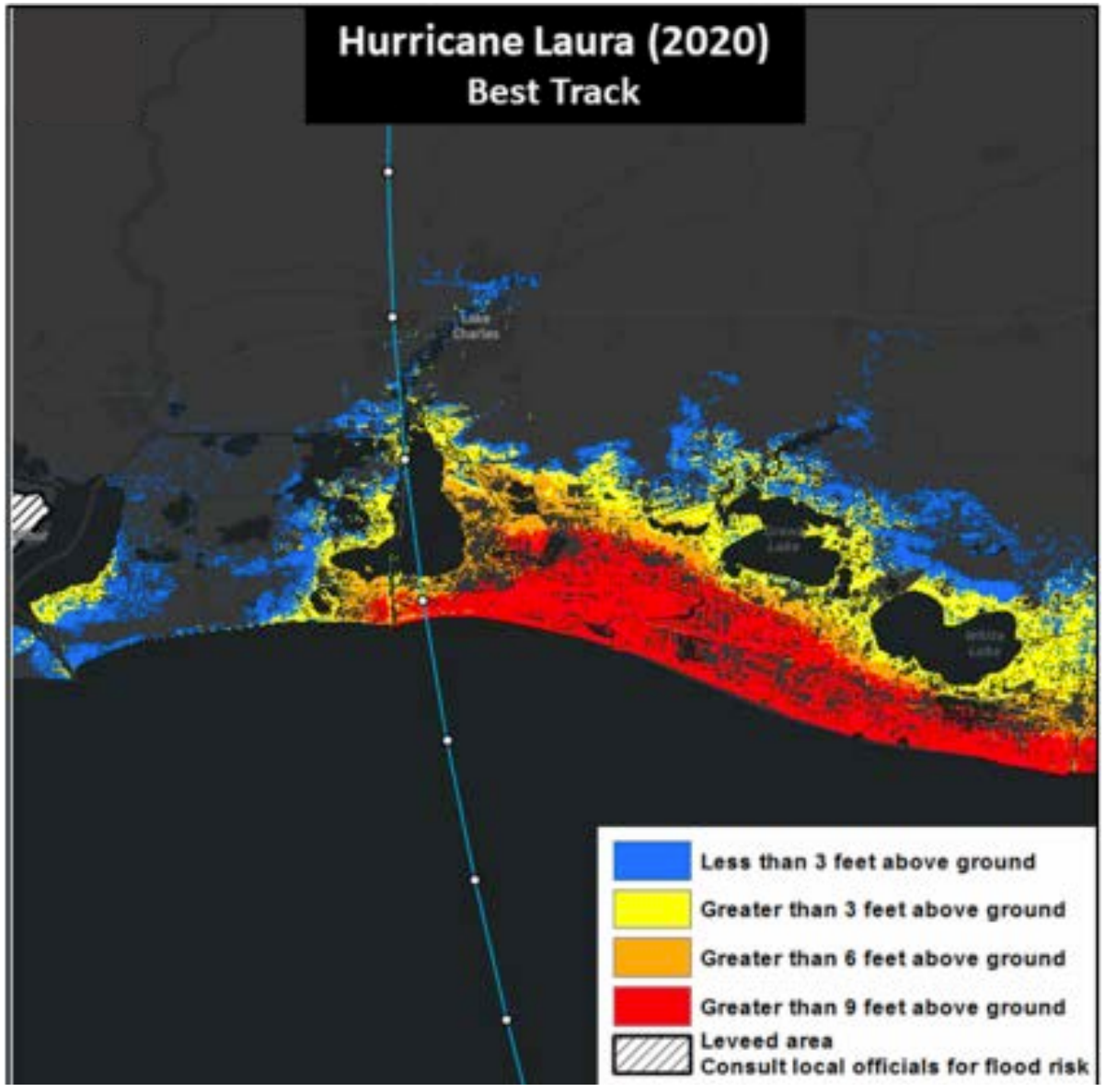
Hurricane Laura Inundation Depth

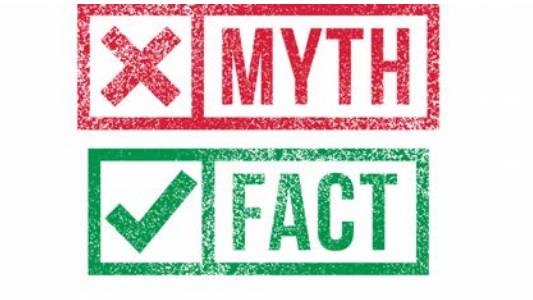


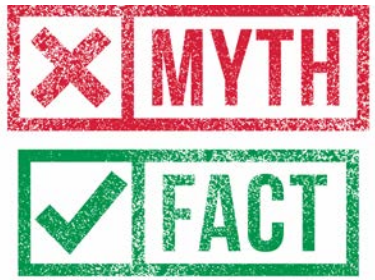
MYTH OR FACT?

Vulnerability

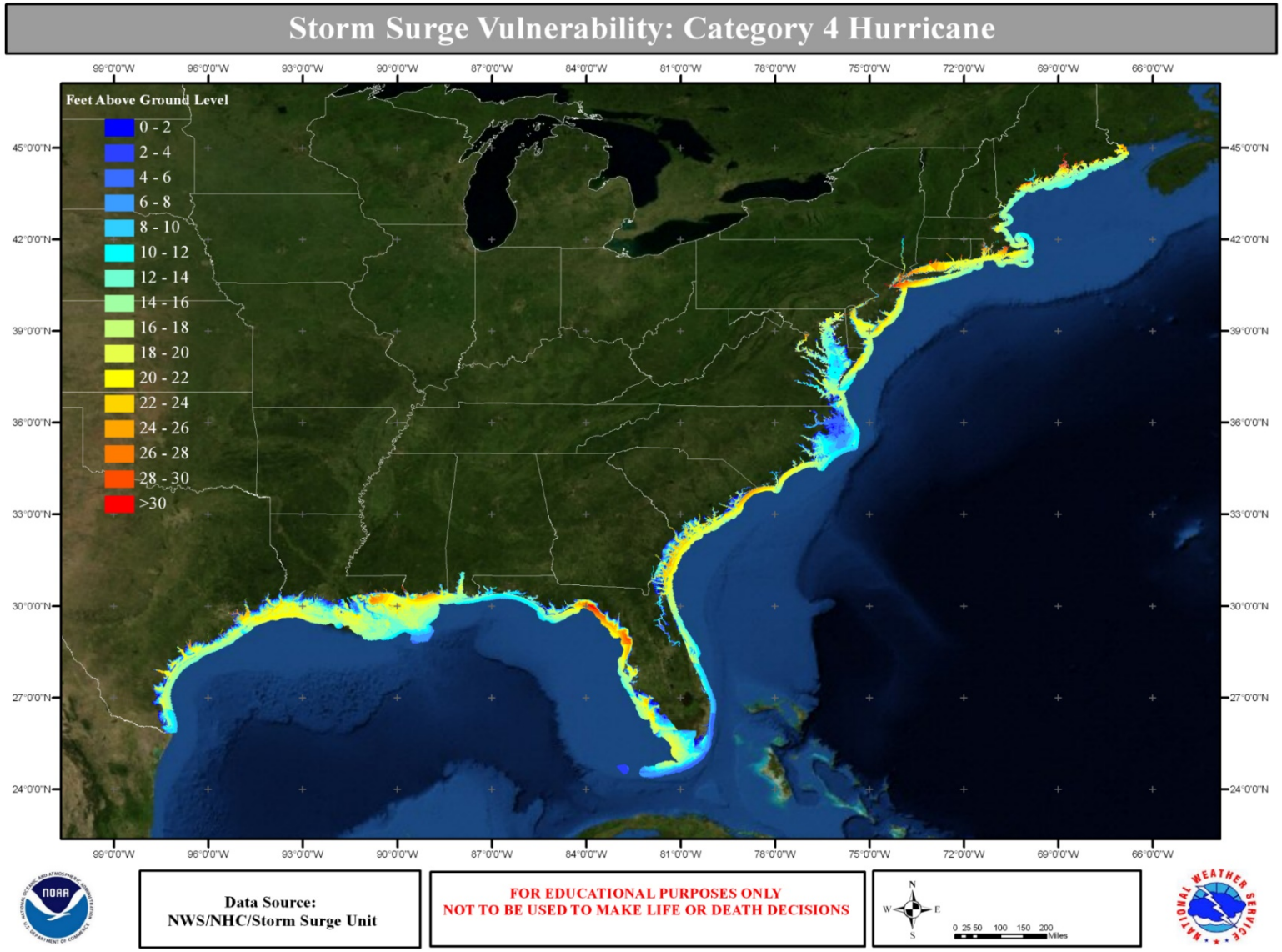
Are some areas more vulnerable to storm surge than others?

Fact





Storm Surge Vulnerability Example

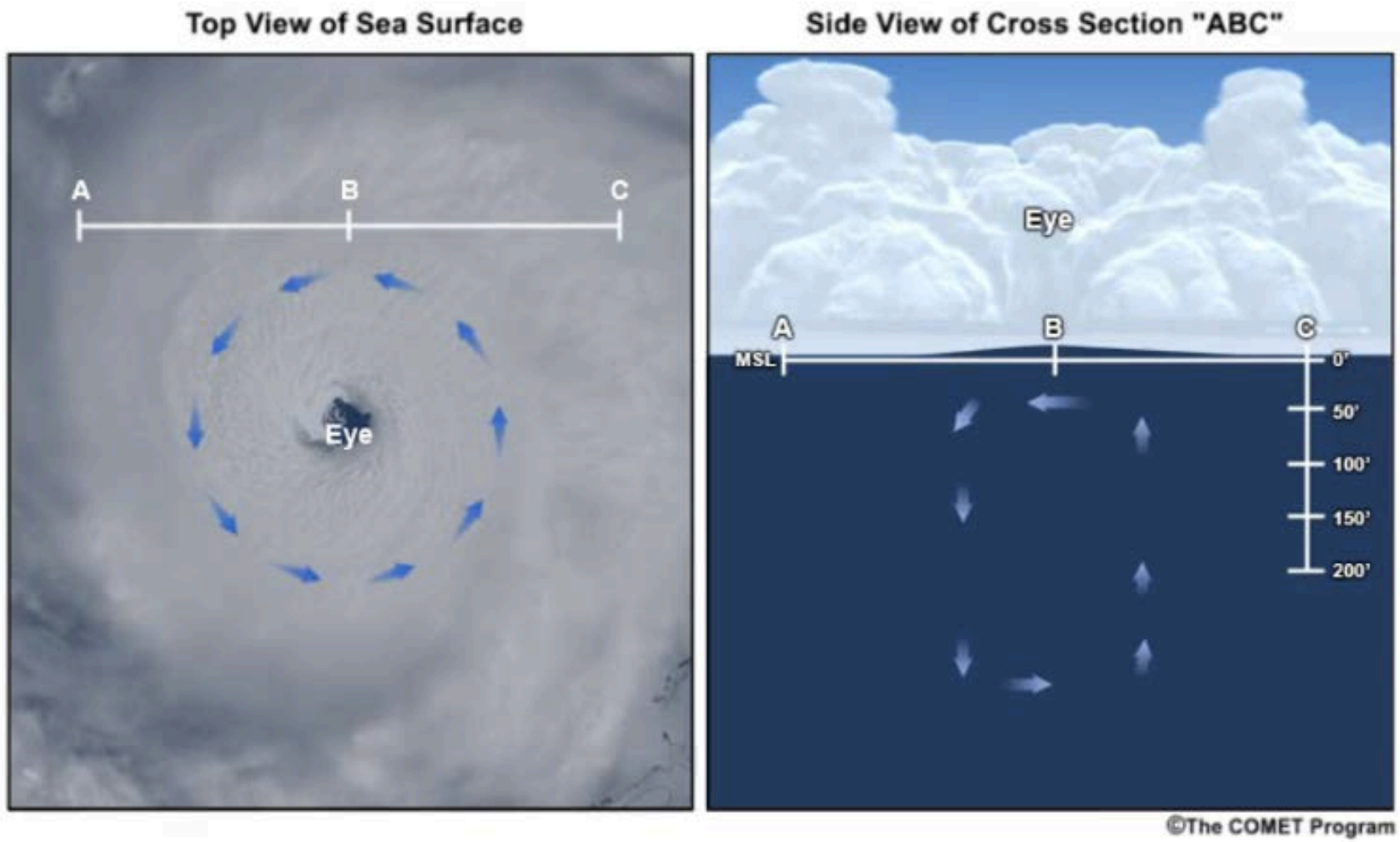


STORM SURGE

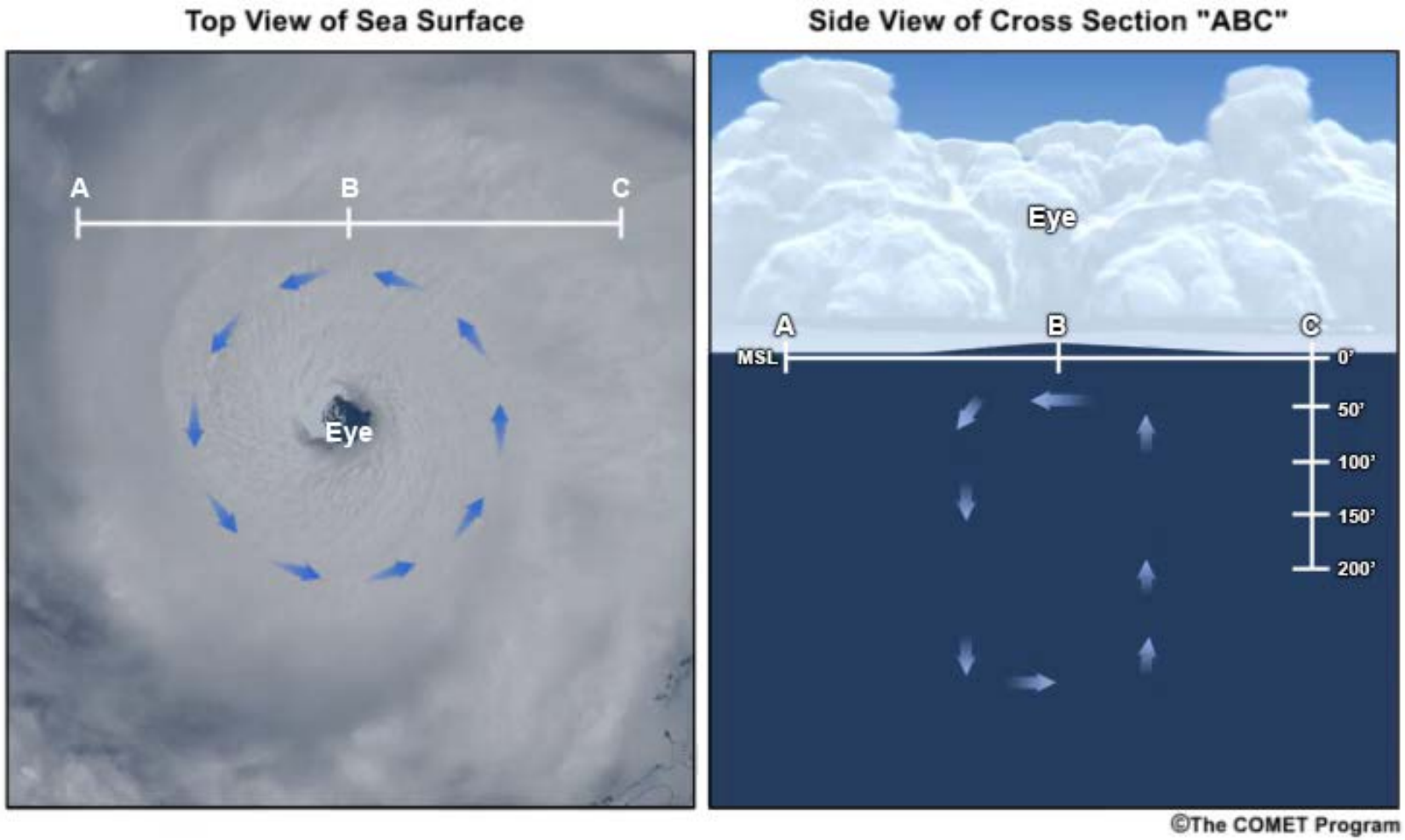
Where does storm surge occur?

What exactly is storm surge and how does it work?

Deep Water


Top View of Sea Surface
Side View of Cross Section "ABC"
A
B
C
Eye
Eye
A
B
C
MSL
0'
50'
100'
150'
200'
©The COMET Program

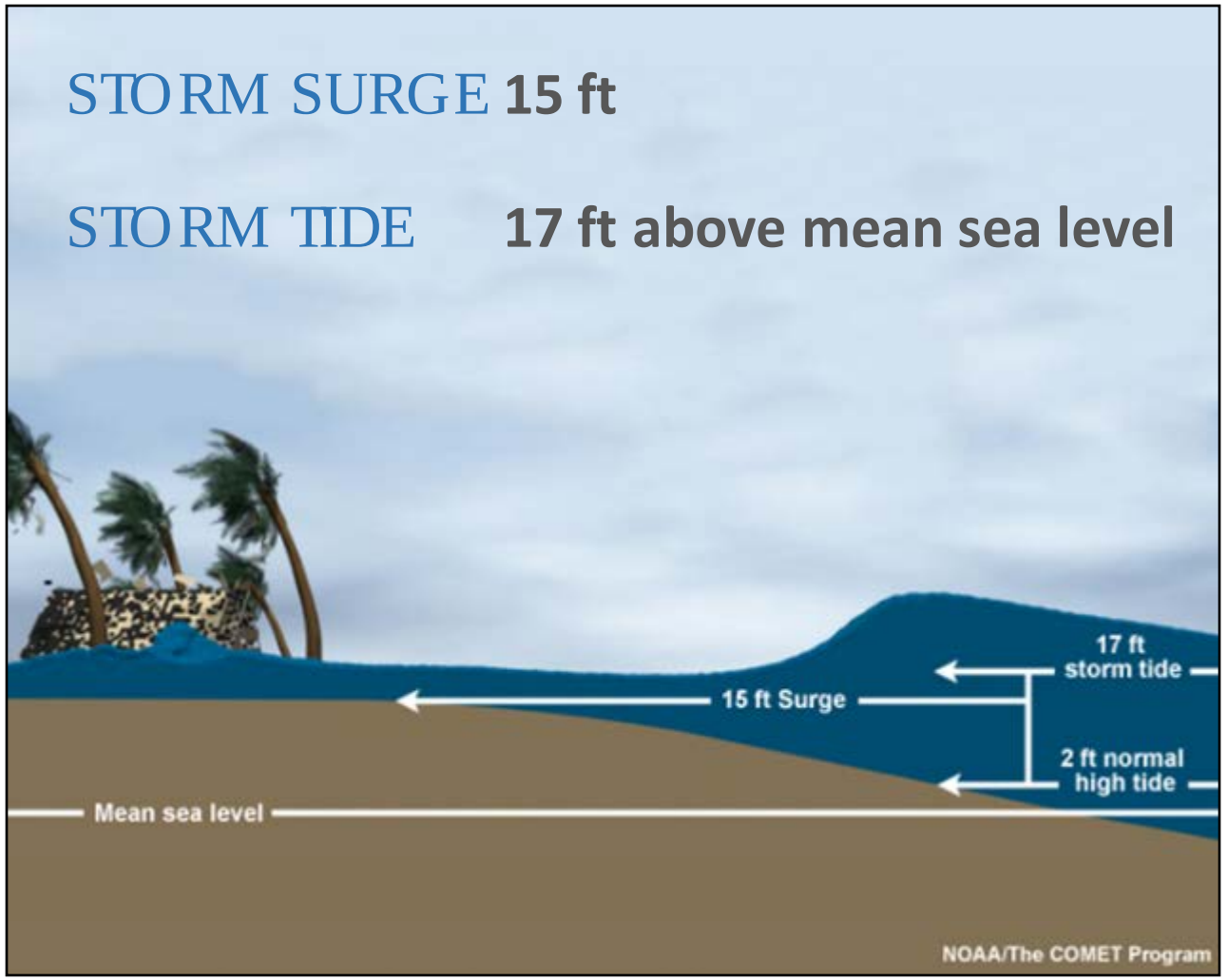
From Deep Water to Shallow Water



STORM SURGE
Storm Surge vs Storm Tide

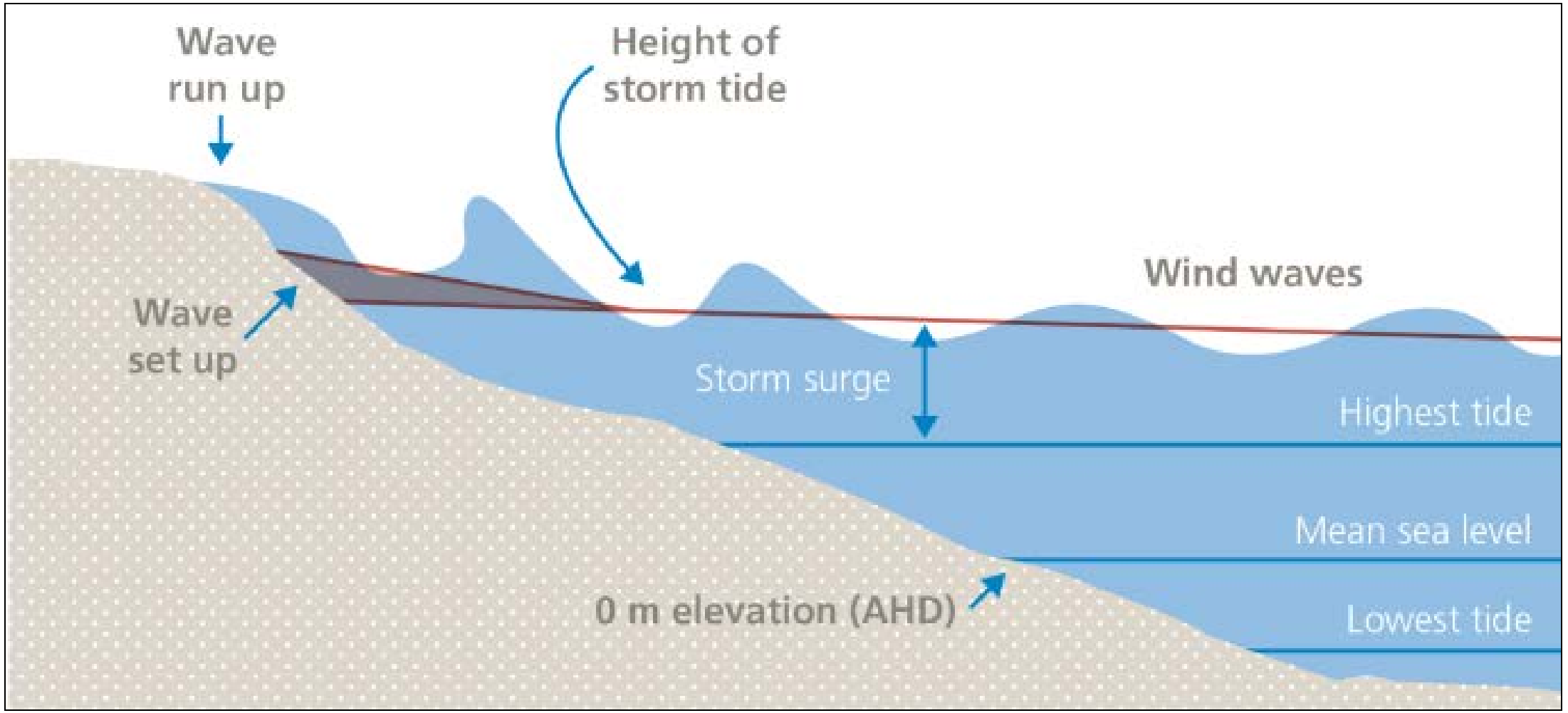
STORM SURGE
An abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

STORM TIDE
Water level due to the combination of storm surge and the astronomical tide.



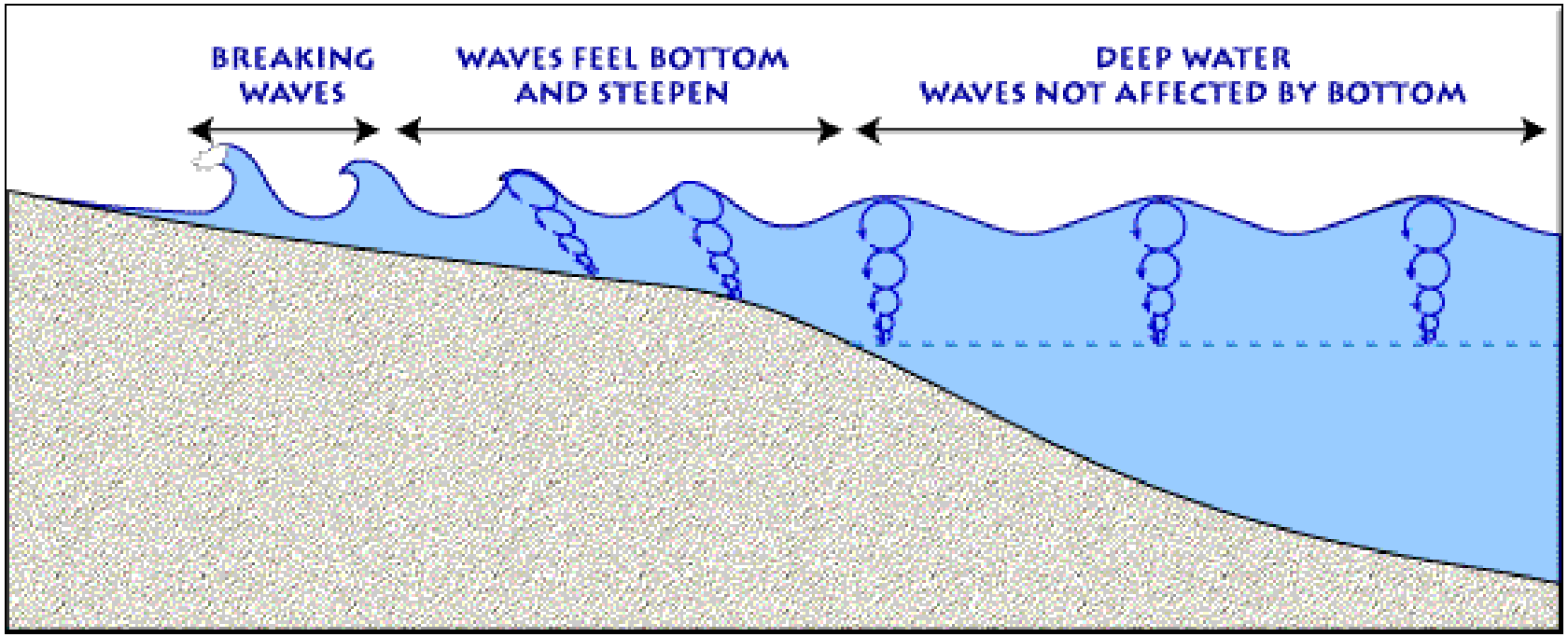
STORM SURGE
Components of 'Total Water Level'

Storm surge + Tides + Wave Setup + Freshwater

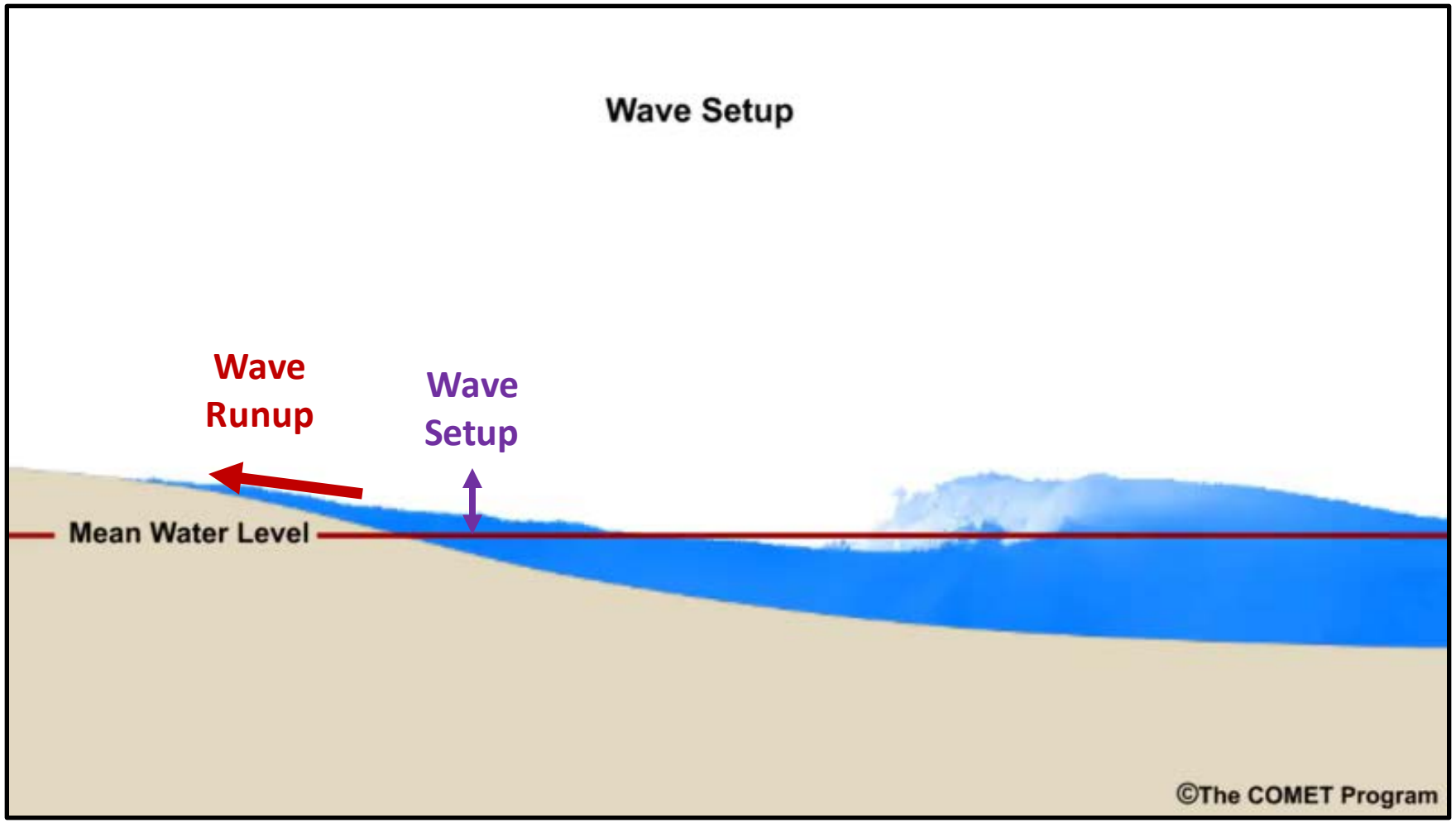


What about waves?

- Breaking waves also contribute to the total water level through wave runup/setup
- WAVE RUNUP is the time-varying fluctuation of water-level elevation at the shoreline due to wave breaking
- WAVE SETUP is the time-averaged water level rise due to wave breaking
- The magnitude of both runup and setup are related to offshore wave period, wave height, and shelf slope



Wave Runup and Setup

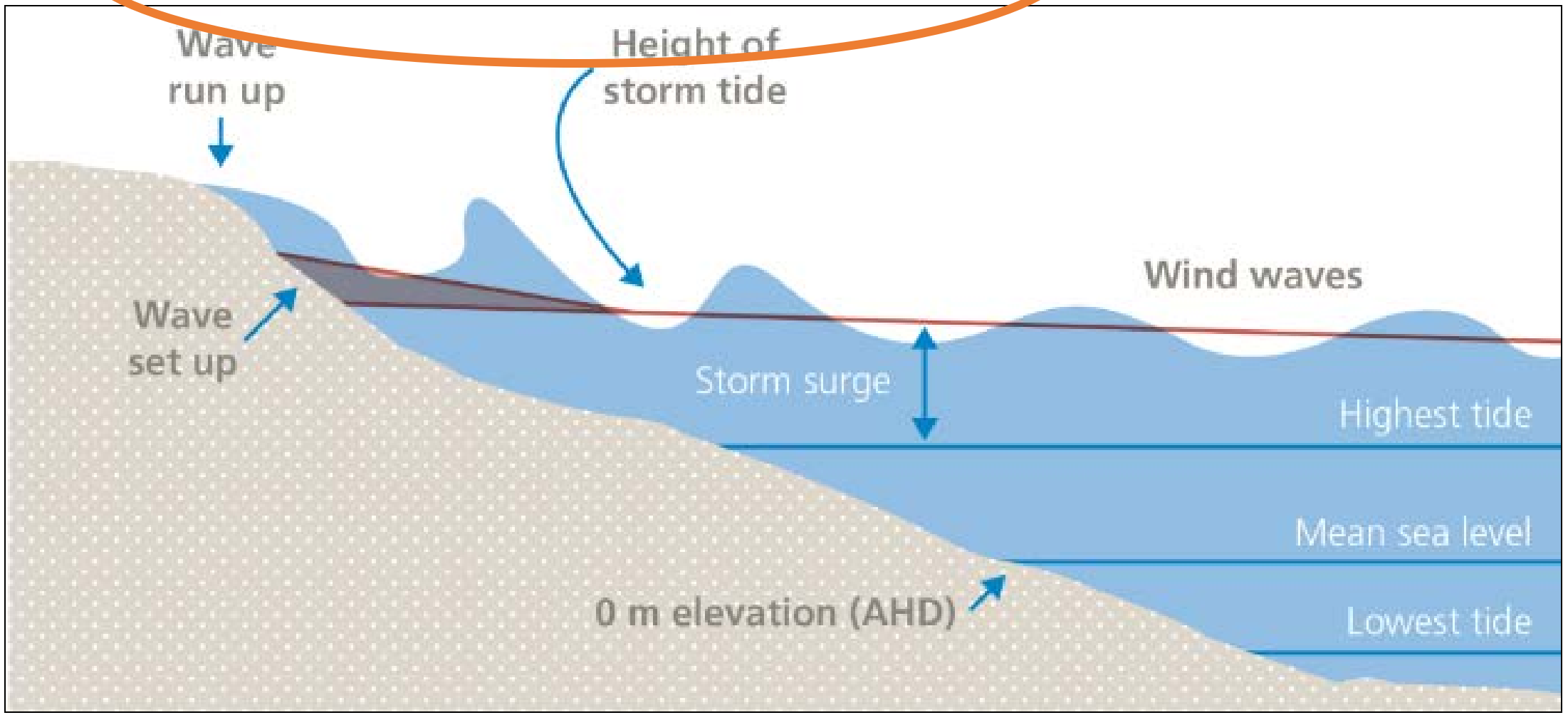


Freshwater Input

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

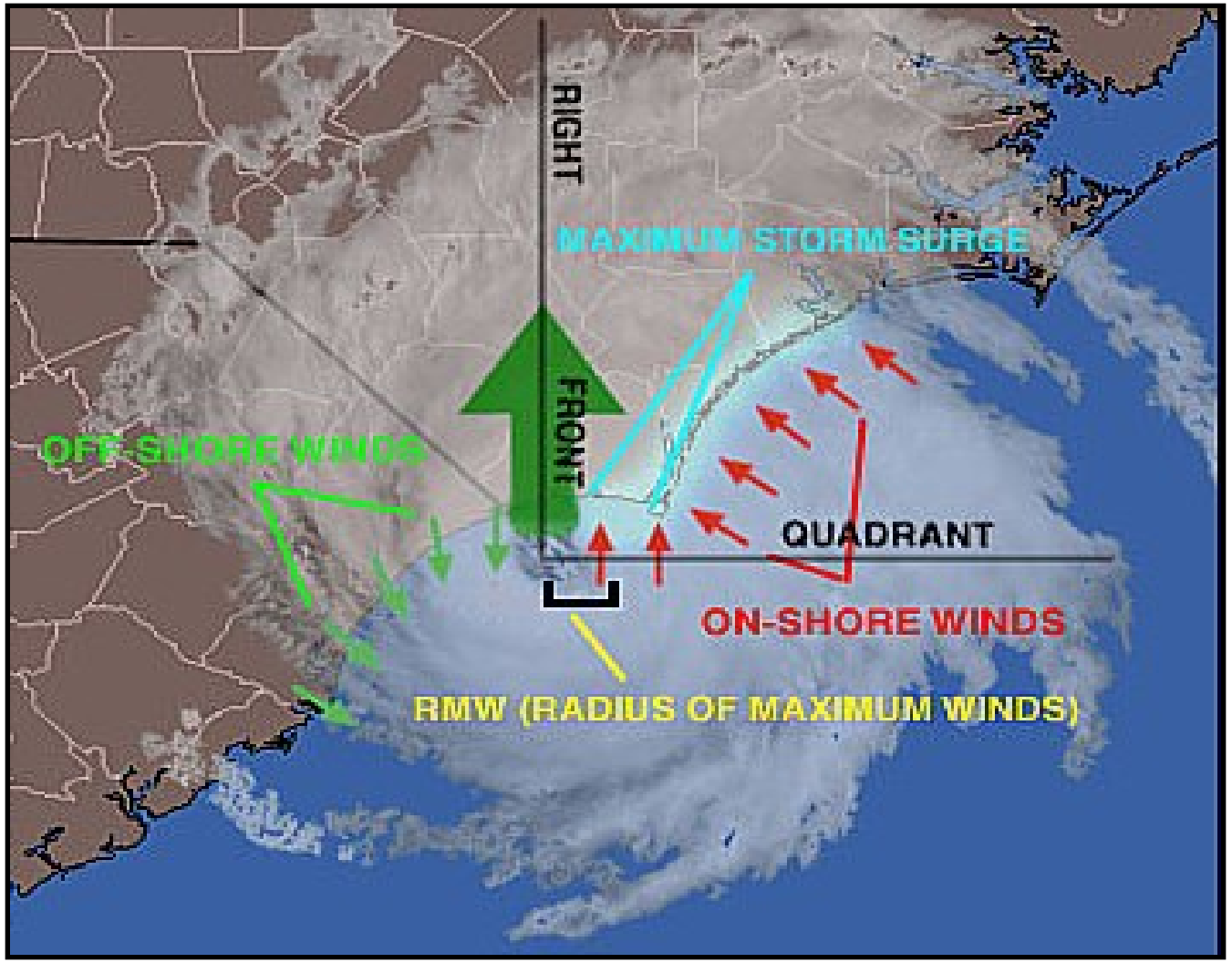
STORM SURGE
Components of 'Total Water Level'

Storm surge + Tides + Wave Setup + Freshwater



What are the factors that affect storm surge?

Understanding Surge



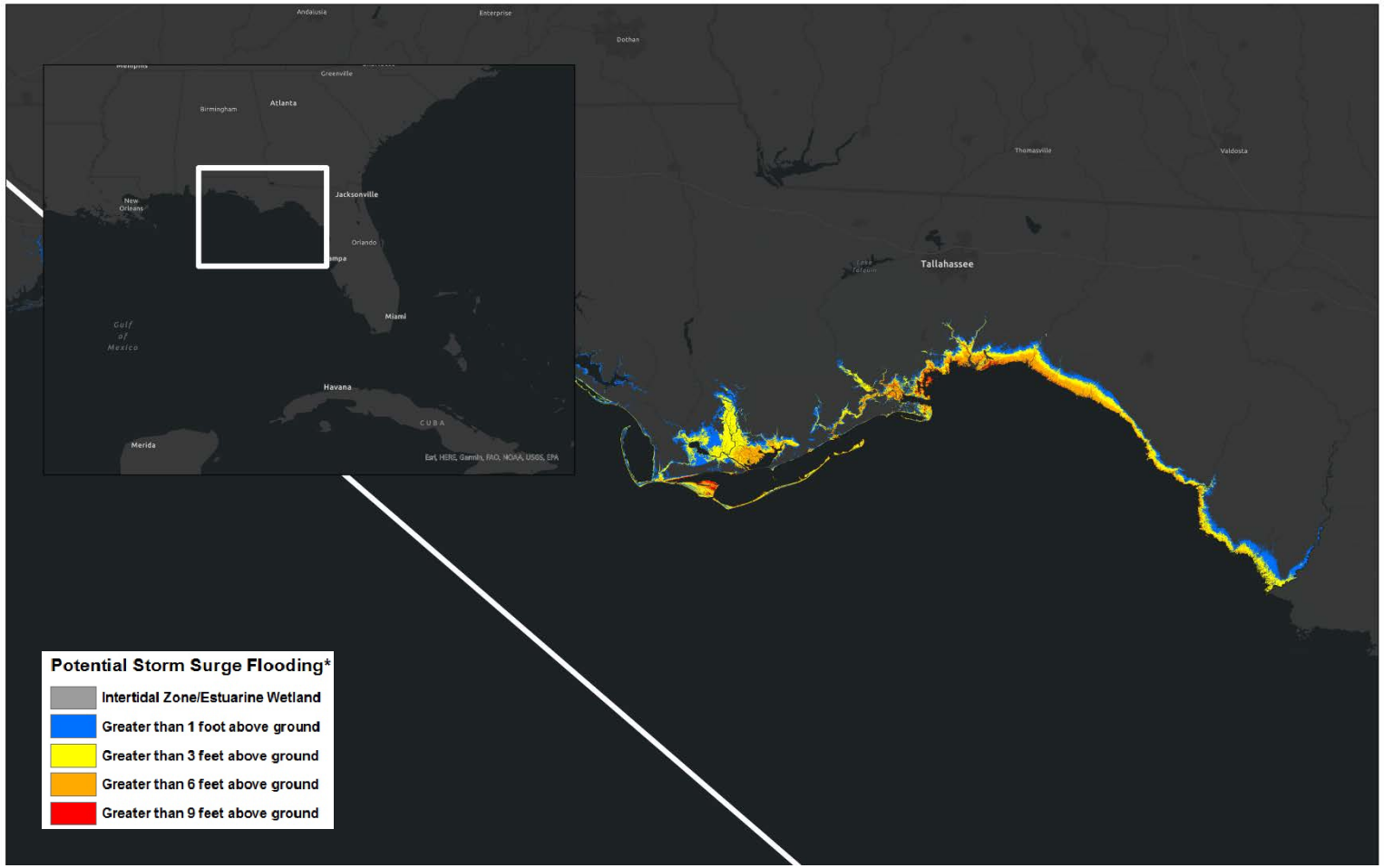
Factors Affecting Storm Surge

STORM SURGE FACTORS

- **Intensity**
  Stronger storm = More storm surge
- **Size (Radius of Maximum Winds)**
  Larger = More storm surge
- **Forward Speed**
  Slower storm = Storm surge farther inland
- **Angle of Approach**
  Alters focus of storm surge
- **Width and Slope of Shelf (Bathymetry)**
  Gradual sloping shelf = More storm surge

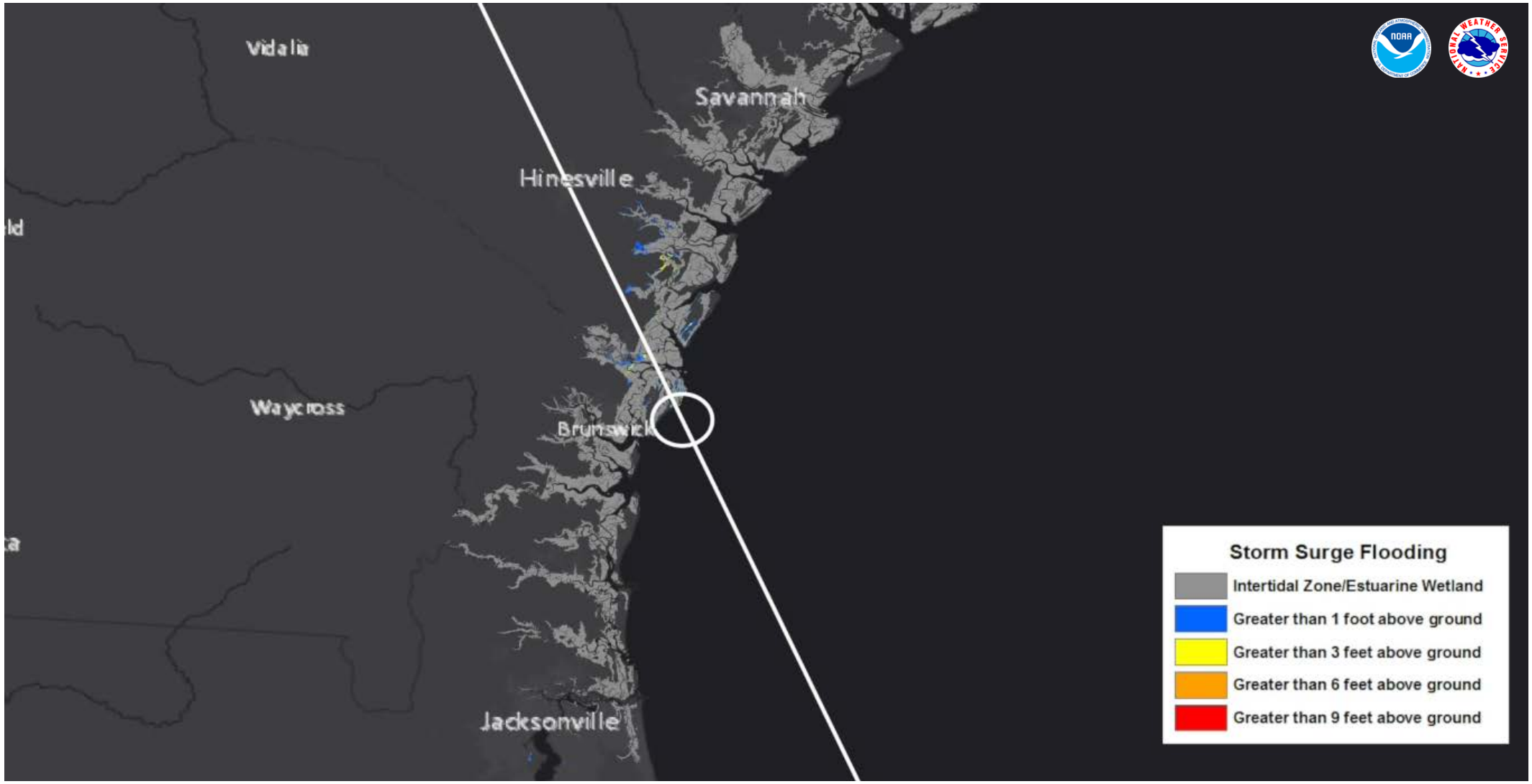
STORM SURGE FACTORS
What's the effect of intensity? (wind speed)

Category 4



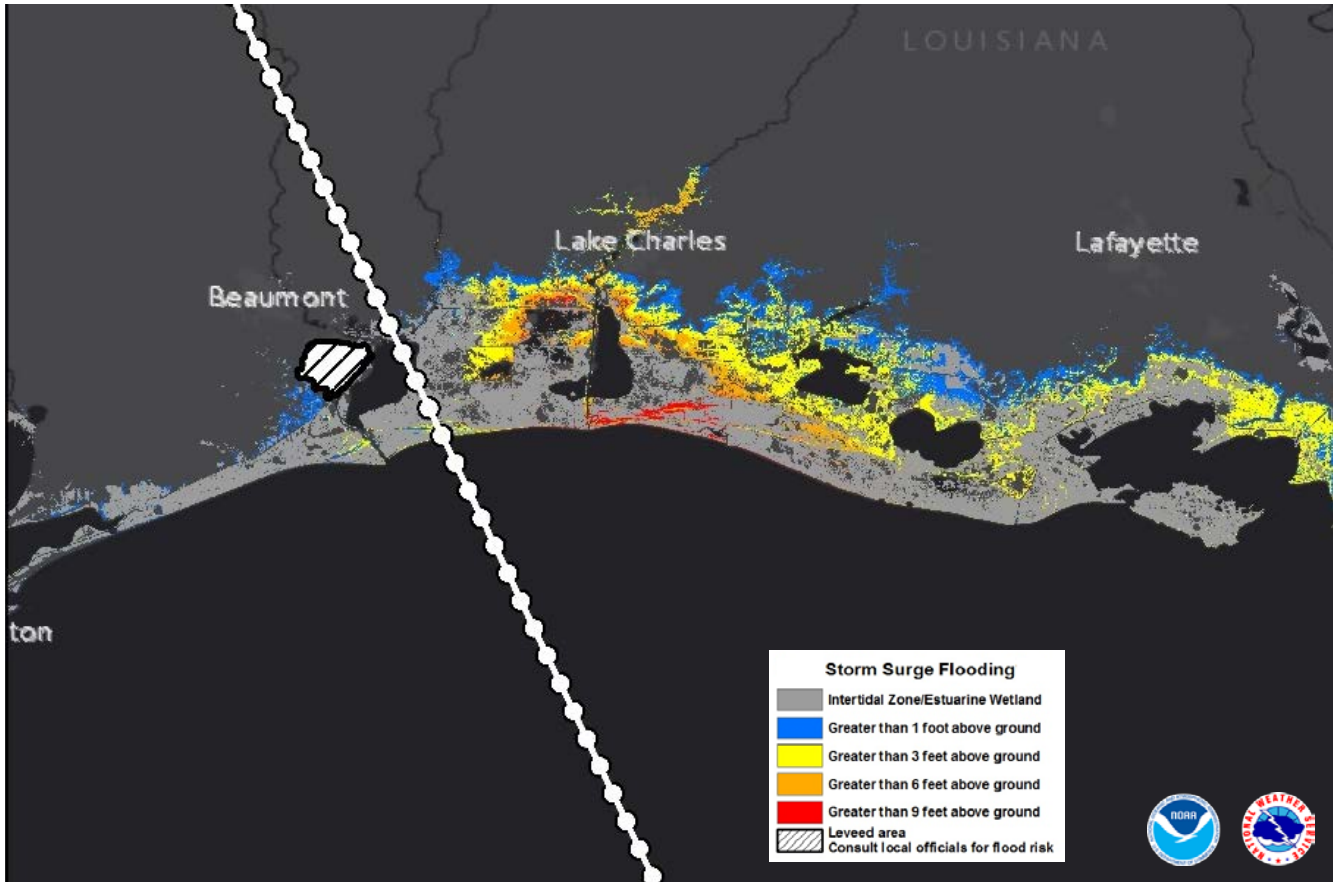
STORM SURGE FACTORS
What's the effect of size?

STORM SURGE FACTORS
What's the effect of size?



STORM SURGE FACTORS
What's the effect of forward speed?

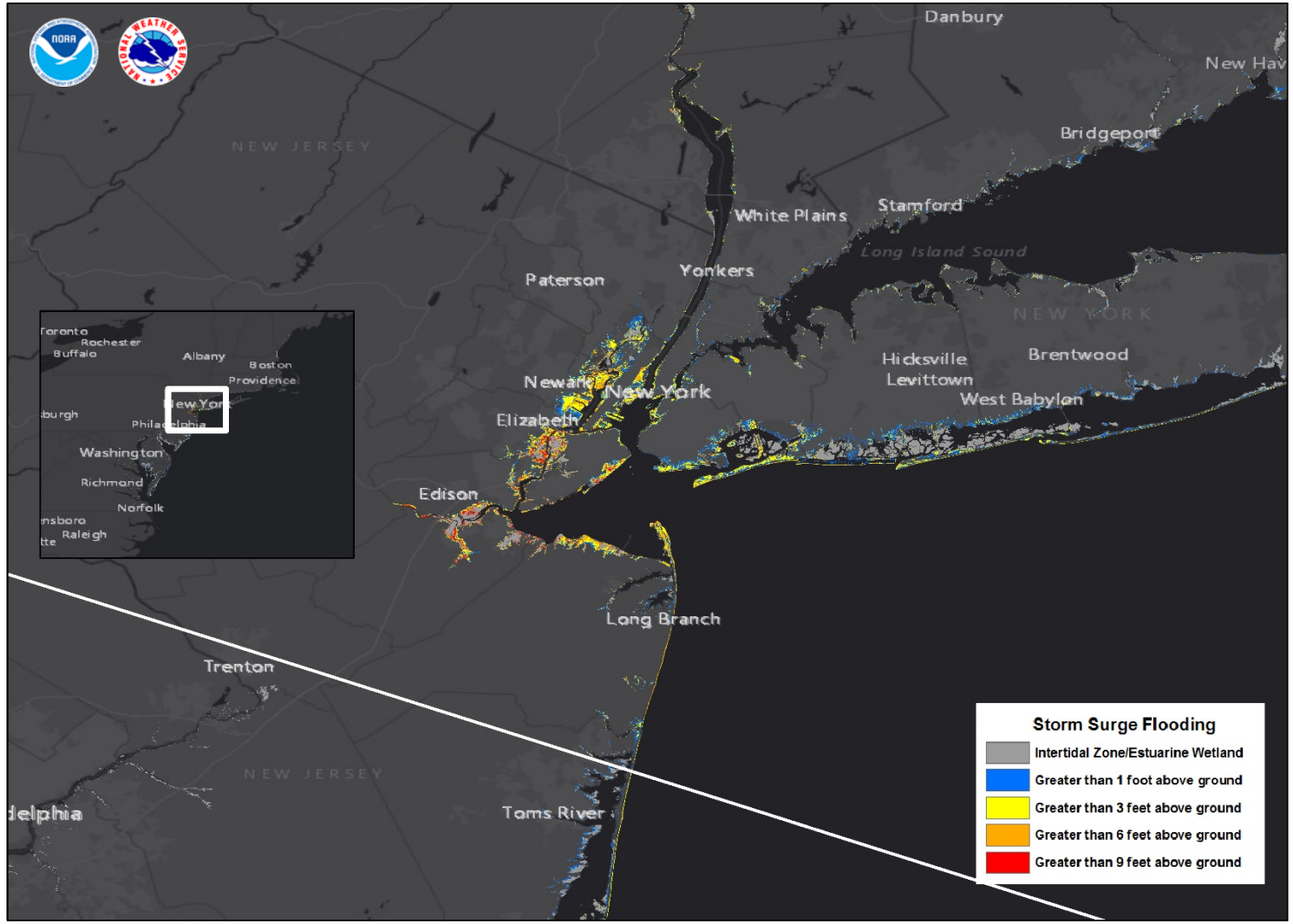
Forward Speed
25 mph



Faster Storms:
Higher maximum at coast

Slower Storms:
Farther inland penetration

STORM SURGE FACTORS
What's the effect of angle of approach?



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

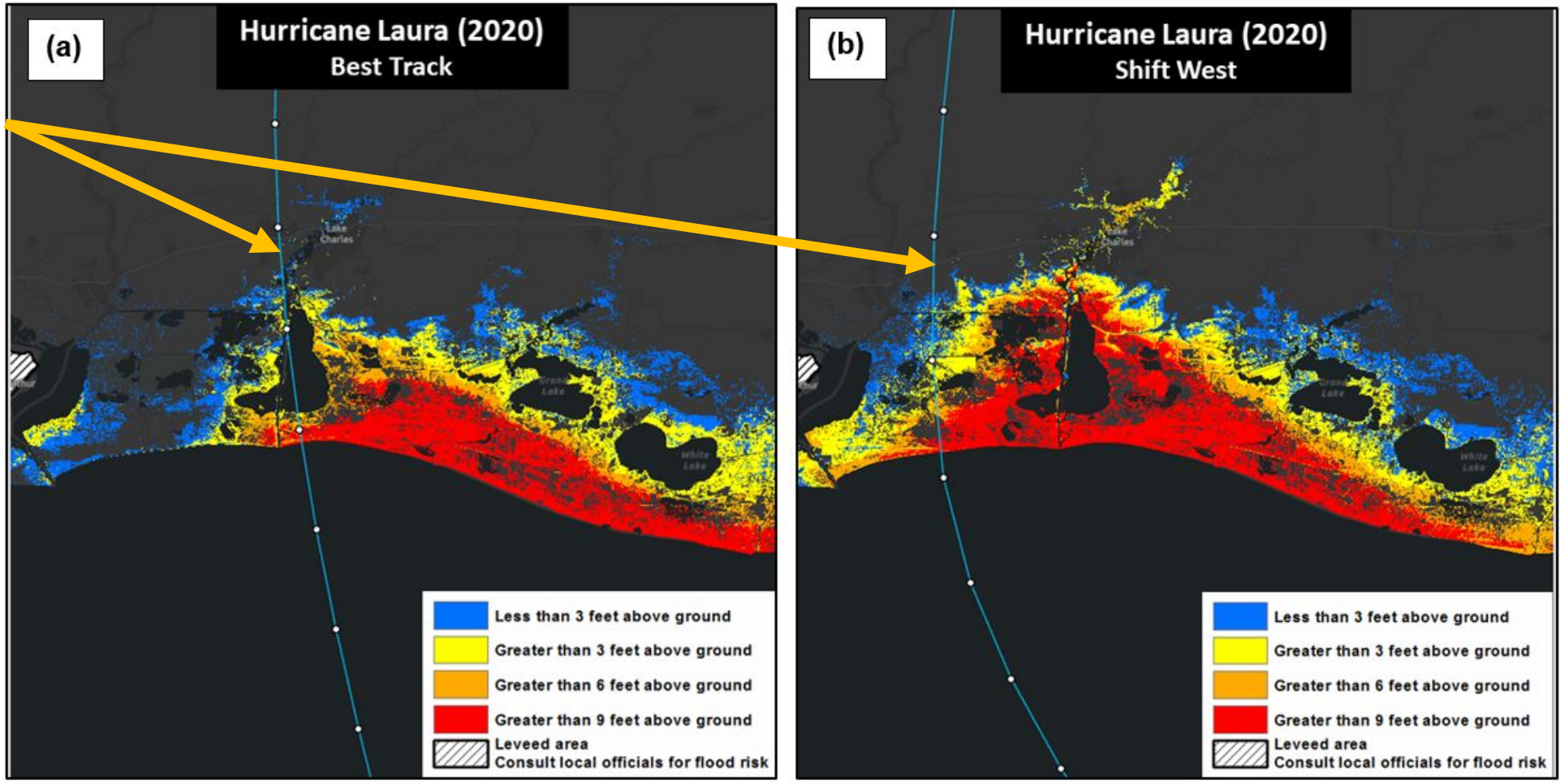
Angle of Approach

NNW

WNW

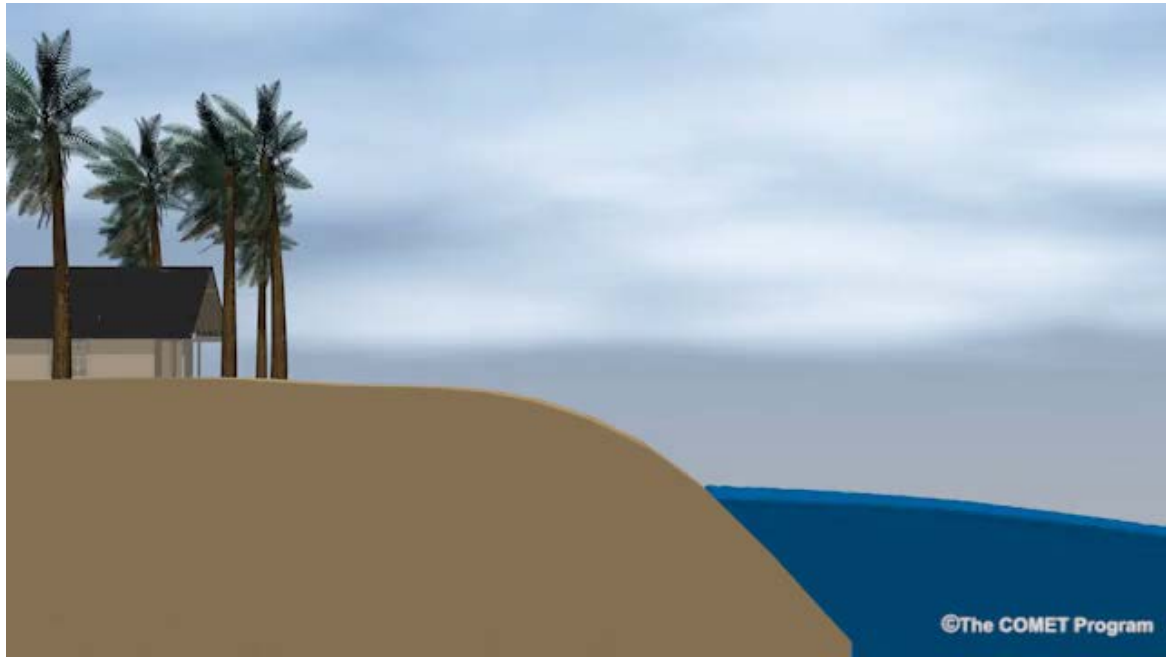
Factors Affecting Storm Surge

A **slight shift in hurricane track** can make a dramatic difference in storm surge at a specific location



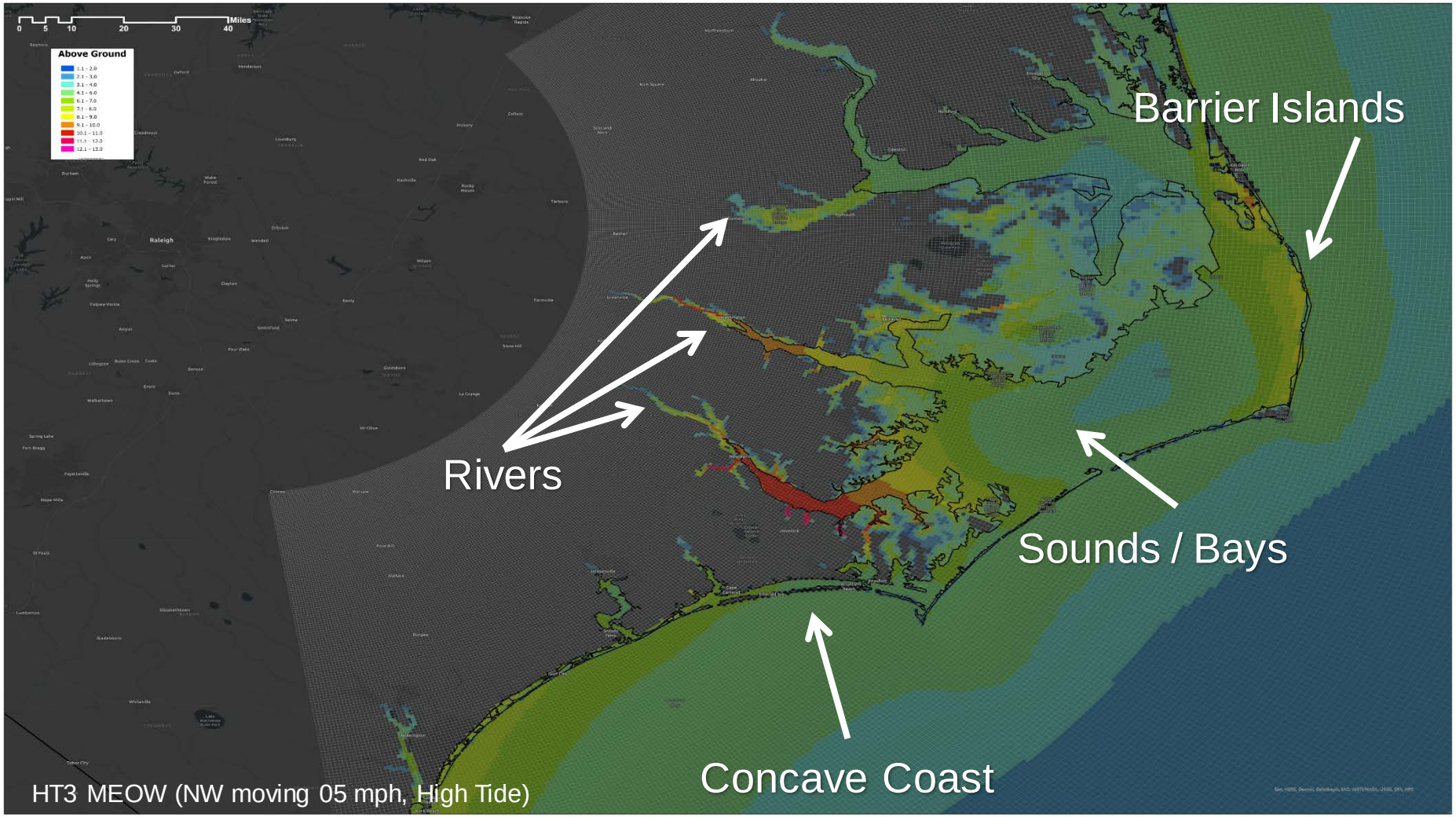
STORM SURGE
What's the effect of width/slope of shelf?

Wide shelf – Gentle slope



Narrow shelf – Sharp slope

STORM SURGE
What's the effect of local features along the coast?

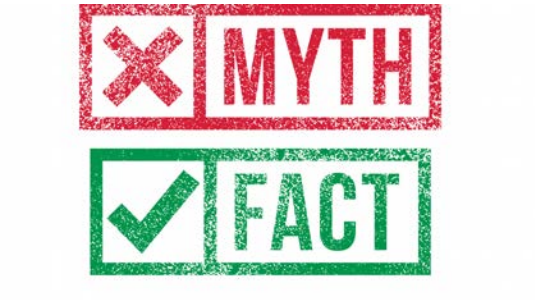


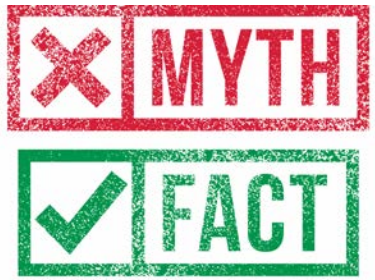
MYTH OR FACT?

Storm Strength

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

Myth





No More Surge in the Saffir-Simpson Scale!

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

Category	Wind speed			Storm surge	
	mph	km/h	kn	ft	m
Five	≥ 156	≥ 250	≥ 136	> 18	> 5.5
Four	131–155	210–249	114–135	13–18	4.0–5.5
Three	111–130	178–209	96–113	9–12	[illegible]
Two	96–110	154–177	83–95	6–8	1.8–2.4
One	74–95	119–153	64–82	4–5	1.2–1.5
Additional classifications					
Tropical storm	39–73	63–117	35–63	0–3	0–0.9
Tropical depression	0–38	0–62	0–34	0	0

KATRINA (3)
IKE (2)

SANDY (1)
ISAAC (1)

CHARLEY (4)

No Such Thing as "Just a Tropical Storm"

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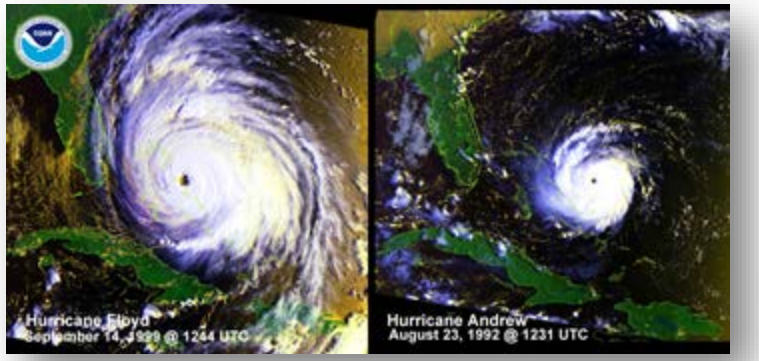
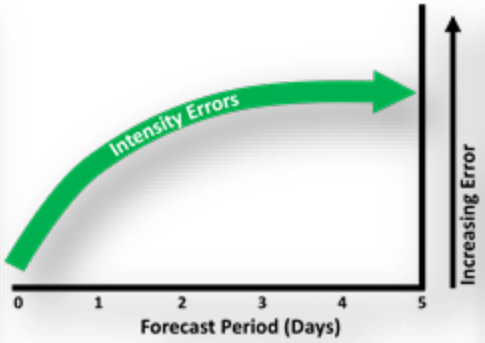
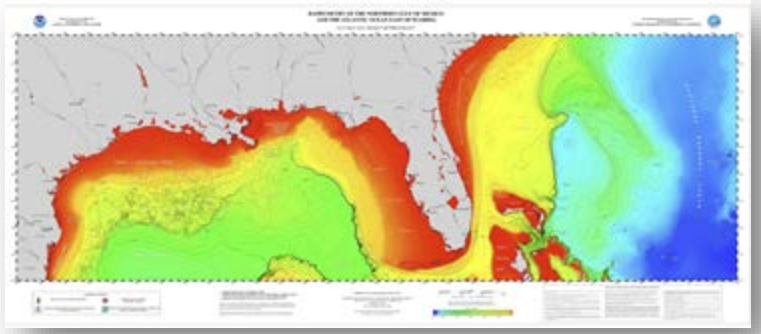
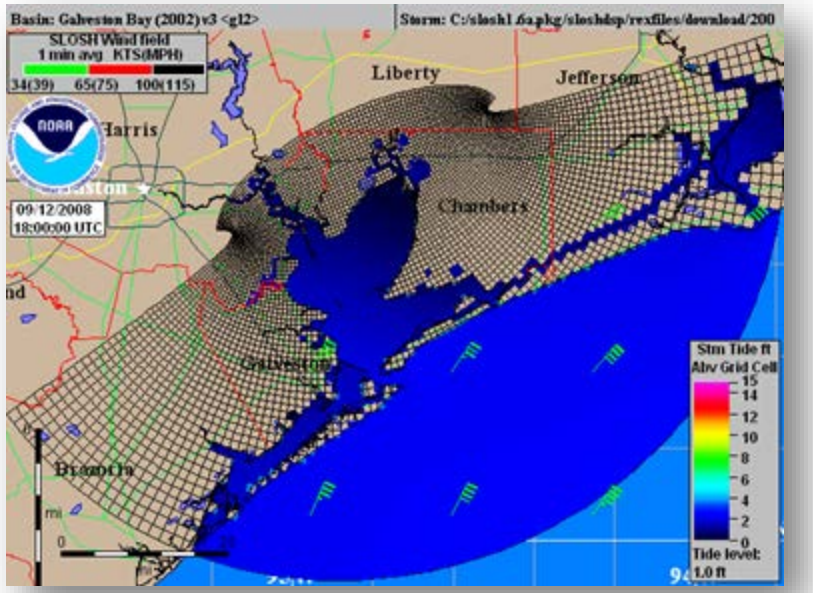
Making the Perfect Storm Surge Forecast





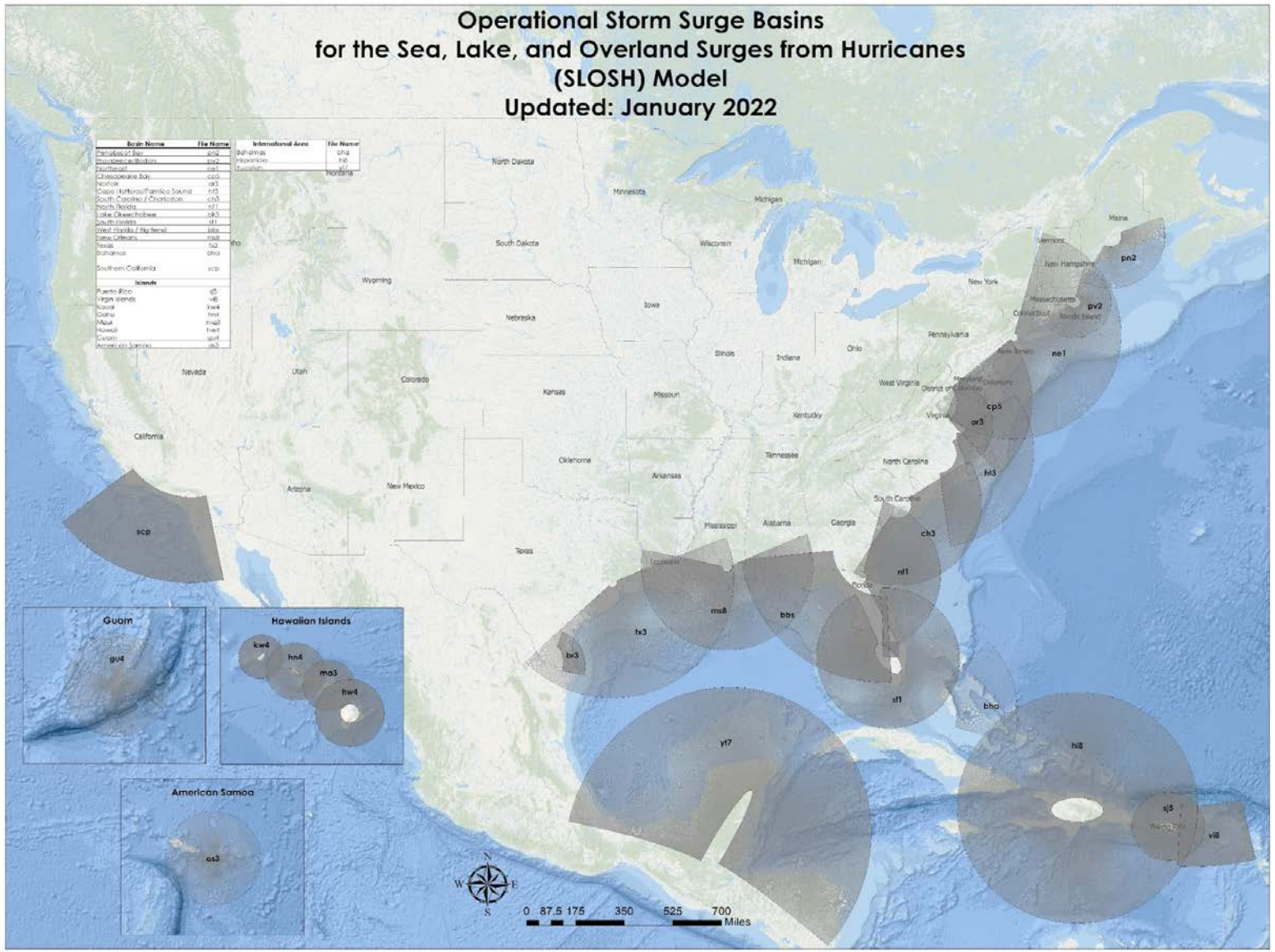




SLOSH MODEL

Sea,
Lake, and
Overland
Surges from
Hurricanes

A numerical model used to estimate storm surge heights for 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 (Psurge)

Potential Storm Surge Flooding Graphic

Storm Surge Watch/Warning

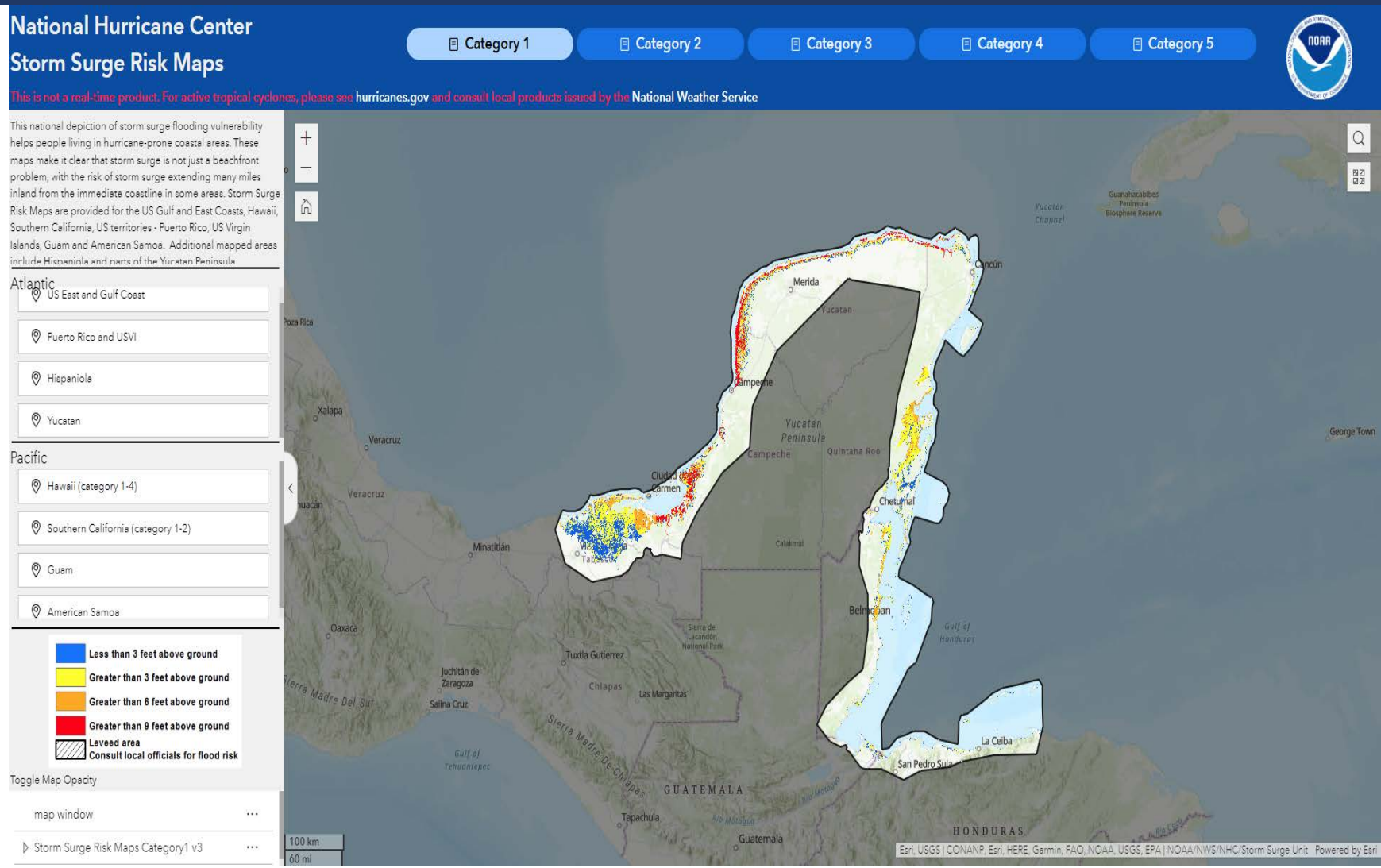
Experimental Peak Storm Surge Graphic

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

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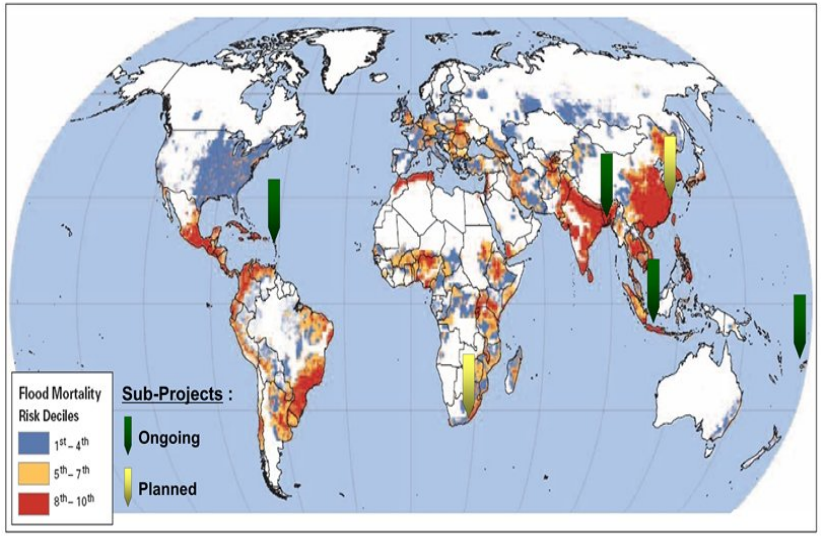
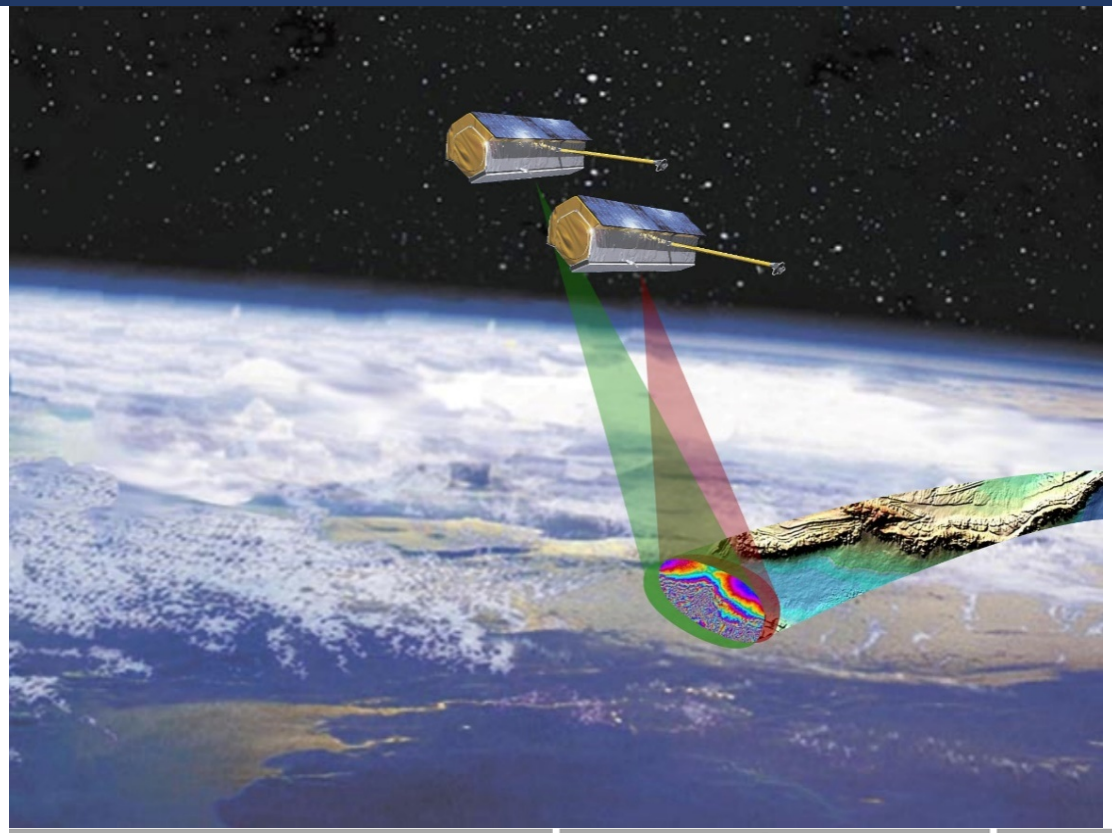
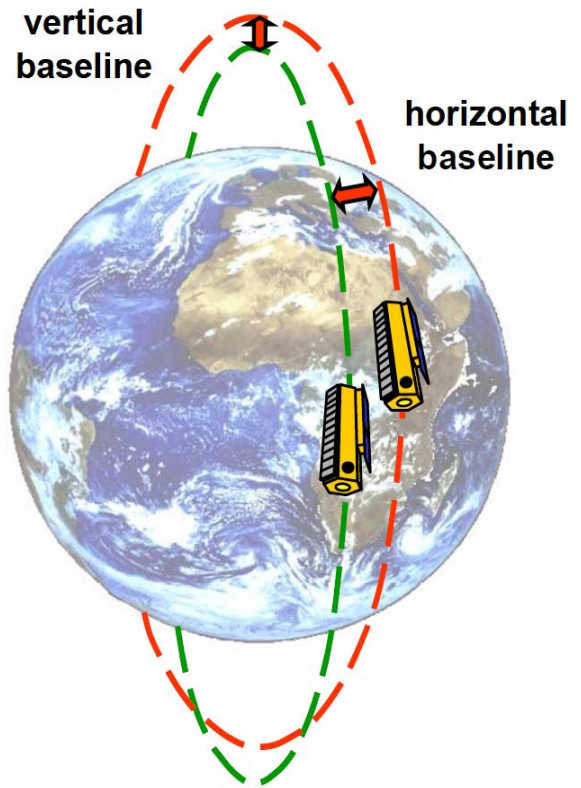
History of CIFDP-C

- 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



Ta n DEM-X

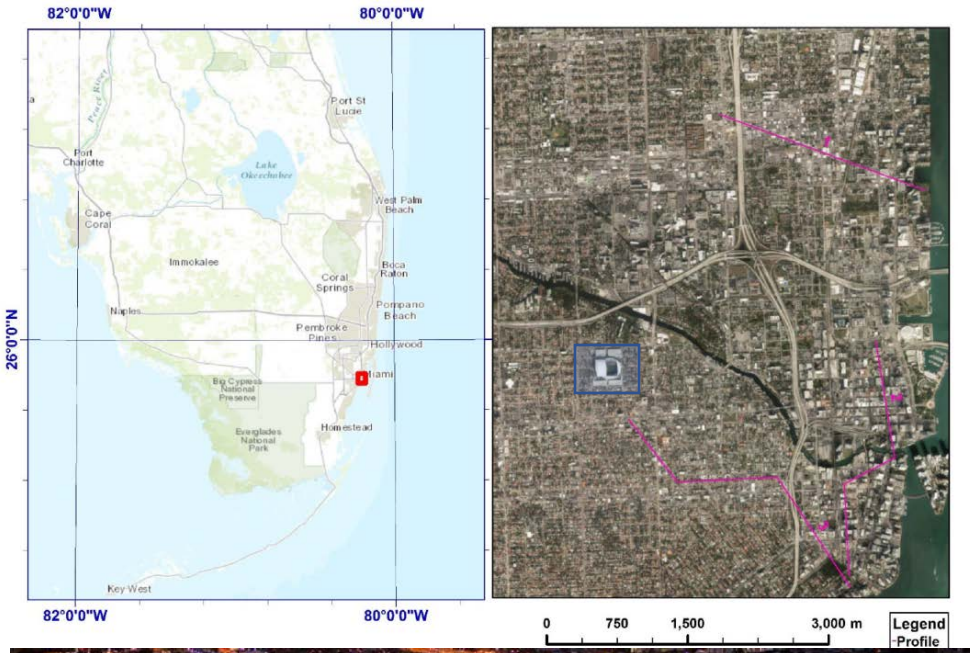


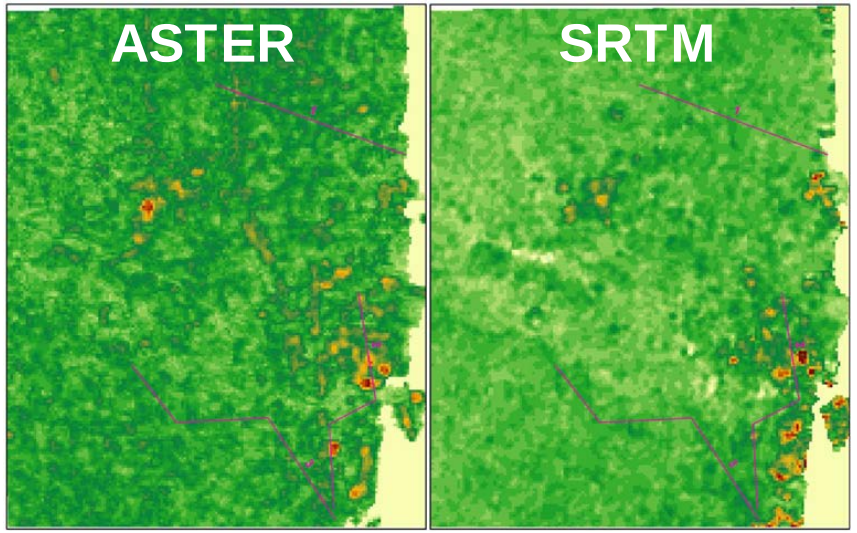


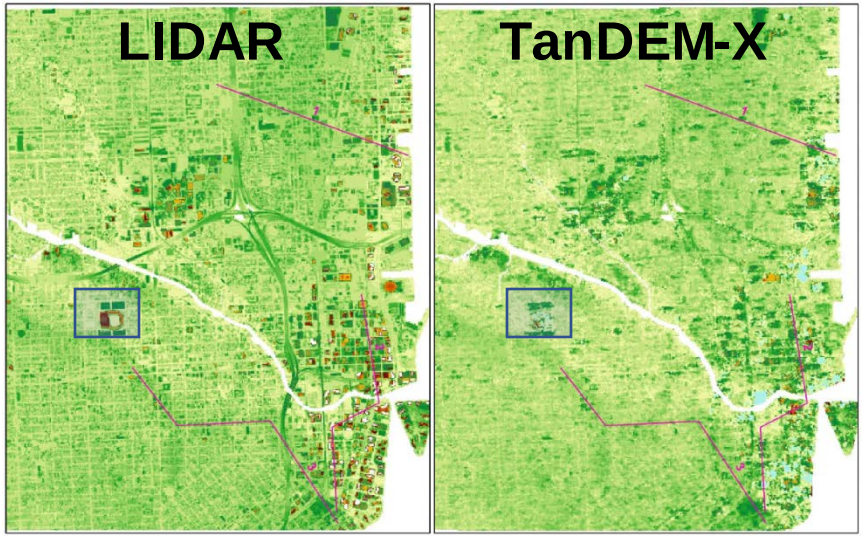
Requirements	Specification	DTED-2	TanDEM-X DEM
Relative Vertical Accuracy	90 % linear point-to-point error over a 1° by 1° cell	12 m (slope < 20 %) 15 m (slope > 20 %)	2 m (slope < 20 %) 4 m (slope > 20 %)
Absolute Vertical Accuracy	90 % linear error	18 m	10 m
Relative Horizontal Accuracy	90 % circular 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





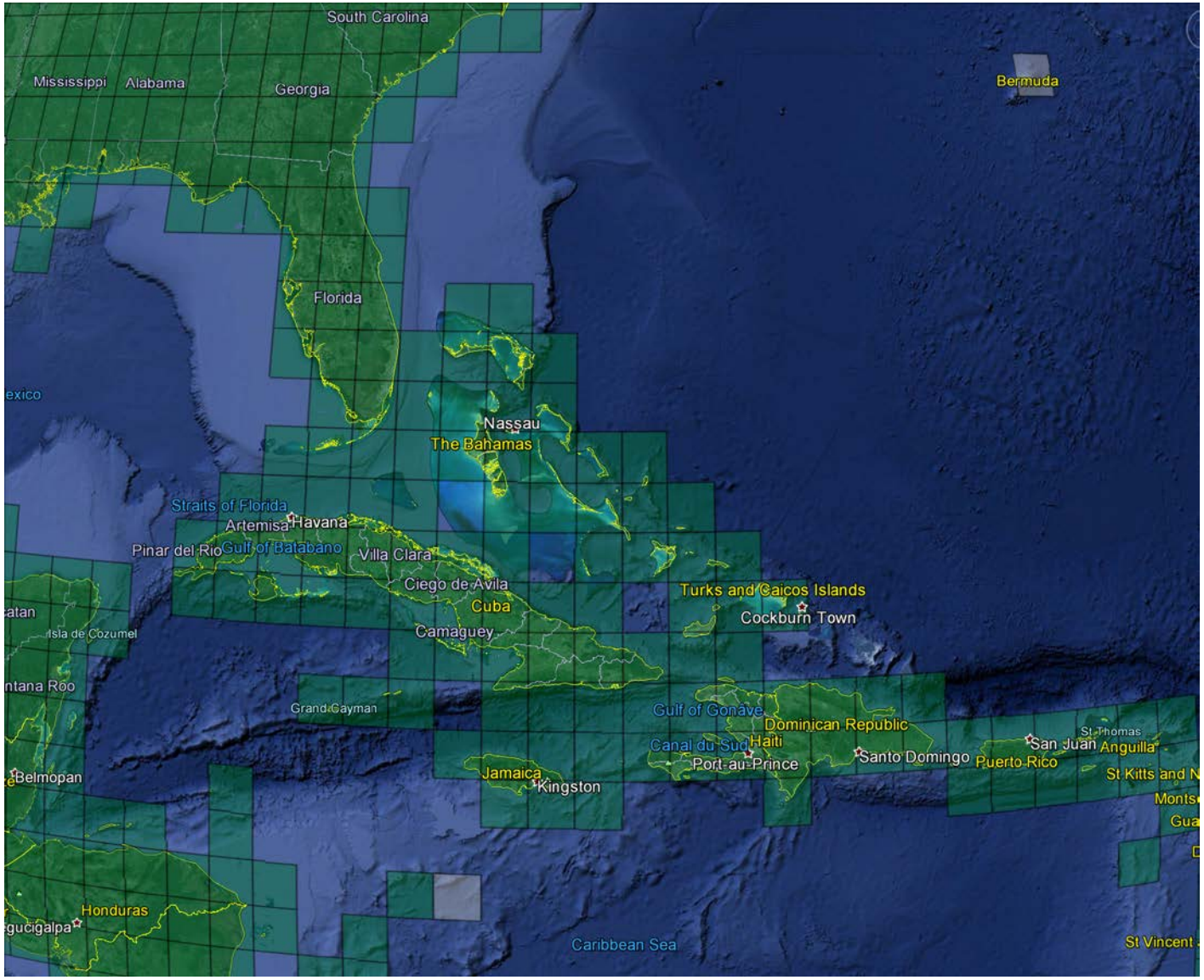


Data Availability

Availability 2015

Established an agreement with U.S. DOD for cost savings for CIFDP-C

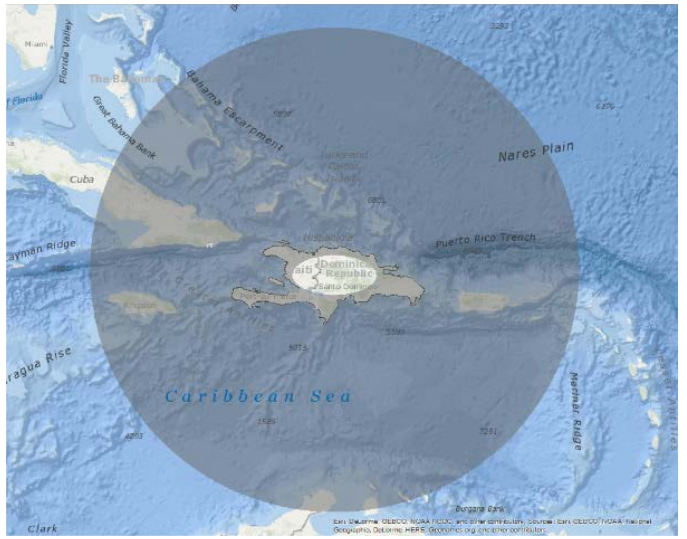
TANDEM-X DEMs not sharable per licensing agreement but final modeling results are

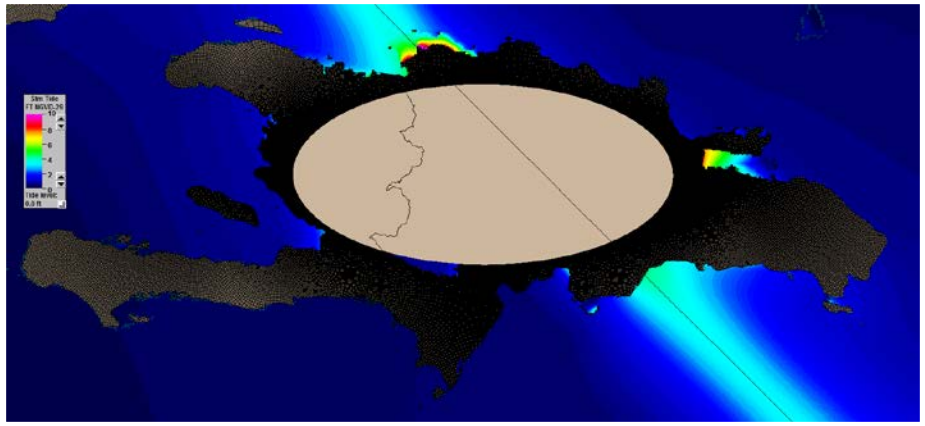


SLOSH + Waves Development

Coastal Inundation Forecasting Demonstration Project (CIFDP)

- 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





2nd 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).

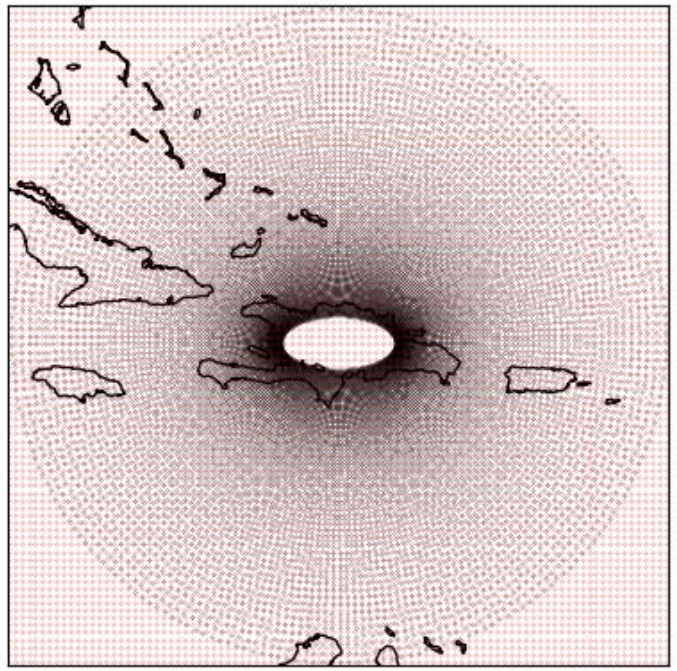
$$\frac{\partial \vec{M}}{\partial t} + \vec{v} \cdot \nabla_{x,y} \vec{M} = \vec{\tau}_w$$

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

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

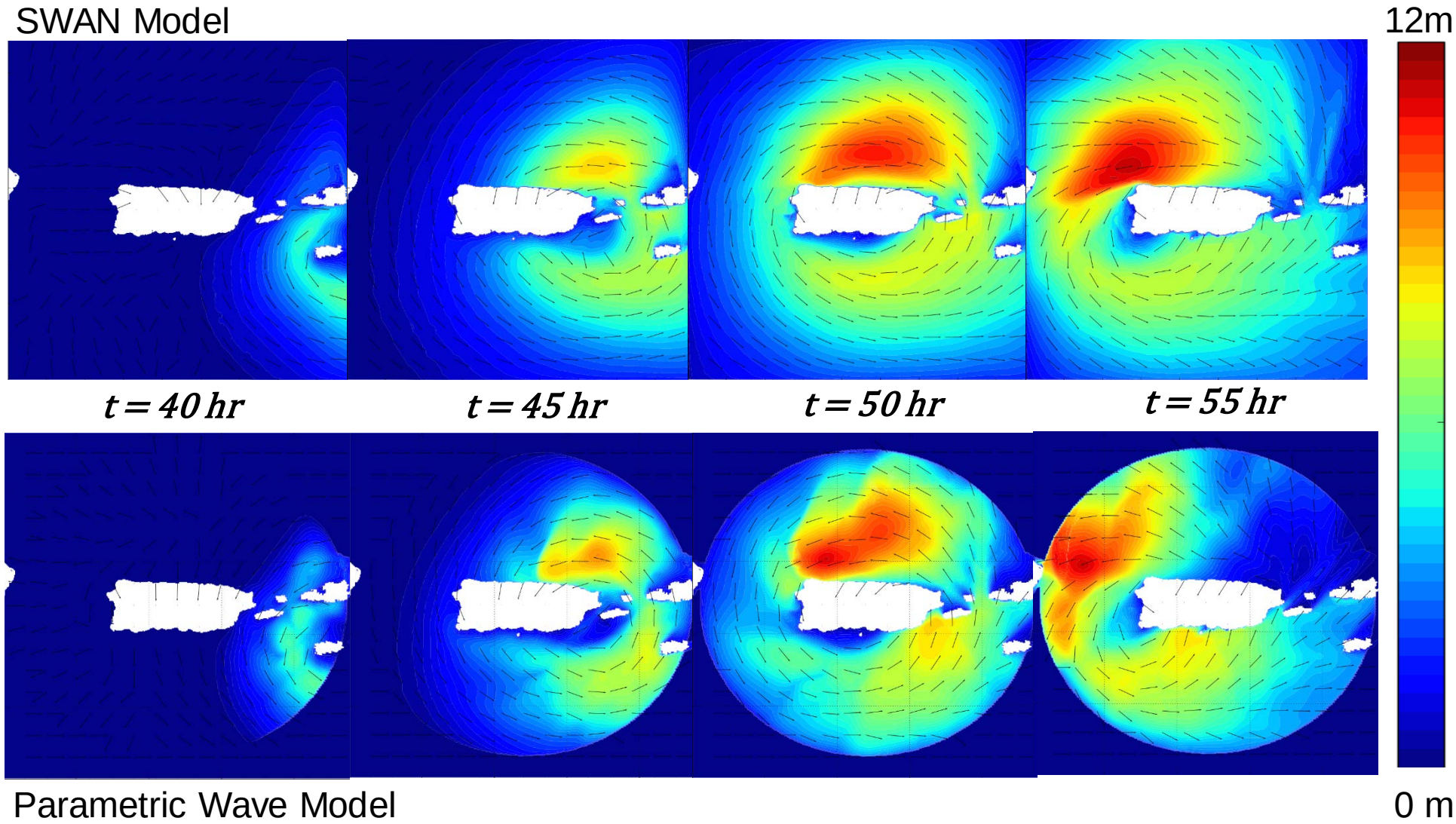
`. Simplified physics, but significantly cheaper than SWAN or WW3

More suitable to couple with SLOSH



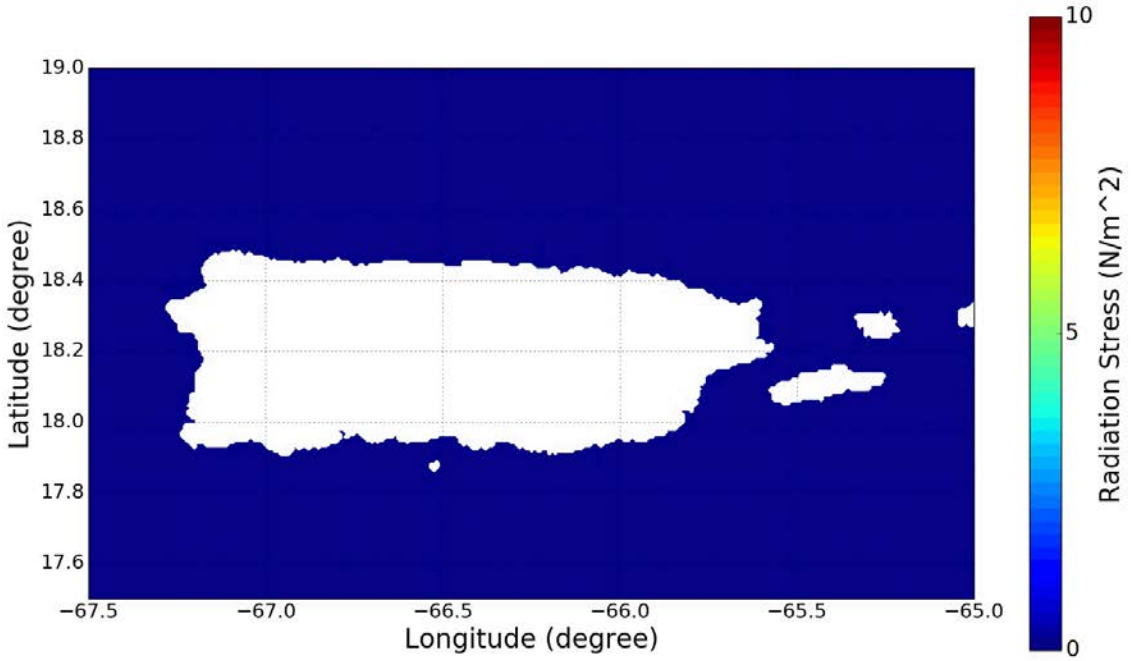
SLOSH basin and wave model grid mesh

Wave Height Comparison (Hurricane Georges, 1998)

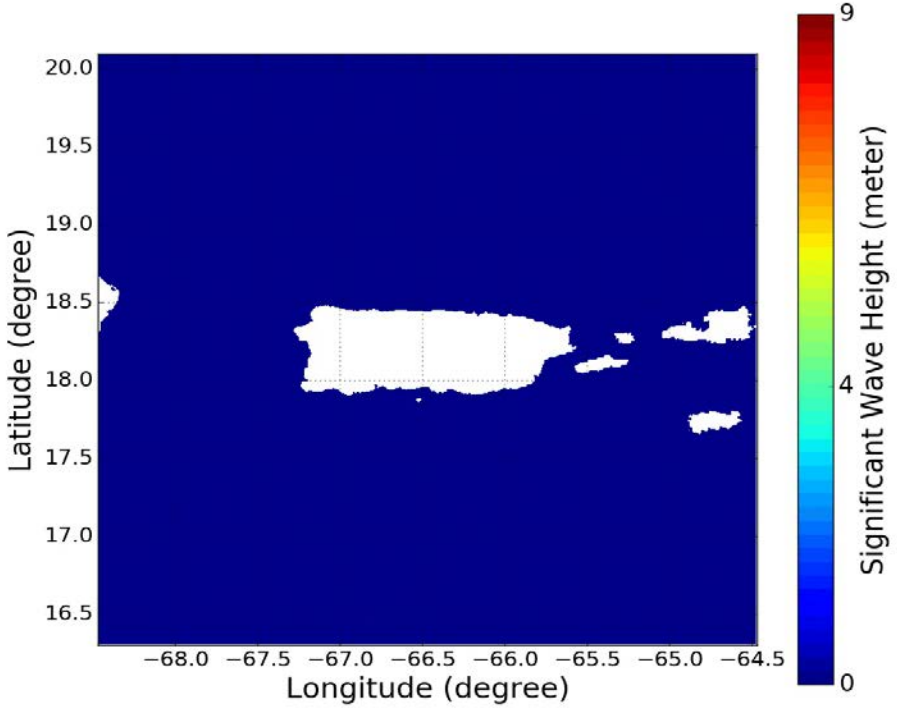


Coupled SLOSH + Waves

Wave Radiation Stress

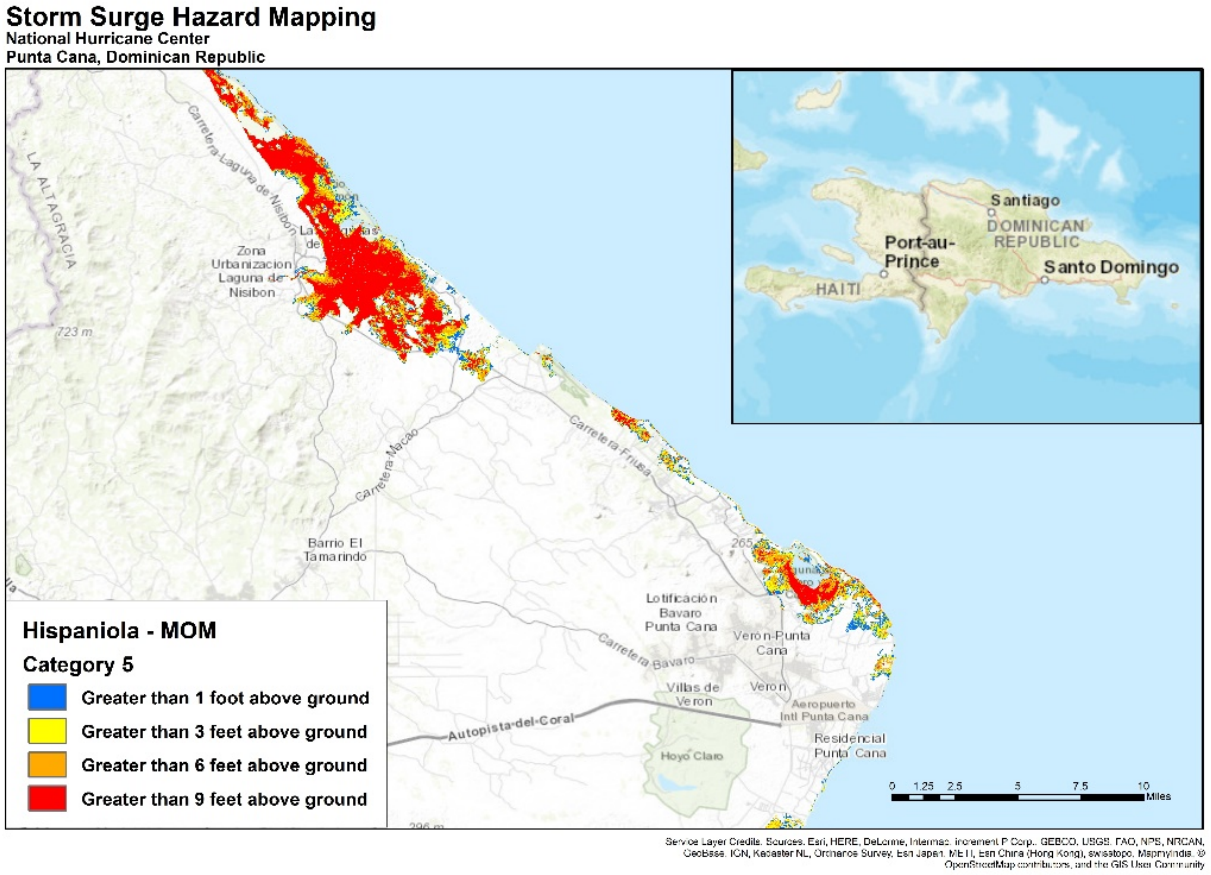


Significant Wave Height

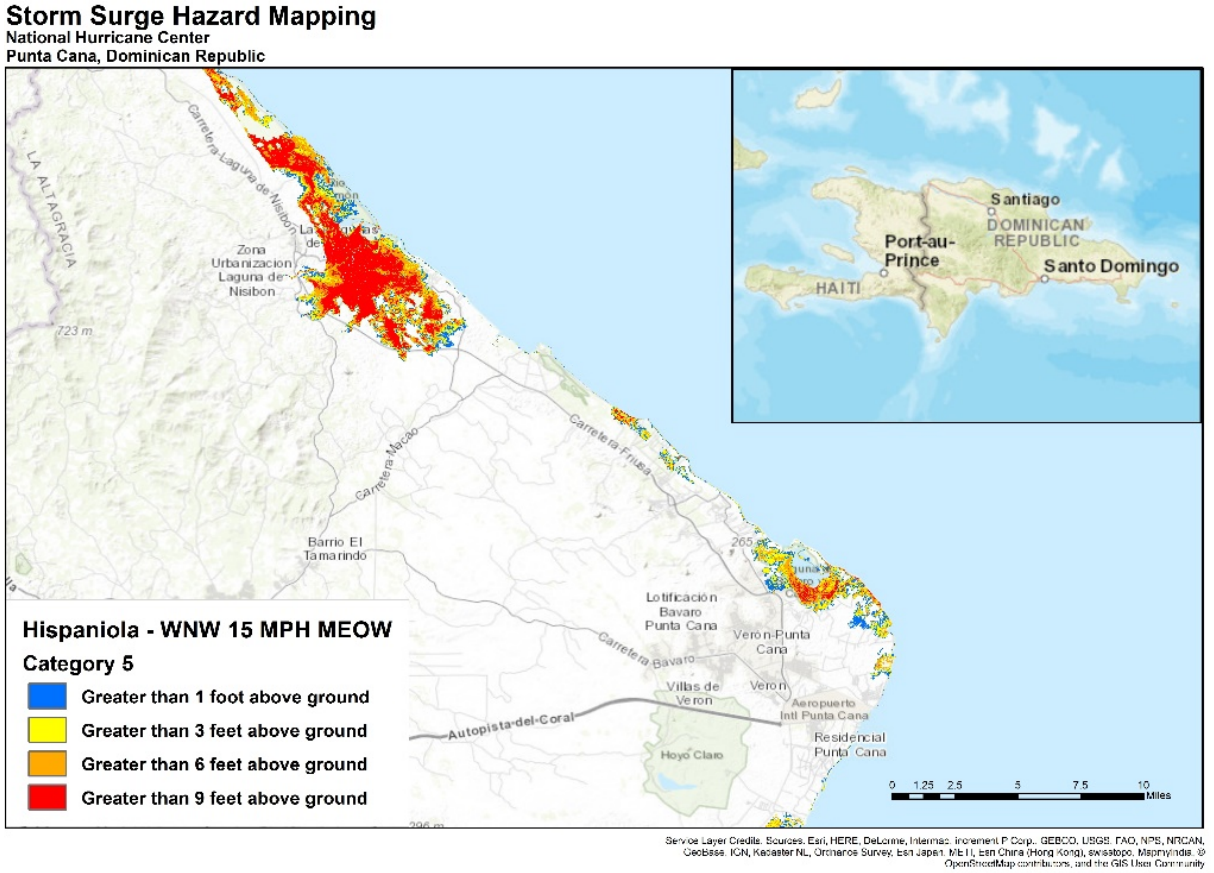


Final Deliverable: High-Resolution Inundation Mapping

Cat 5 - MOM



WNW 15 MPH - MEOW



Bahamas Storm Surge Project Phases

Project Scoping and Preparation:

Stakeholder meetings & workshop (Barbados)

WRN/Storm Surge dual track established

Project Planning and Design:

Initial project design/setup

Establish definitive National Agreement

Data acquisition and processing

System Development & Validation:

Final bathy/topo processing

Final SLOSH model configuration and testing.

Develop specialized training needs & requirements

Postprocessing and Distribution:

MOMs/MEOW creation, QA/QC, post-processing, inundation mapping

Transmit GIS data and HVX integration

Test/evaluate for hurricane season

System Integration and Training:

System implementation, project evaluation, specialized training workshop

Fully deploy for hurricane season

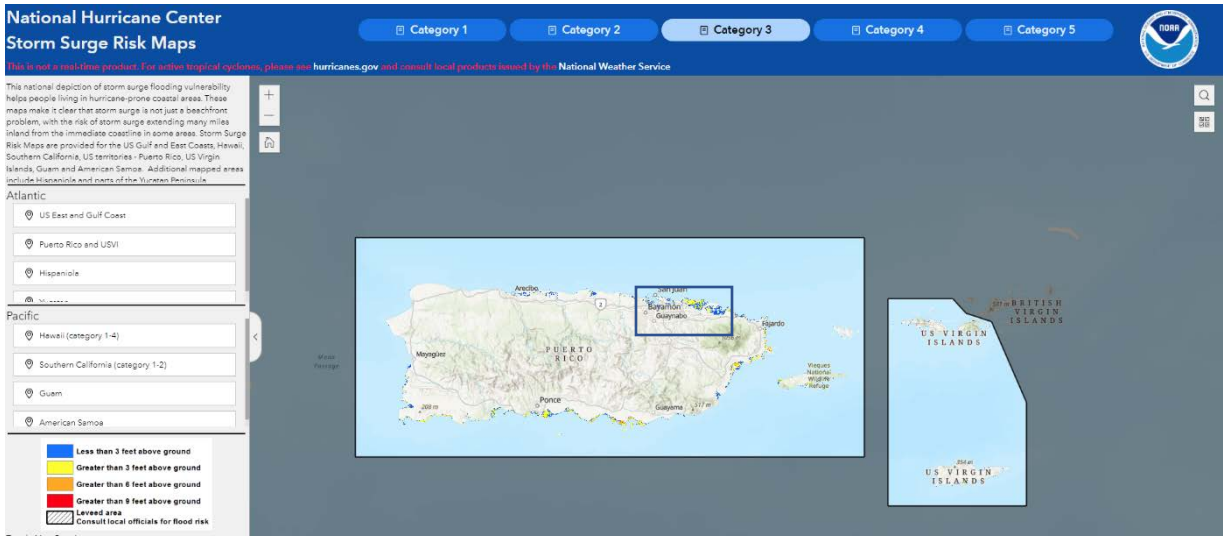
Project evaluation and recommended application to region (RA-IV)

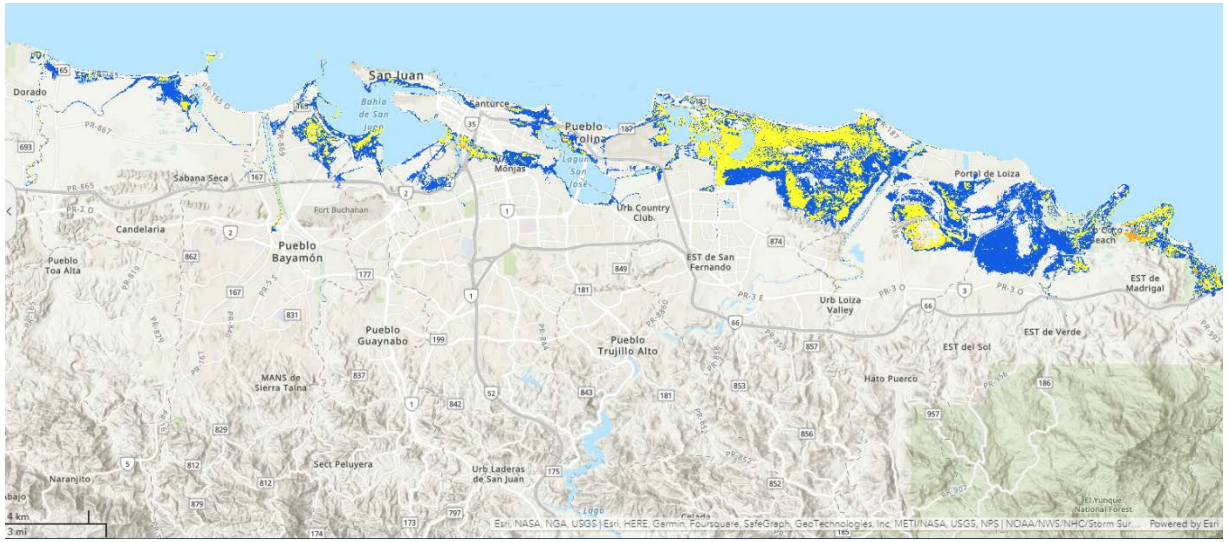
Dissemination and Data Availability

- 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

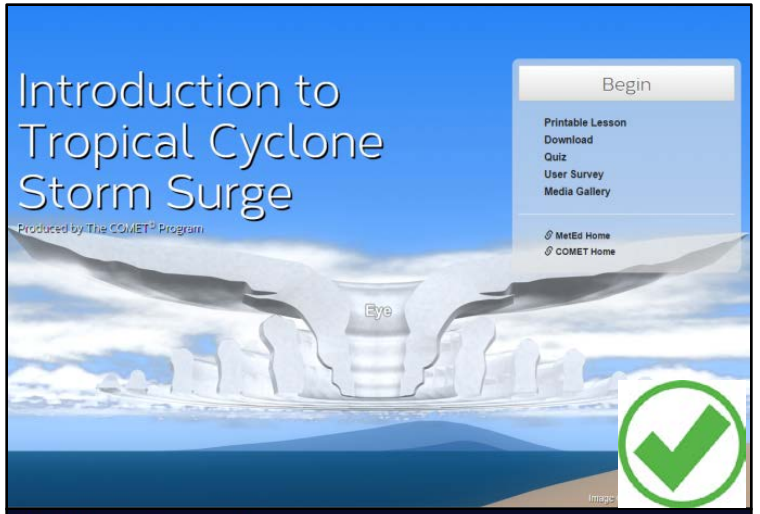
https://www.nhc.noaa.gov/nationalsurge/

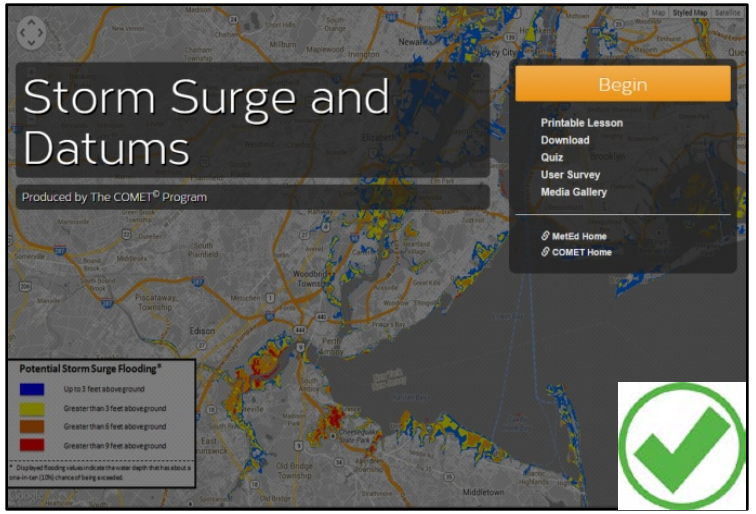




Existing Forecaster and Civil Defense Training Modules

Tropical Cyclone Forecast Uncertainty





Storm Surge Forecasting