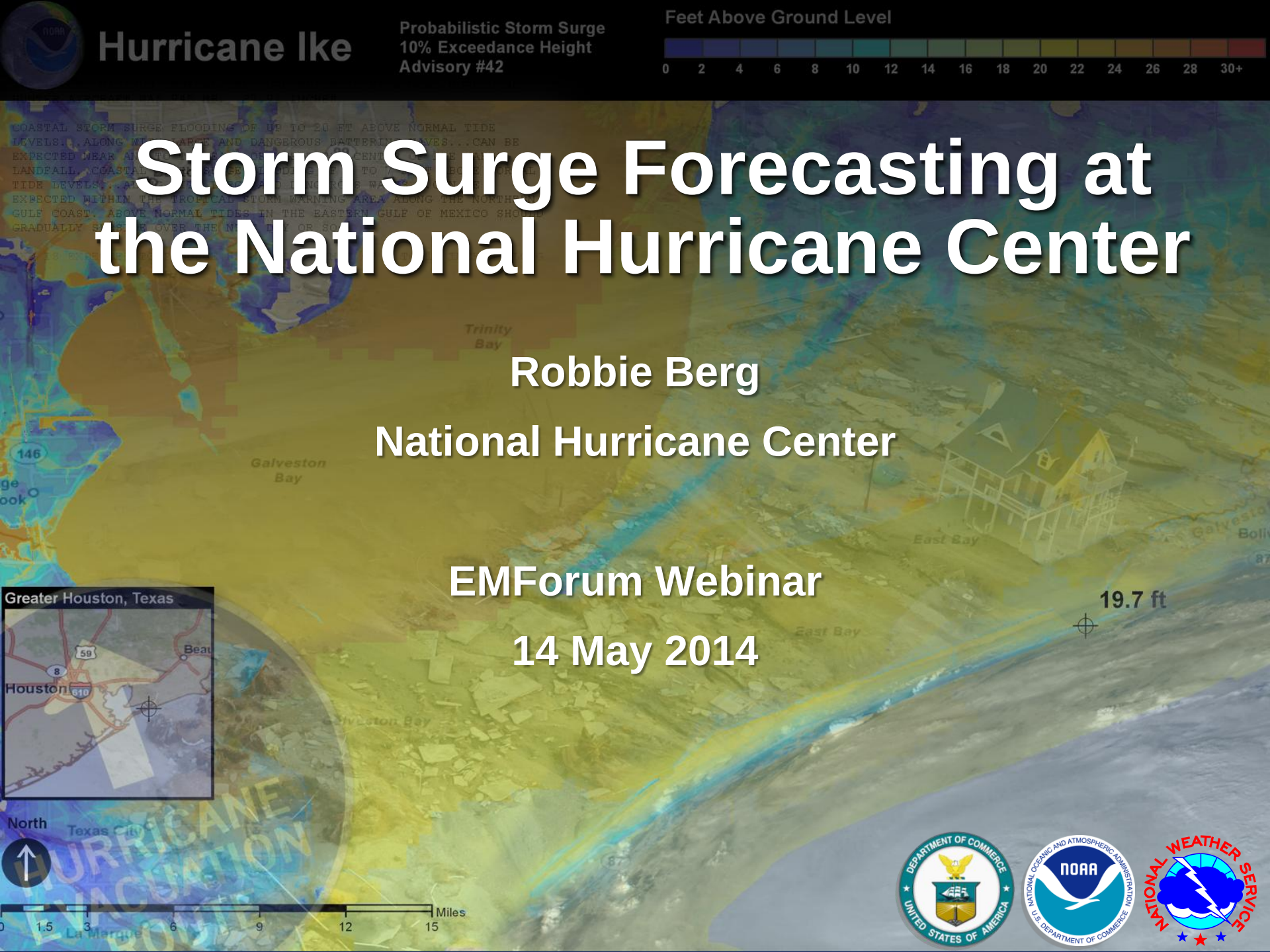


Storm Surge Forecasting at the National Hurricane Center

Robbie Berg

National Hurricane Center

EMForum Webinar

14 May 2014

Modeling Surge

- Statistical
  - Utilize historical data to develop statistical relationships
  - Necessary data is non-existent

Modeling Surge

- Statistical
  - Utilize historical data to develop statistical relationships
  - Necessary data is non-existent
- Deterministic Numerical Models
  - Forecast surge based on solving physical equations
  - Strongly dependent on accurate meteorological input
  - Current uncertainty in tropical cyclone forecasts render such methods inaccurate

Modeling Surge

Statistical

- Utilize historical data to develop statistical relationships
- Necessary data is non-existent

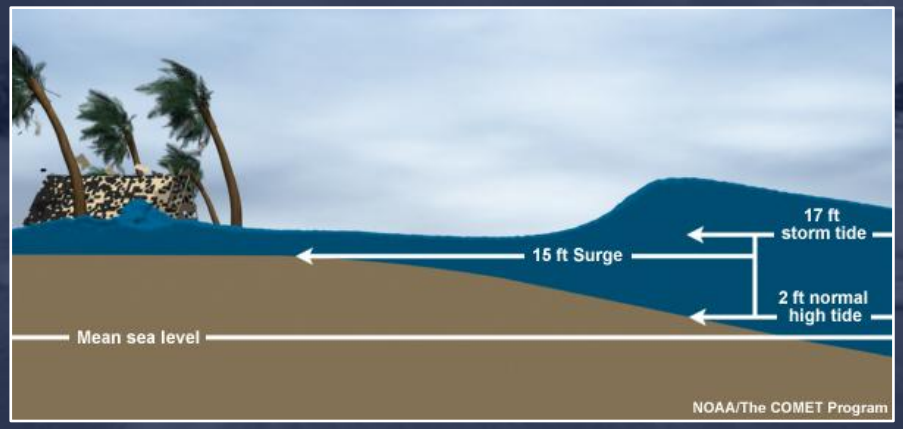
Deterministic Numerical Models

- Forecast surge based on solving physical equations
- Strongly dependent on accurate meteorological input
- Current uncertainty in tropical cyclone forecasts render such methods inaccurate

- Numerical Model Ensemble
  - Many different runs of the same model but with different conditions (family of storms)
  - Best approach for determining storm surge vulnerability for an area since it takes into account forecast uncertainty

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

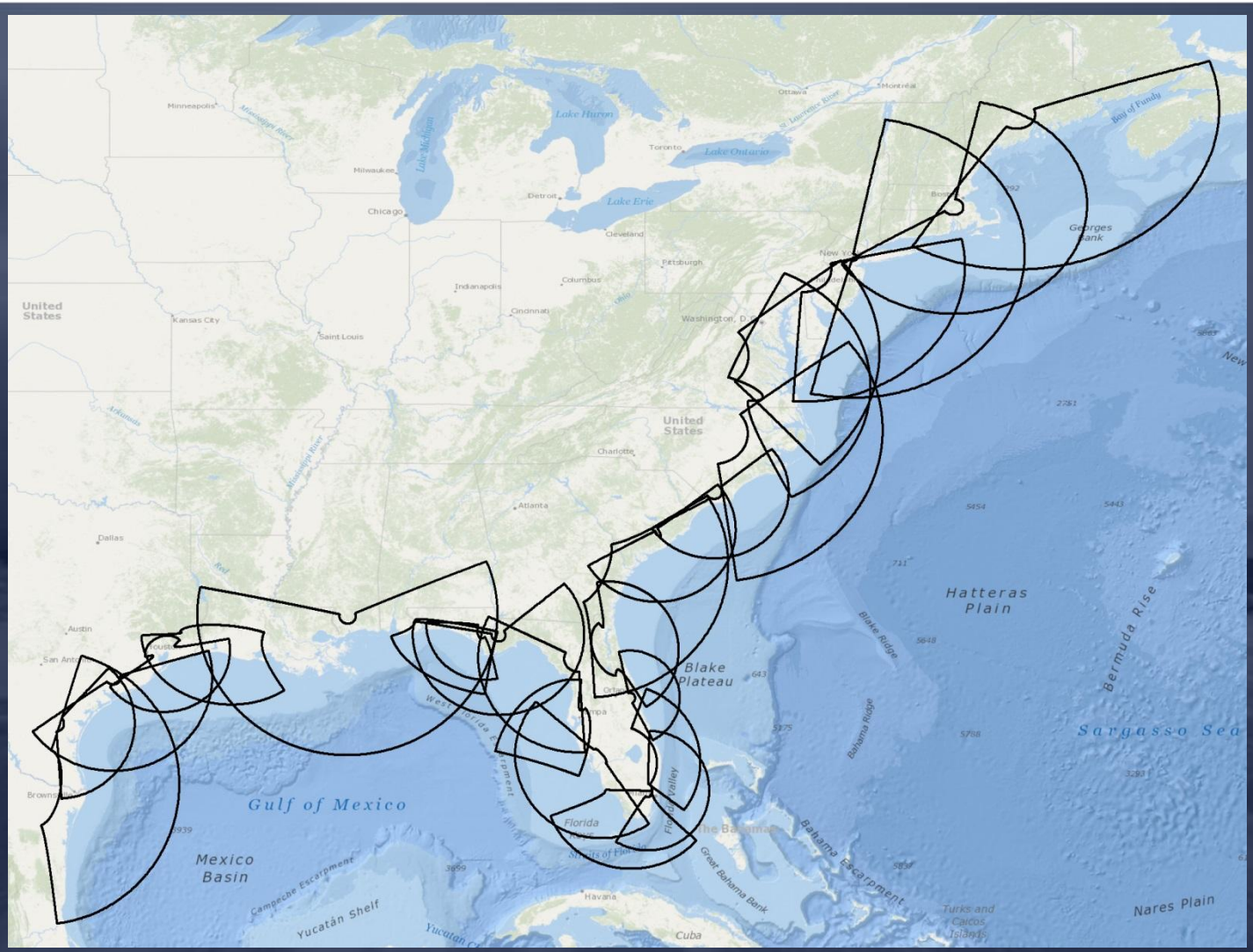


SLOSH
Strengths and Limitations

- 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 tides

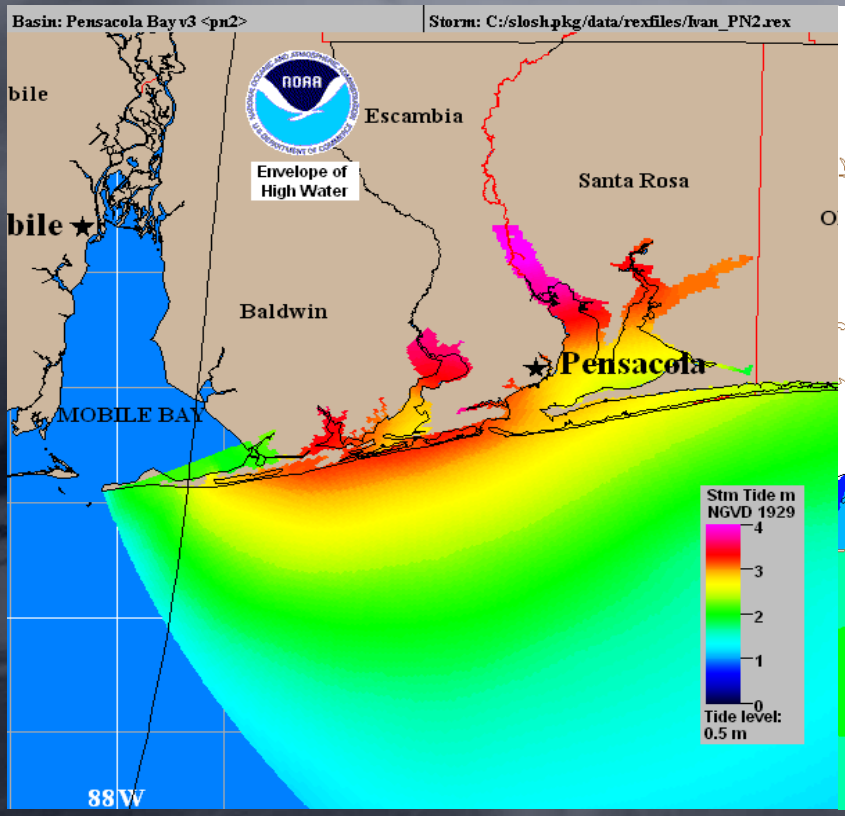
- SLOSH does not include:
  - Breaking waves/wave run-up
  - Normal river flow and rain

SLOSH Grids

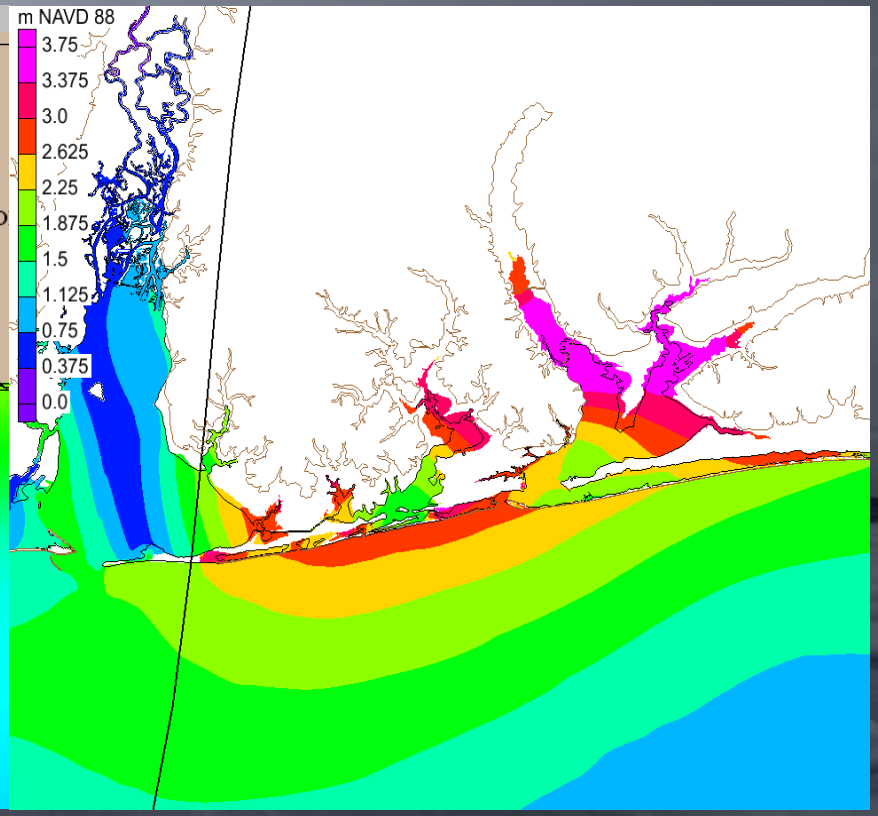

Minneapolis
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
Toronto
Ottawa
Montréal
Milwaukee
Detroit
Chicago
Cleveland
Pittsburgh
Columbus
Indianapolis
Cincinnati
Washington, D.C.
New York
Boston
Bay of Fundy
Georges Bank
United States
Kansas City
Saint Louis
Charlotte
Atlanta
Dallas
Austin
San Antonio
Houston
Brownsville
Gulf of Mexico
Mexico Basin
Campeche Escarpment
Yucatán Shelf
Florida
Florida Valley
Florida Escarpment
Havana
Cuba
The Bahamas
Great Bahama Bank
Bahama Escarpment
Turks and Caicos Islands
Nares Plain
Blake Plateau
Blake Ridge
Bahama Ridge
Hatteras Plain
Bermuda Rise
Sargasso Sea
Mississippi River
Ohio
Red
Arkansas

SLOSH and ADCIRC

Overall flooding pattern very similar



SLOSH run, Hurricane Ivan

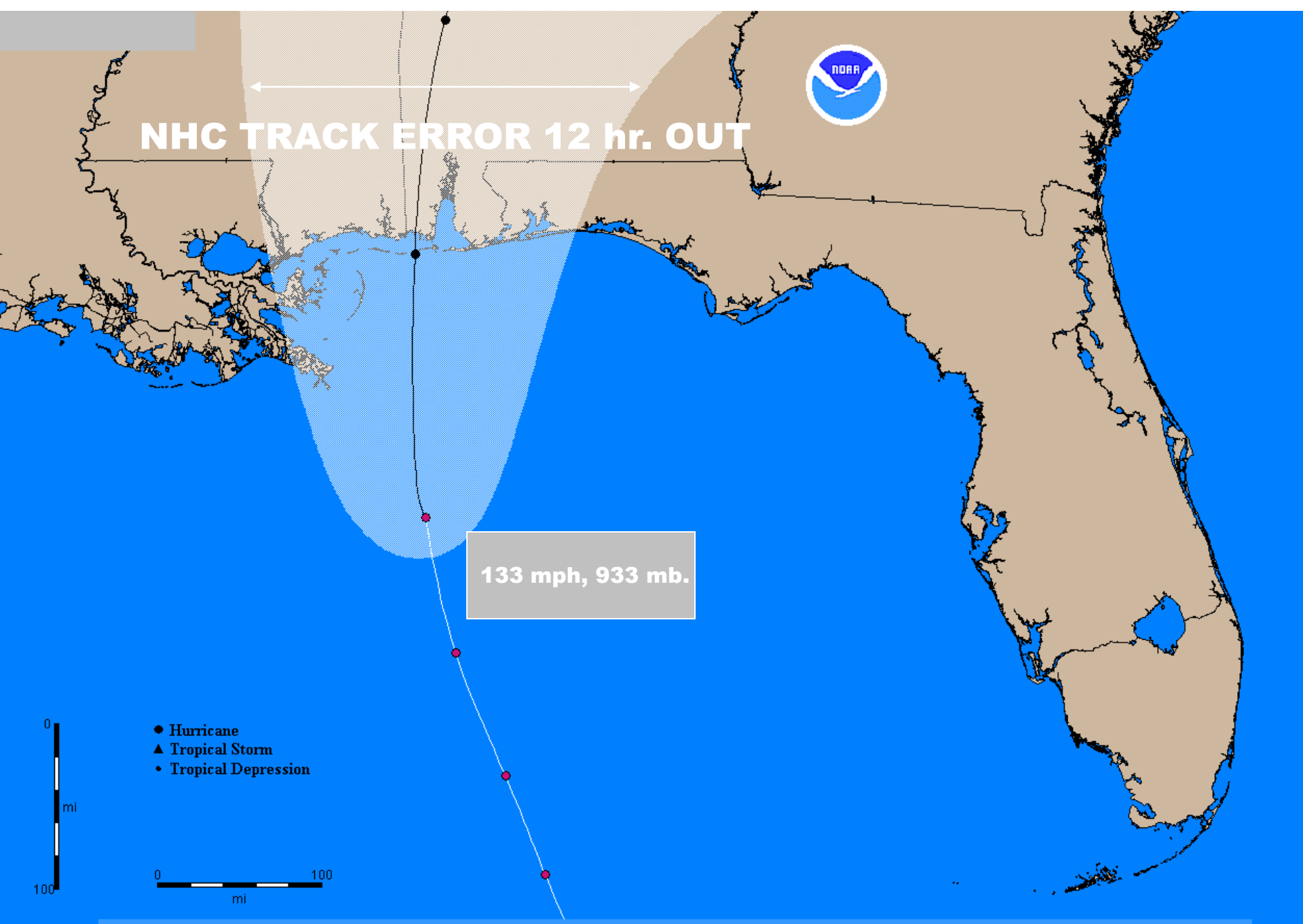


ADCIRC run, Hurricane Ivan

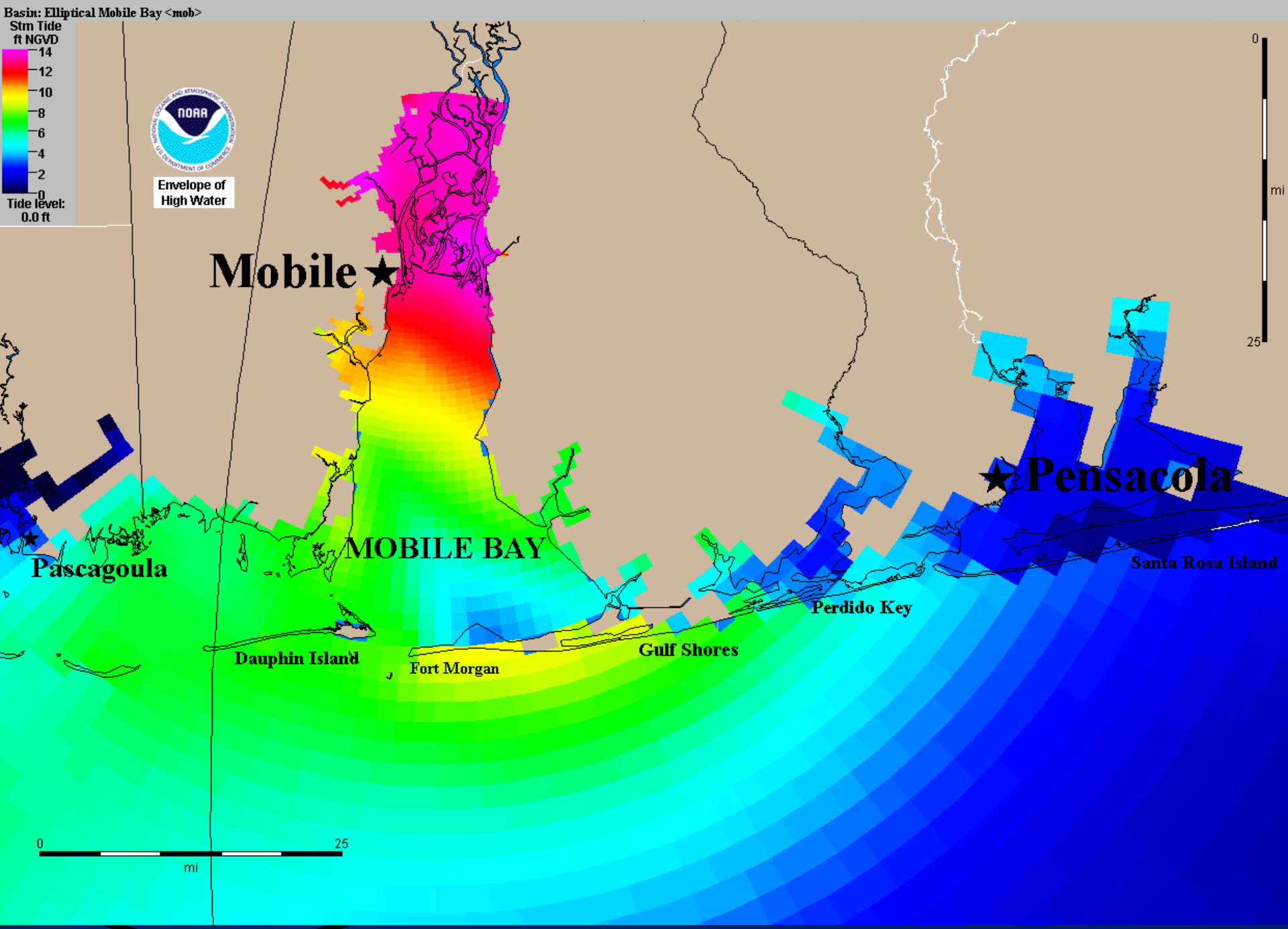
Forecasting Storm Surge

- All storm surge models are STRONGLY dependent on the accuracy of the meteorological input
- Meteorological uncertainty will dominate over storm surge model specifications (physics, resolution, etc)
- Different vertical datums/reference levels
- Storm surge is only one component in the real water level rise

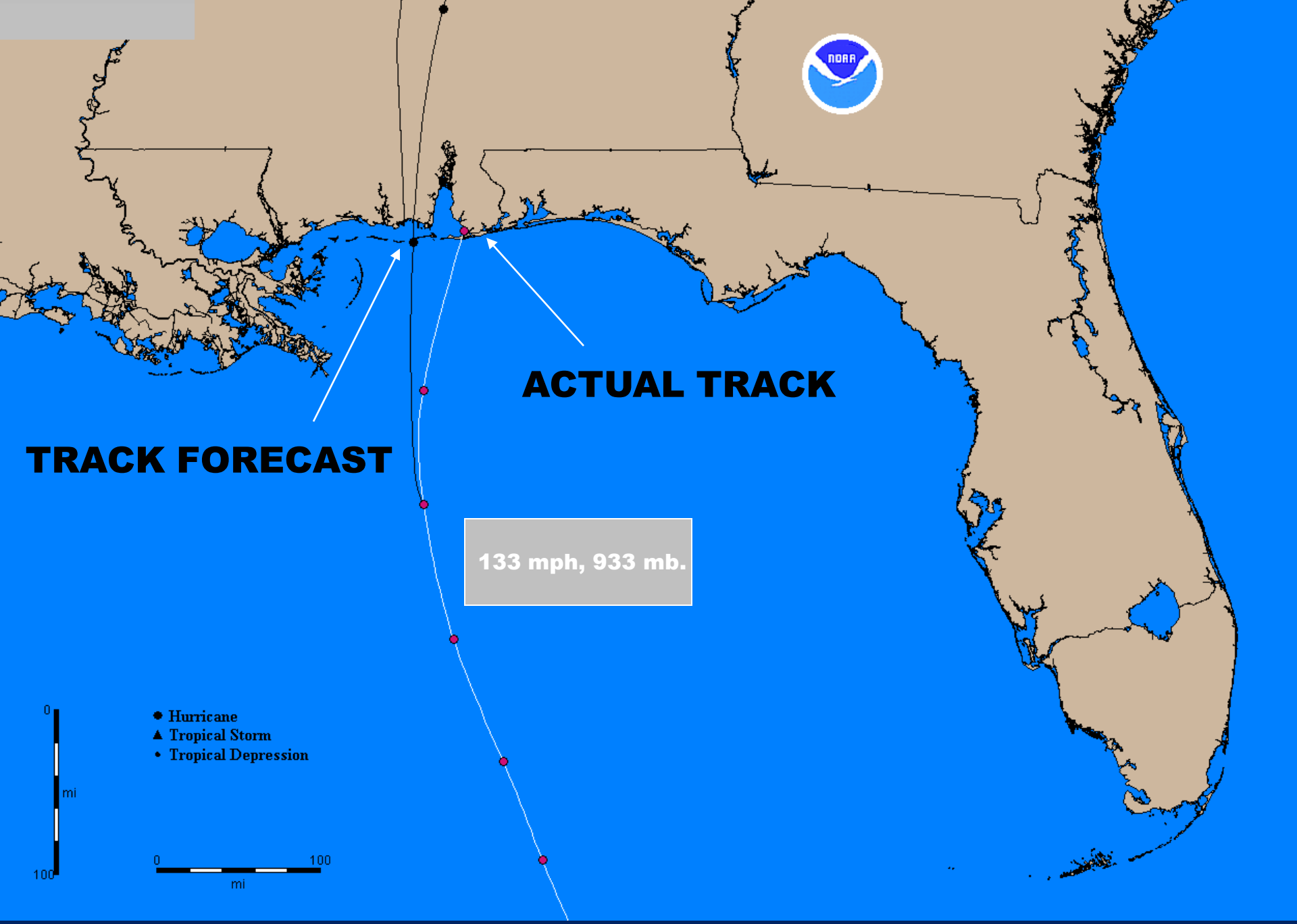
Total water rise = surge + tides + waves + freshwater flow



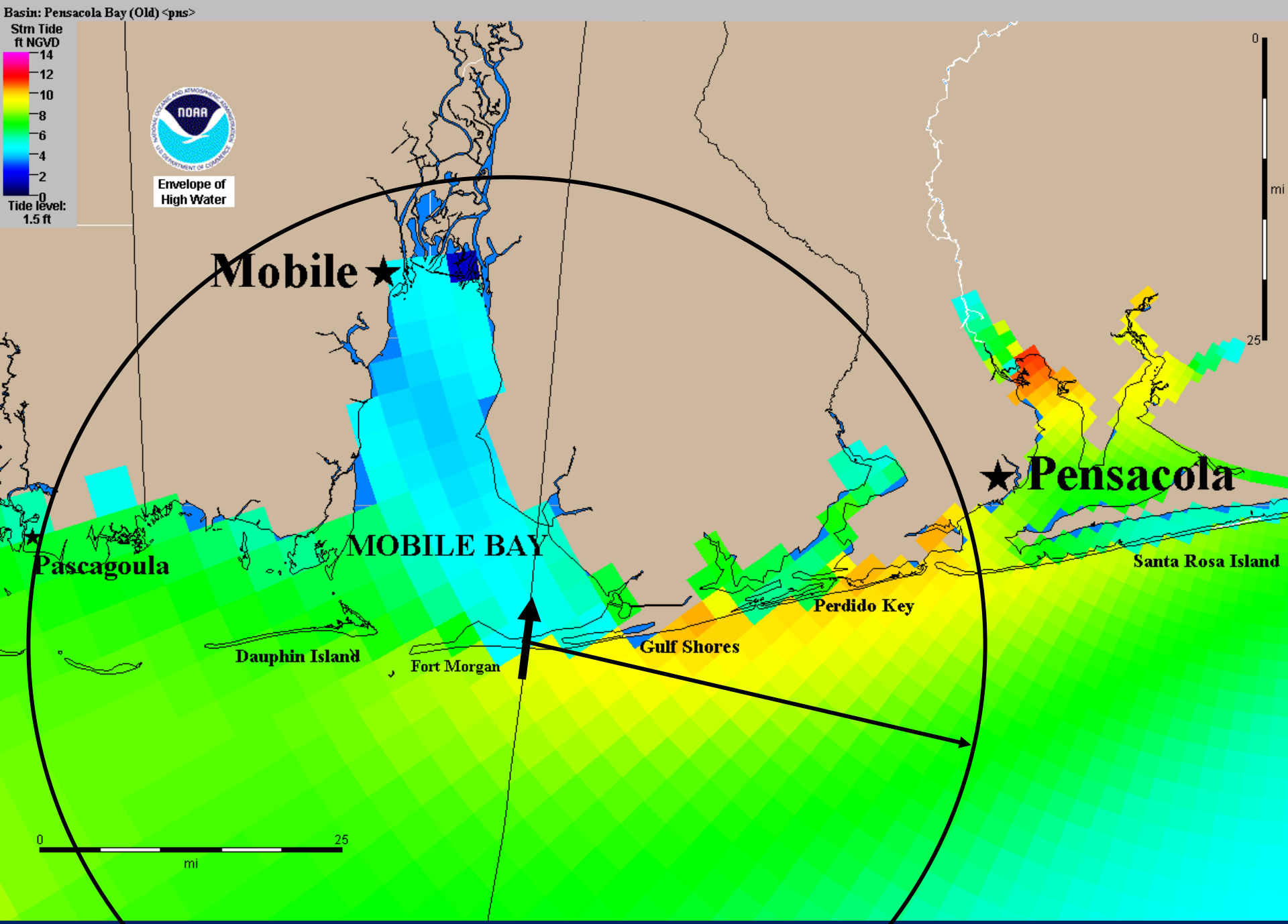
Hurricane Advisory - Approximately 12 hr. before landfall



Surge Based on NHC -12 hr. Advisory



Actual Hurricane Track 30 mi. E of -12 hr. Advisory Forecast Track



Surge Based on NHC Storm Best Track

The Perils of Not Accounting for Uncertainty

Must use ensemble approaches

Don’t put all your eggs in one basket!

Alternative to Single Runs

Atlas of pre-computed surge maps based on

- Different directions of motion
- Different landfall locations
- Different intensities
- Different storm sizes
- Different forward speeds

Ensemble Guidance

Pre-Computed Storm Surge Simulations

MEOWs

Maximum Envelopes Of Water

MOMs

Maximum Of the MEOWs

Real-Time Storm Surge Simulations

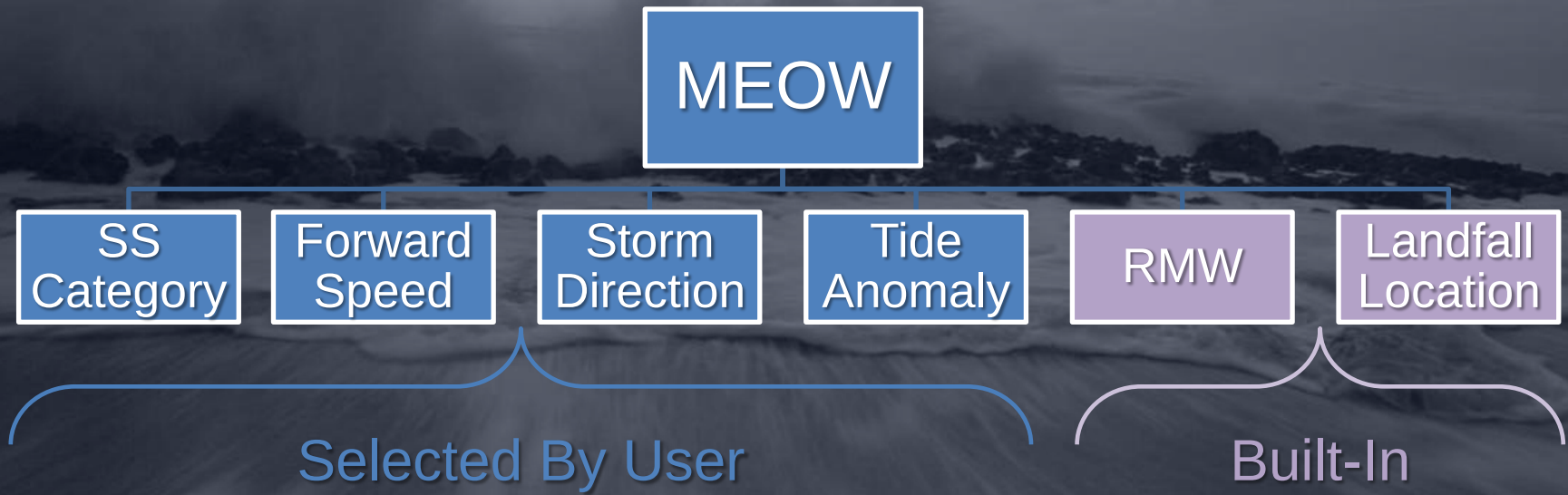
P-Surge

Probabilistic Storm Surge

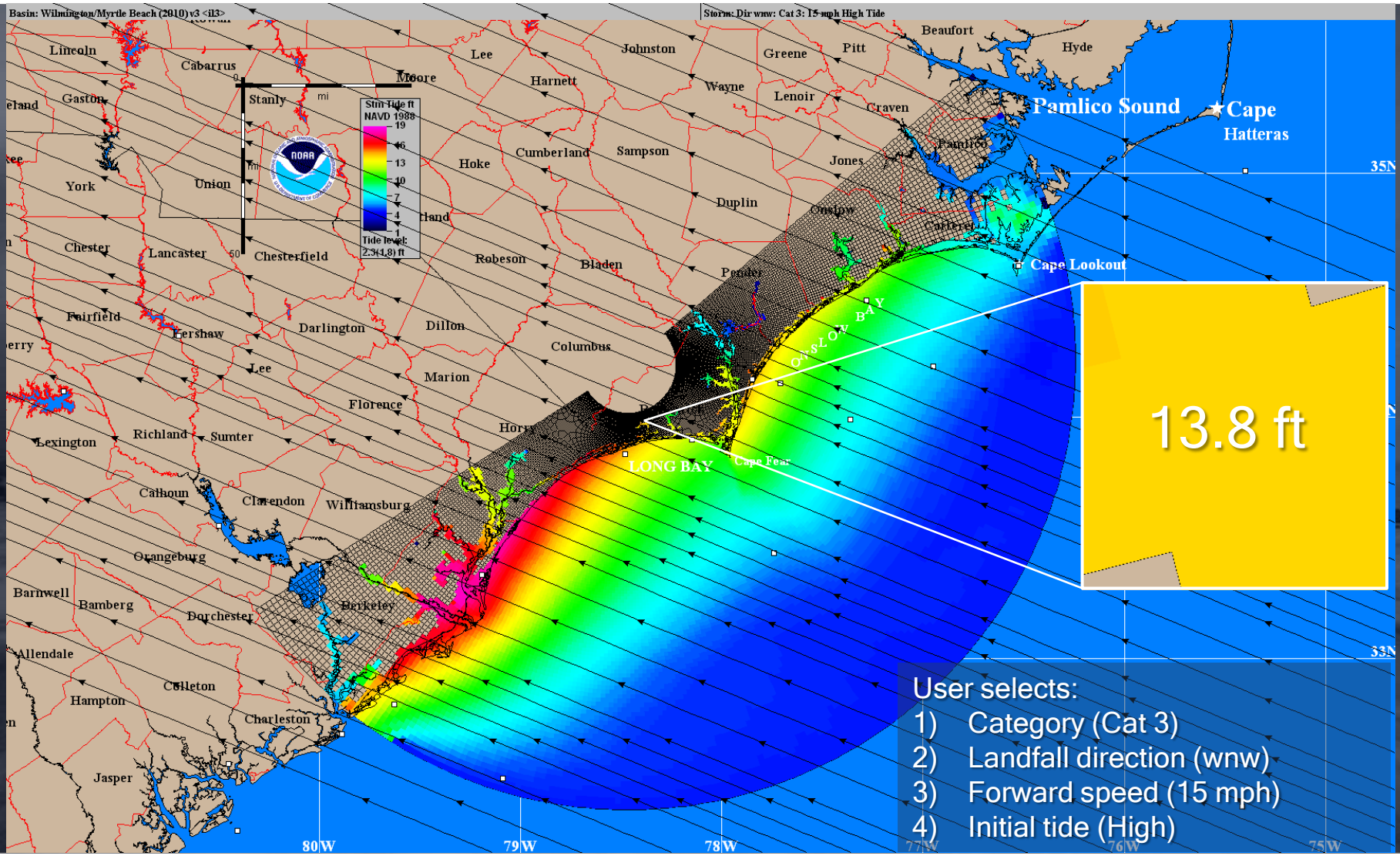

MEOW
Maximum Envelope Of Water

Maximum Envelope of Water (MEOW)

- Products available on SLOSH Display Program (SDP)
- Composite of the maximum storm surge for all surge simulations for a given set of parameters (by basin)
- Used as guidance for planning and operations

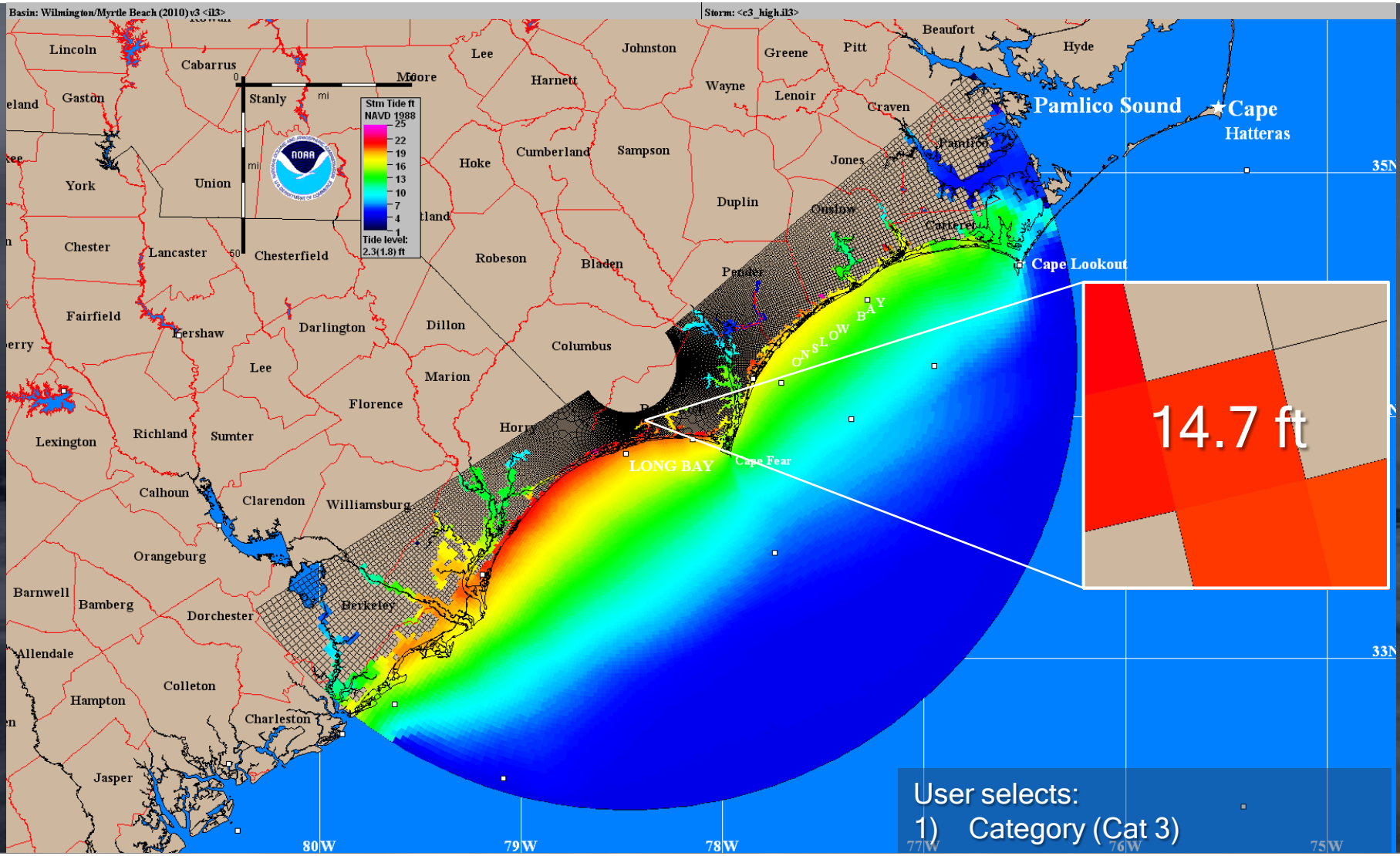


Maximum Envelope of Water (MEOW)




MOM
Maximum Of the MEOWs

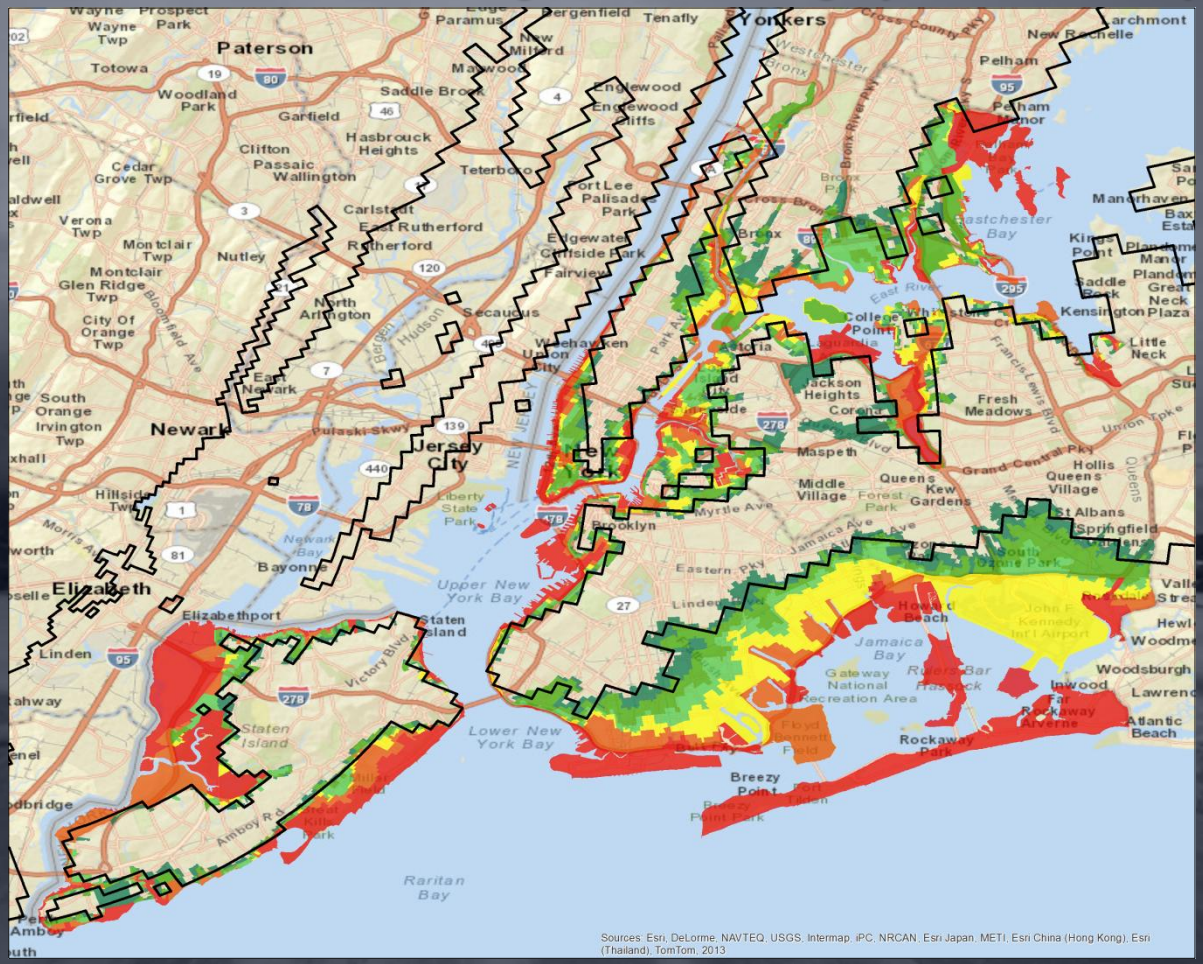
Maximum of the MEOWs (MOMs)



SLOSH MOMs To NYC Evacuation Zones

NYC Evacuation Zones / Category 4, Inland Tide Anomaly

2010 Population	
Zone 1	370,000
Zone 1+2	620,000
Zone 1+2+3	1,020,000
Zone 1+2+3+4	1,470,000
Zone 1+2+3+4+5	2,230,000
Zone 1+2+3+4+5+6	2,990,000

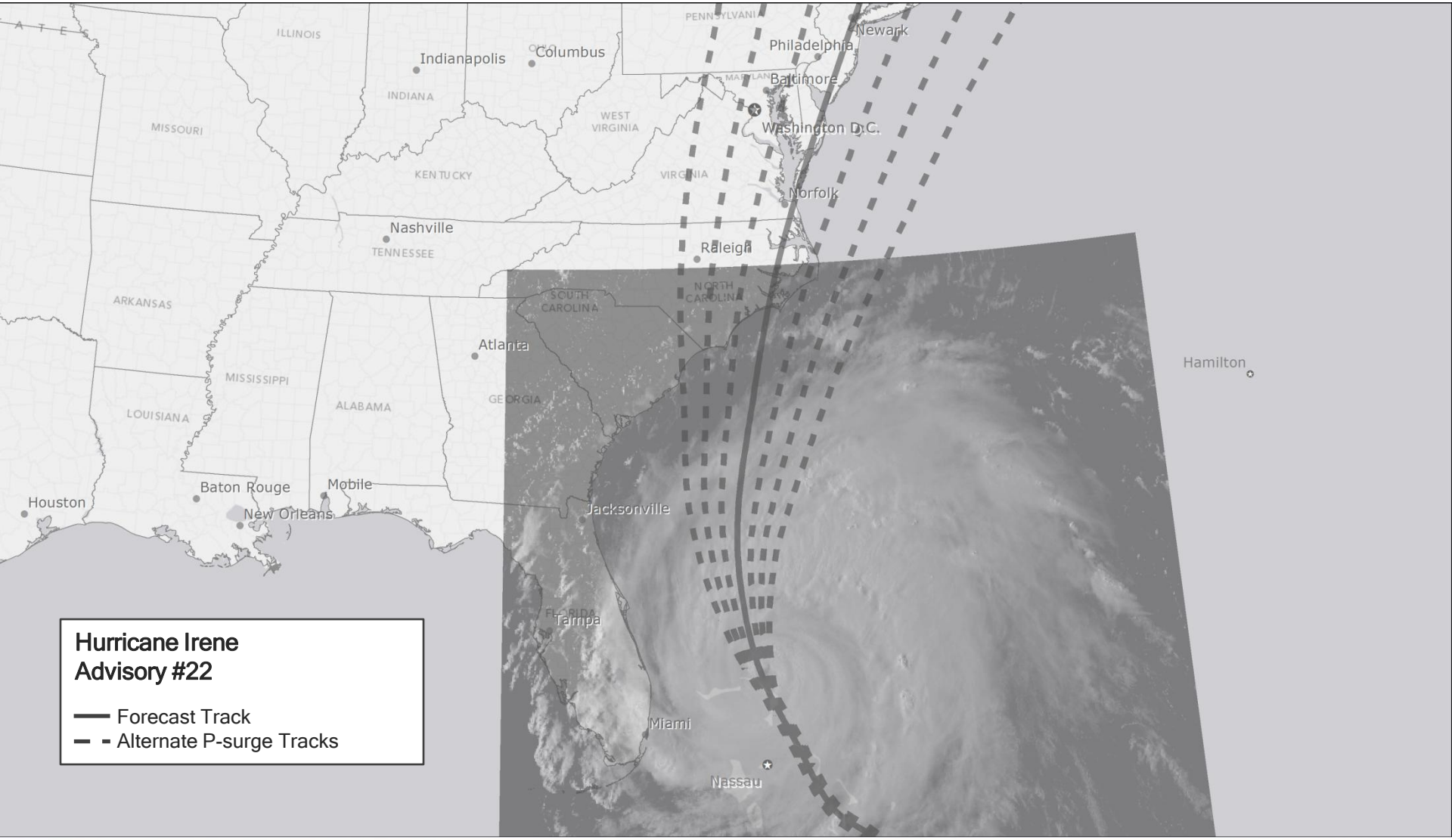


P-surge
Probabilistic Storm Surge

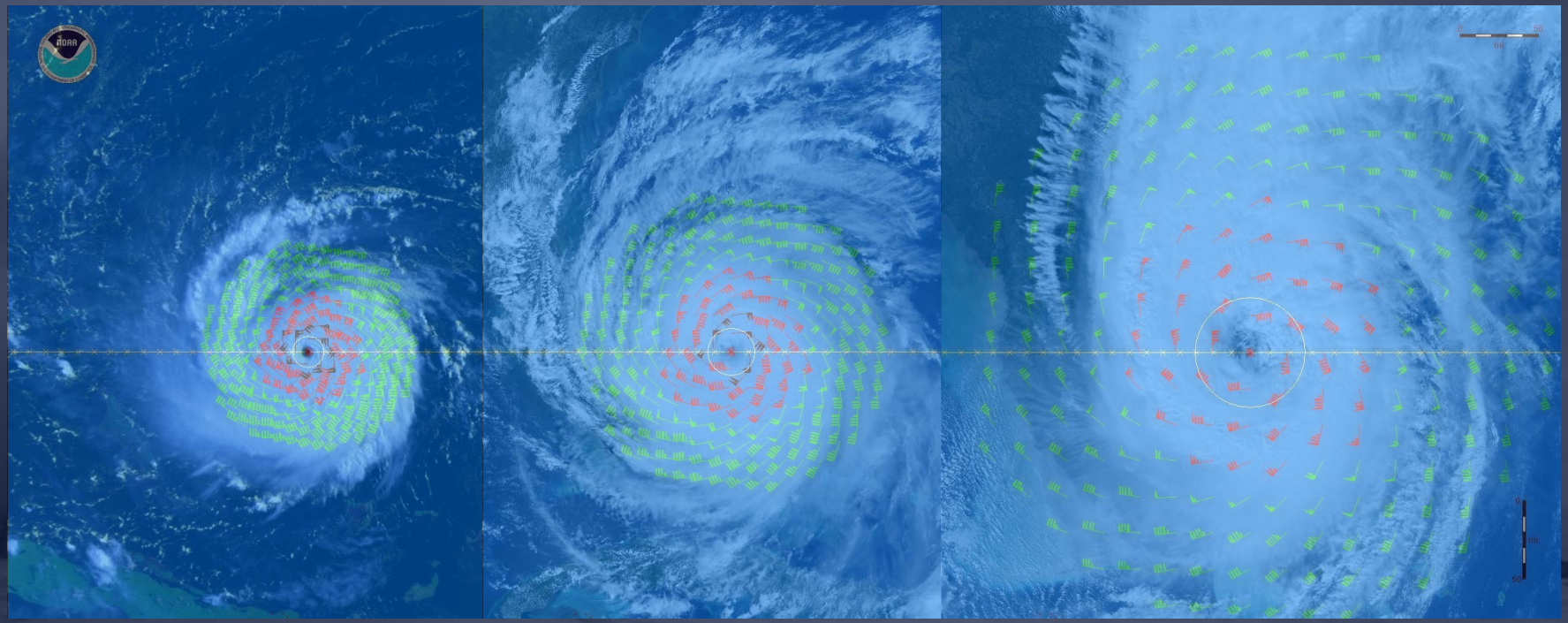
Probabilistic Storm Surge (P-Surge)

- Storm surge probabilities based on NHC official advisory
- Available roughly 48 hours prior to arrival of TS winds
- Accounts for meteorological uncertainty in:
  - Track / landfall location
  - Size
  - Forward speed
  - Intensity
- Uncertainties based on historical errors
- Version 2.0 (2014) also accounts for the tide and is above ground level

Probabilistic Storm Surge (P-surge)
Multiple Tracks and Landfall Locations



Probabilistic Storm Surge (P-surge)
Multiple Tracks and Landfall Locations

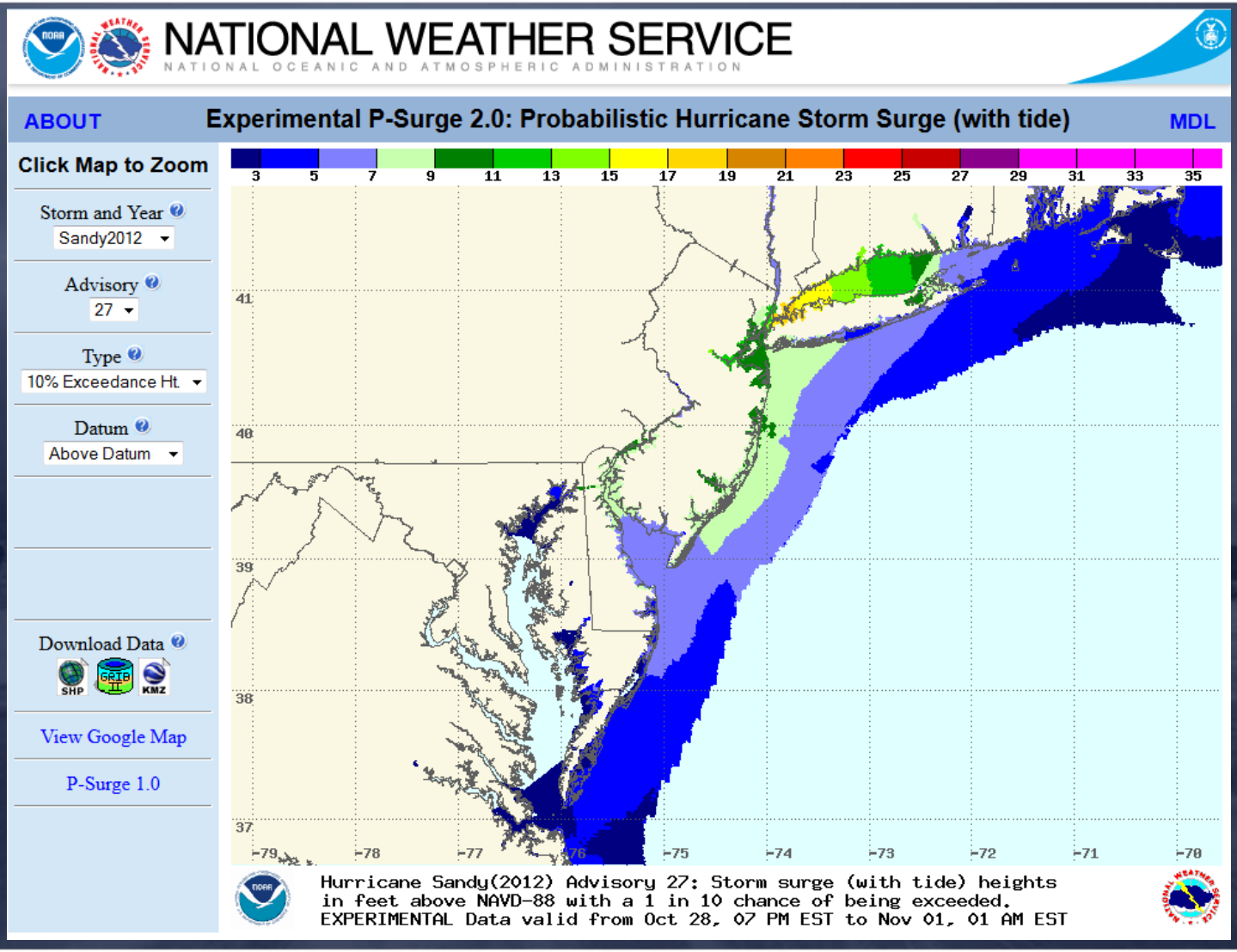


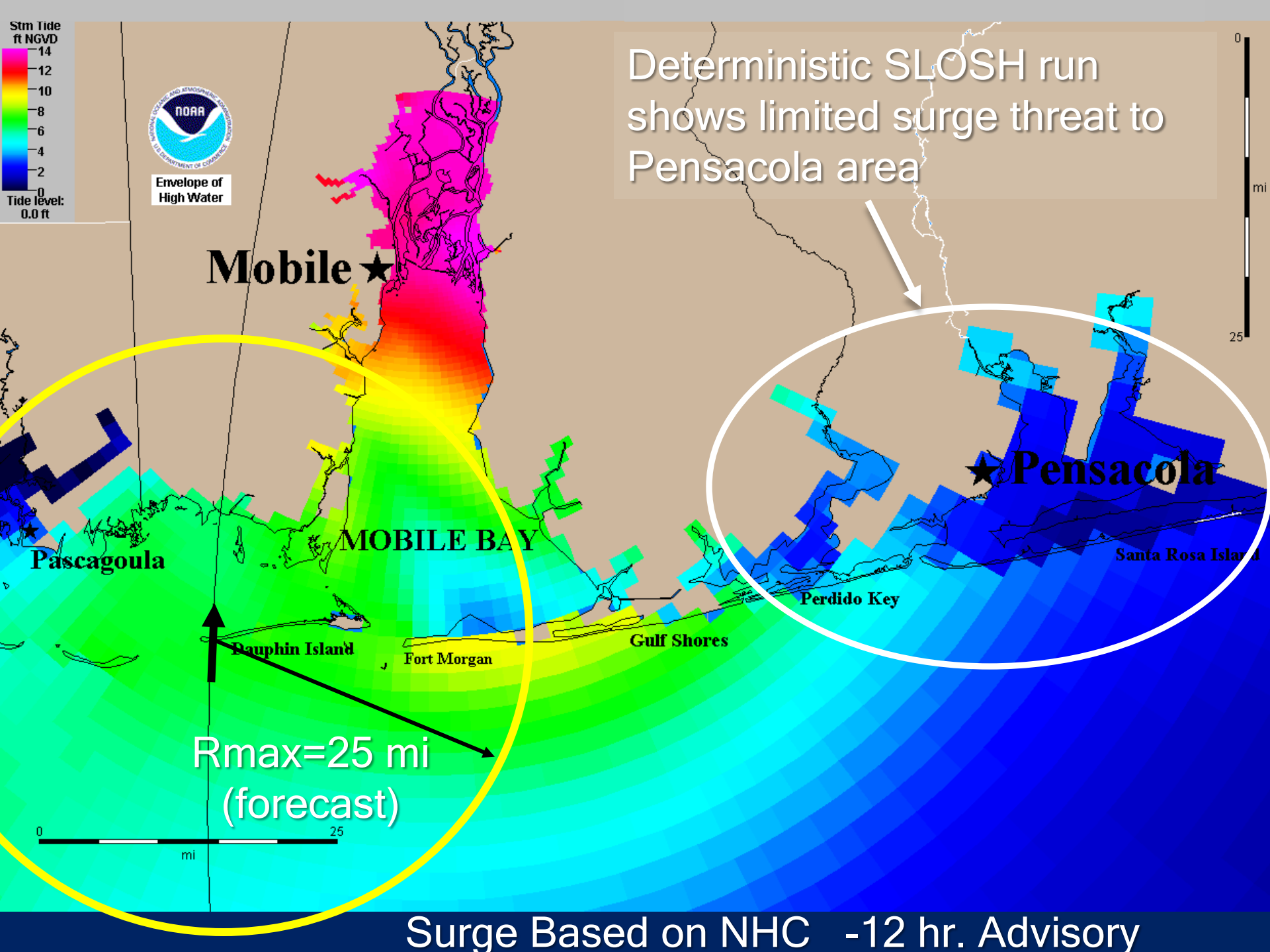
Size: Small, Medium, Large

Forward Speed: Fast, Medium, Slow

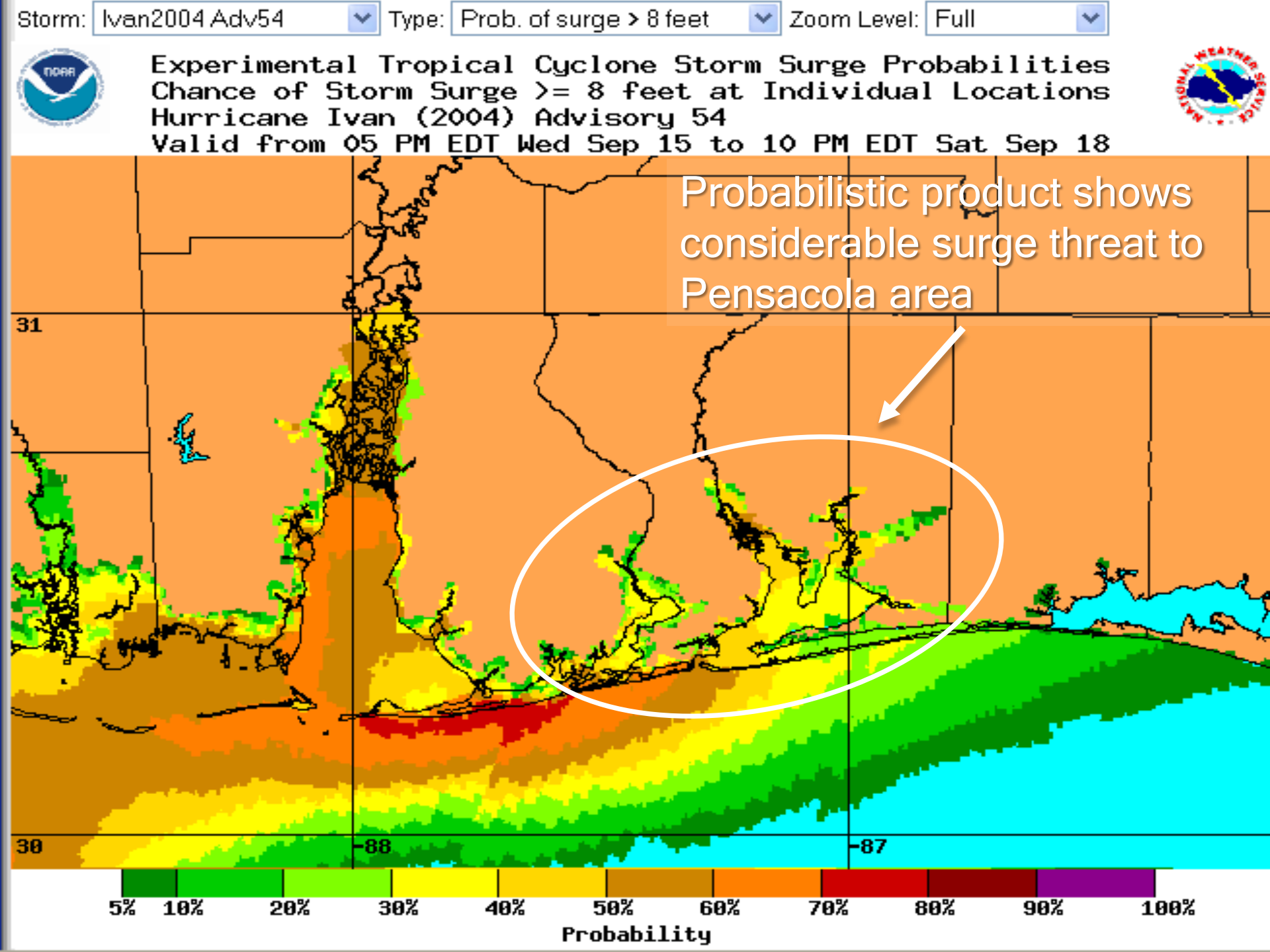
Intensity: Strong, Medium, Weak

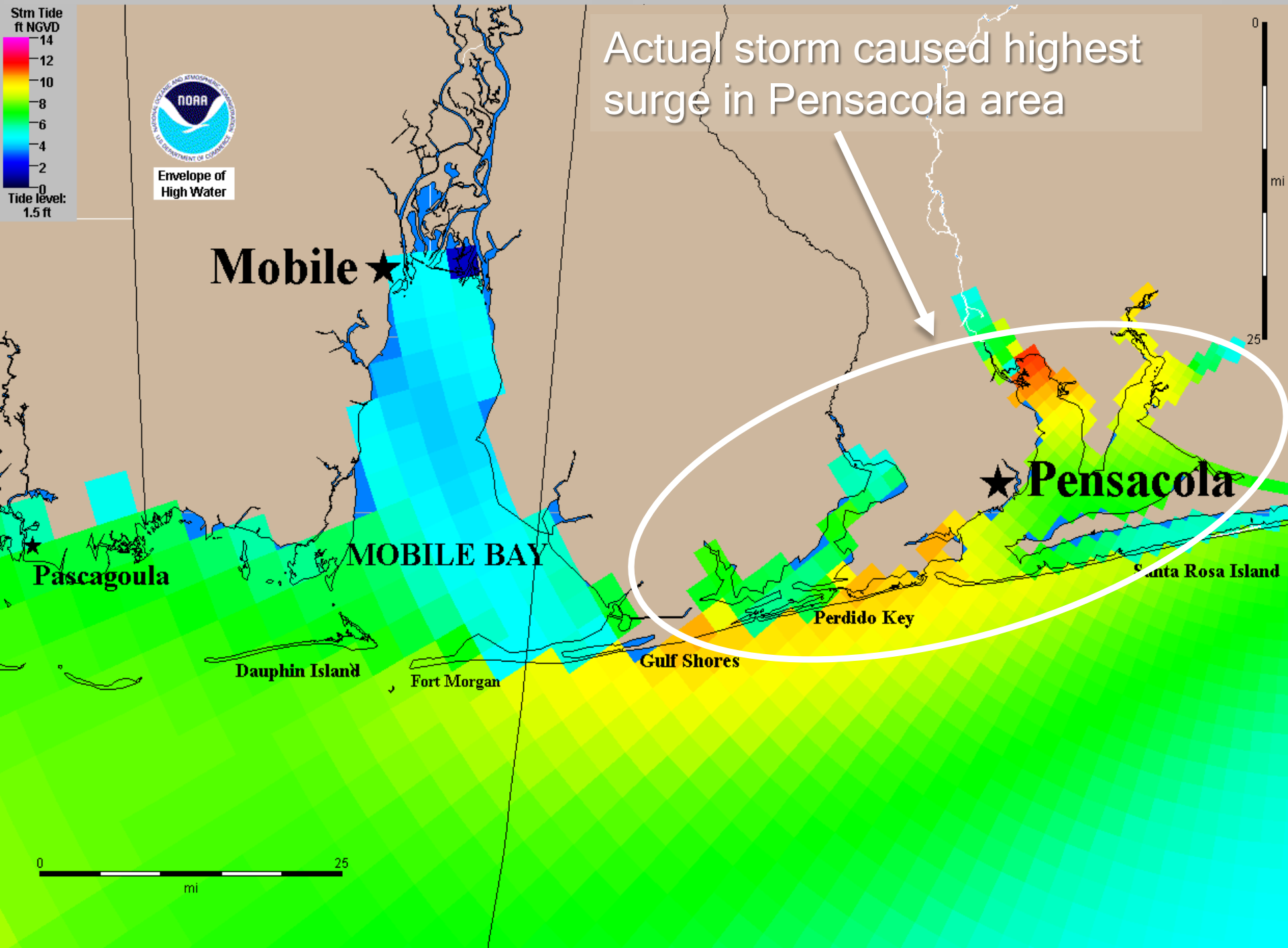
Psurge2.0


NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ABOUT
Experimental P-Surge 2.0: Probabilistic Hurricane Storm Surge (with tide)
MDL
Click Map to Zoom
Storm and Year
Sandy2012
Advisory
27
Type
10% Exceedance Ht
Datum
Above Datum
Download Data
SHP
GRIB II
KMZ
View Google Map
P-Surge 1.0
3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
41
40
39
38
37
-79 -78 -77 -76 -75 -74 -73 -72 -71 -70
Hurricane Sandy(2012) Advisory 27: Storm surge (with tide) heights
in feet above NAVD-88 with a 1 in 10 chance of being exceeded.
EXPERIMENTAL Data valid from Oct 28, 07 PM EST to Nov 01, 01 AM EST

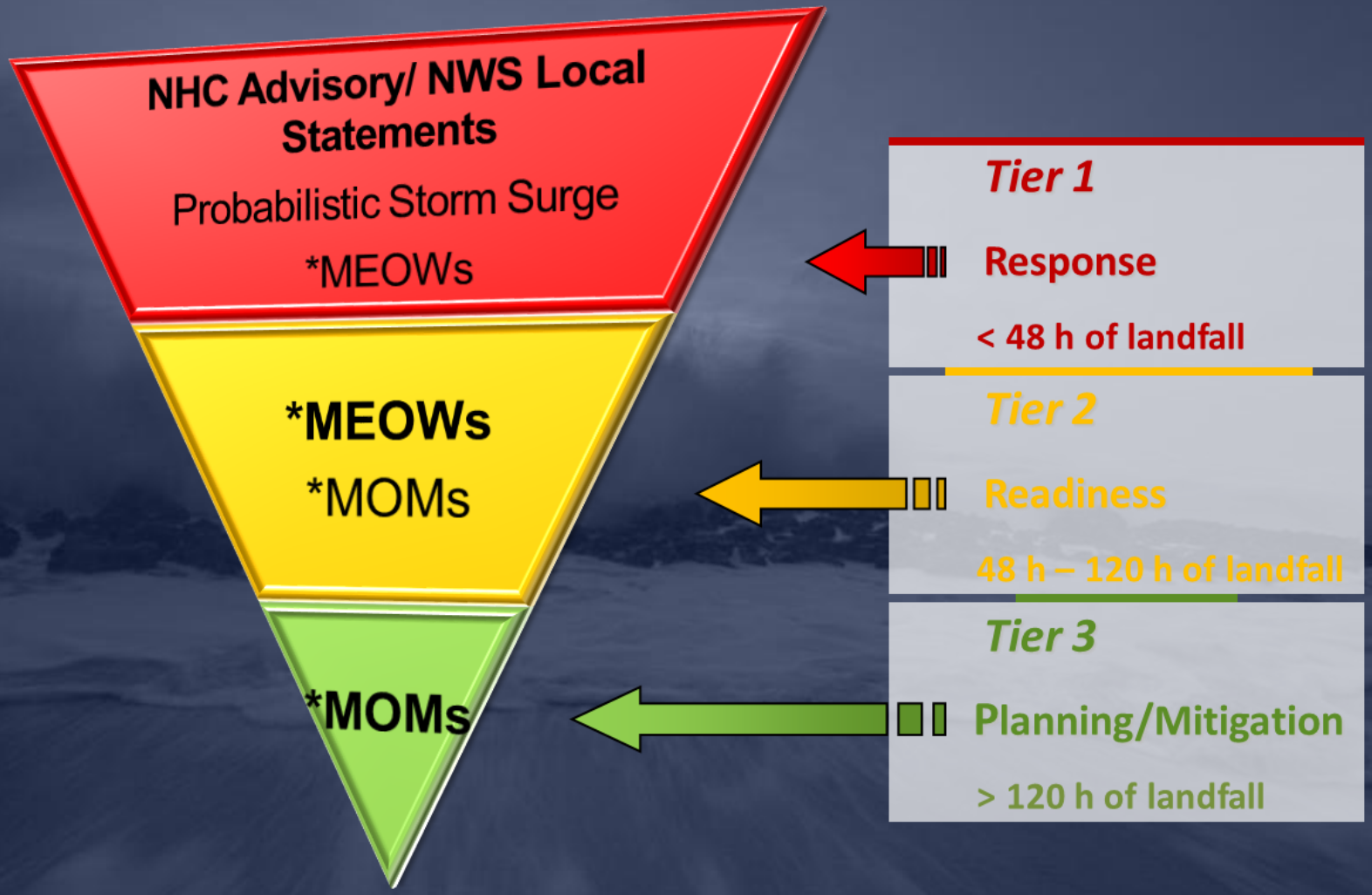


Surge Based on NHC -12 hr. Advisory


Storm: Ivan2004 Adv54
Type: Prob. of surge > 8 feet
Zoom Level: Full
Experimental Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge >= 8 feet at Individual Locations
Hurricane Ivan (2004) Advisory 54
Valid from 05 PM EDT Wed Sep 15 to 10 PM EDT Sat Sep 18
Probabilistic product shows considerable surge threat to Pensacola area
31
30
-88
-87
5%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Probability

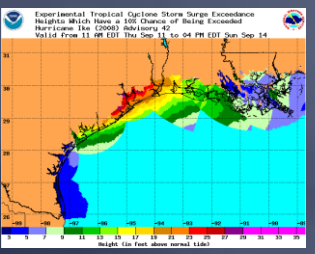

Stm Tide
ft NGVD
14
12
10
8
6
4
2
0
Tide level:
1.5 ft
Envelope of
High Water
Actual storm caused highest surge in Pensacola area
Mobile
Pensacola
Pascagoula
MOBILE BAY
Dauphin Island
Fort Morgan
Gulf Shores
Perdido Key
Santa Rosa Island
0
25
mi
0
25
mi

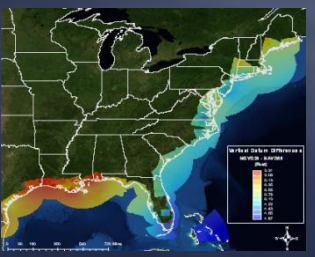
Storm Surge Decision Support Wedge

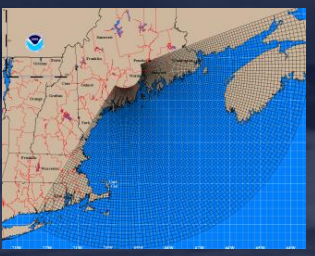


Experimental Potential Storm Surge Flooding Map

NHC Experimental Inundation Graphic

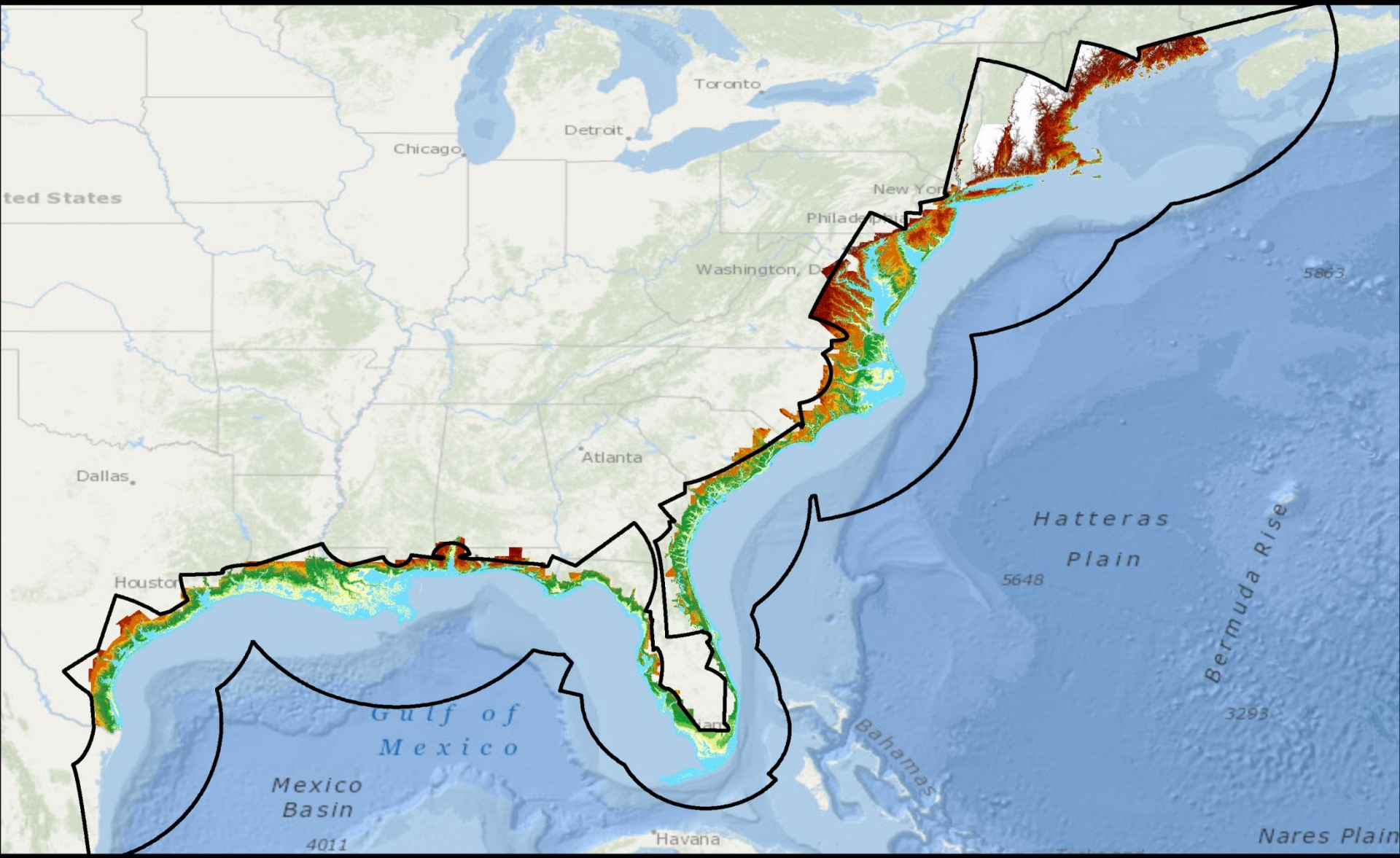




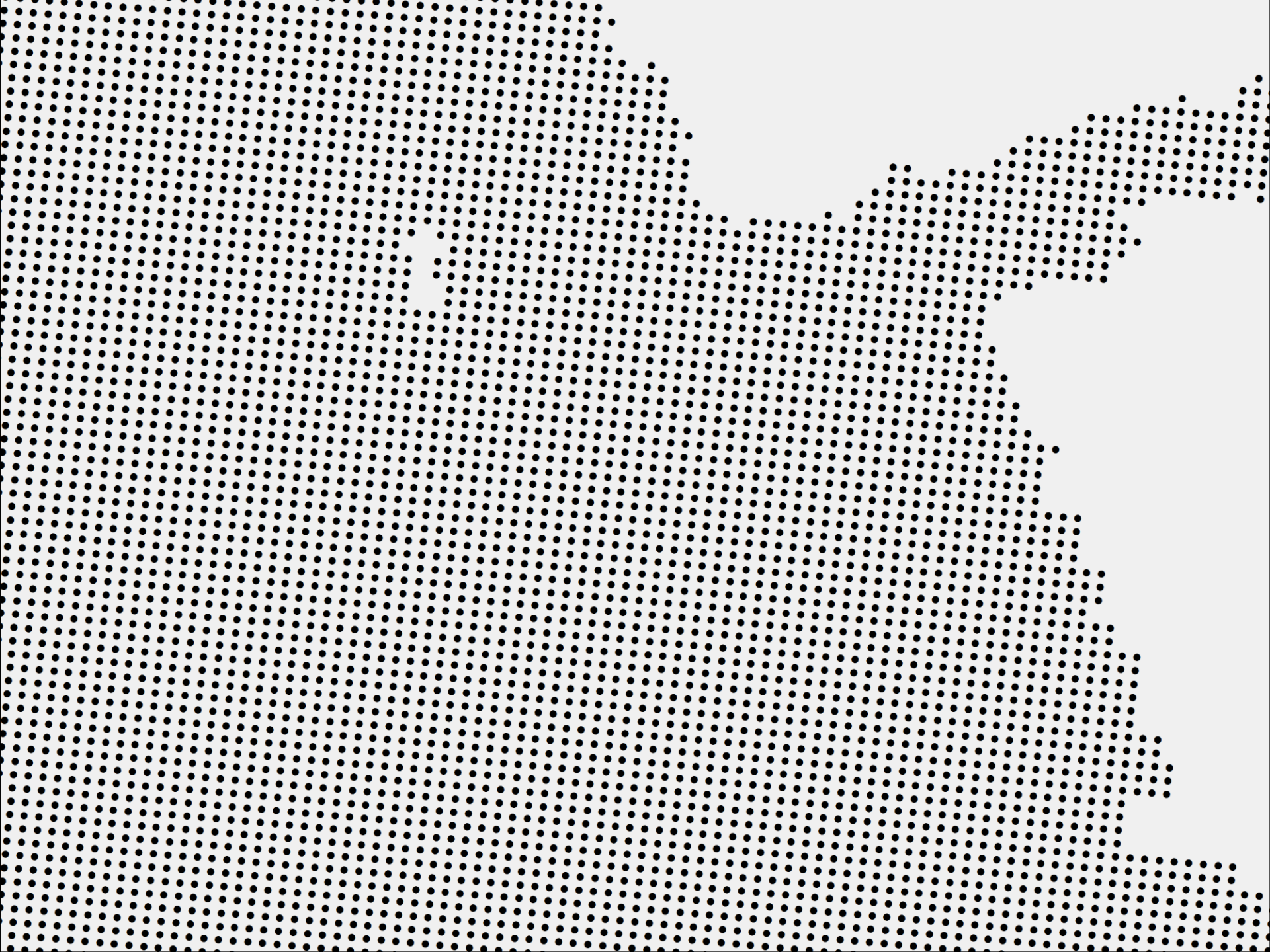


- Which product will drive inundation
  - Experimental psurge2.0 (includes tides)
  - 10% Exceedance
- Grids
  - Latest SLOSH basins updated to NAVD88
- Topography/DEMs
  - NOAA CSC Sea-level rise DEM
    - Resampled to smoother resolution
  - Augmented with USGS NED
- Processing
  - Locally using ArcGIS for Server and Desktop
  - Working toward leveraging NWS integrated dissemination program (IDP) for 2015 season

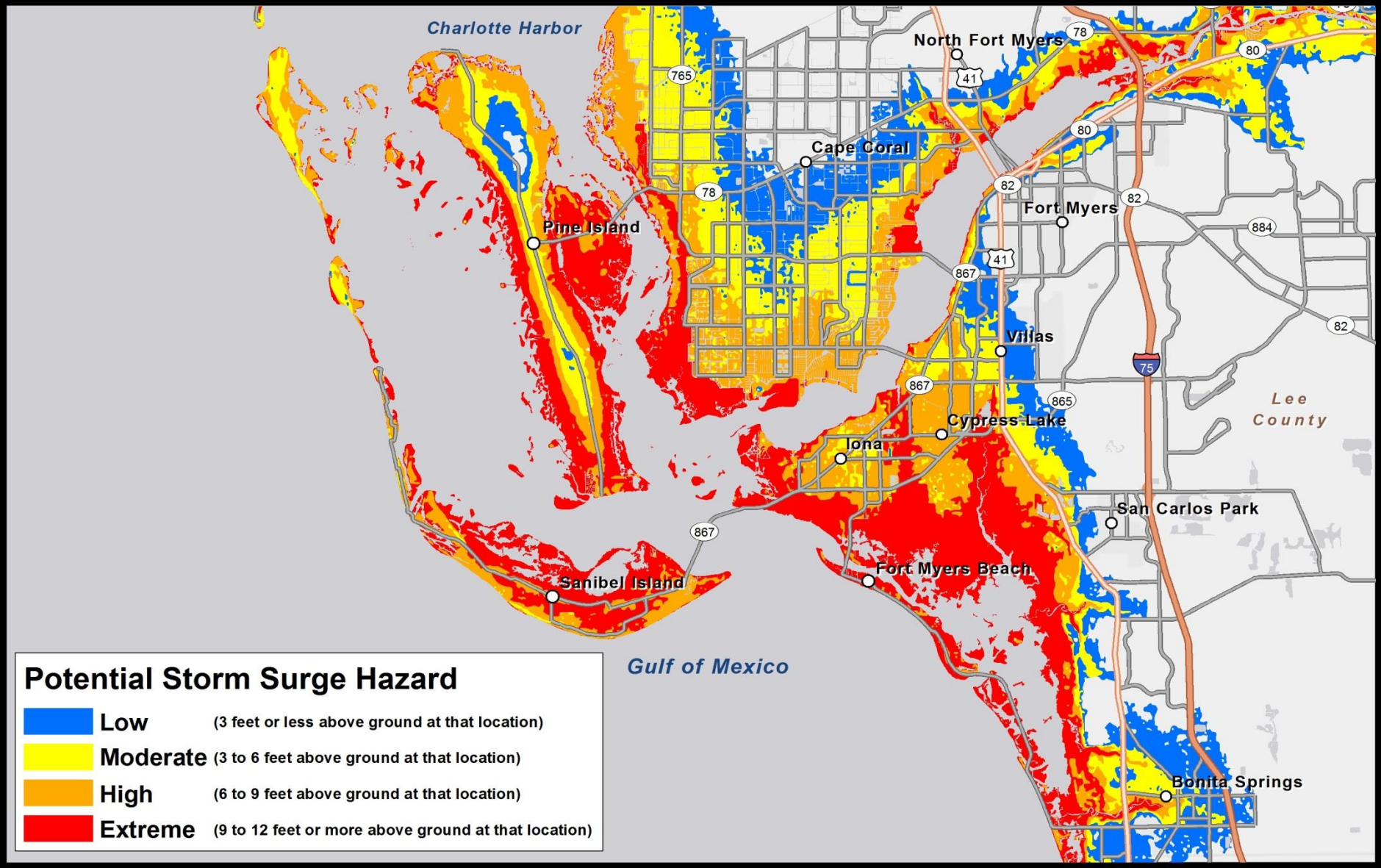
SLOSH Basins and DEMs



National Hurricane Center
Storm Surge Unit

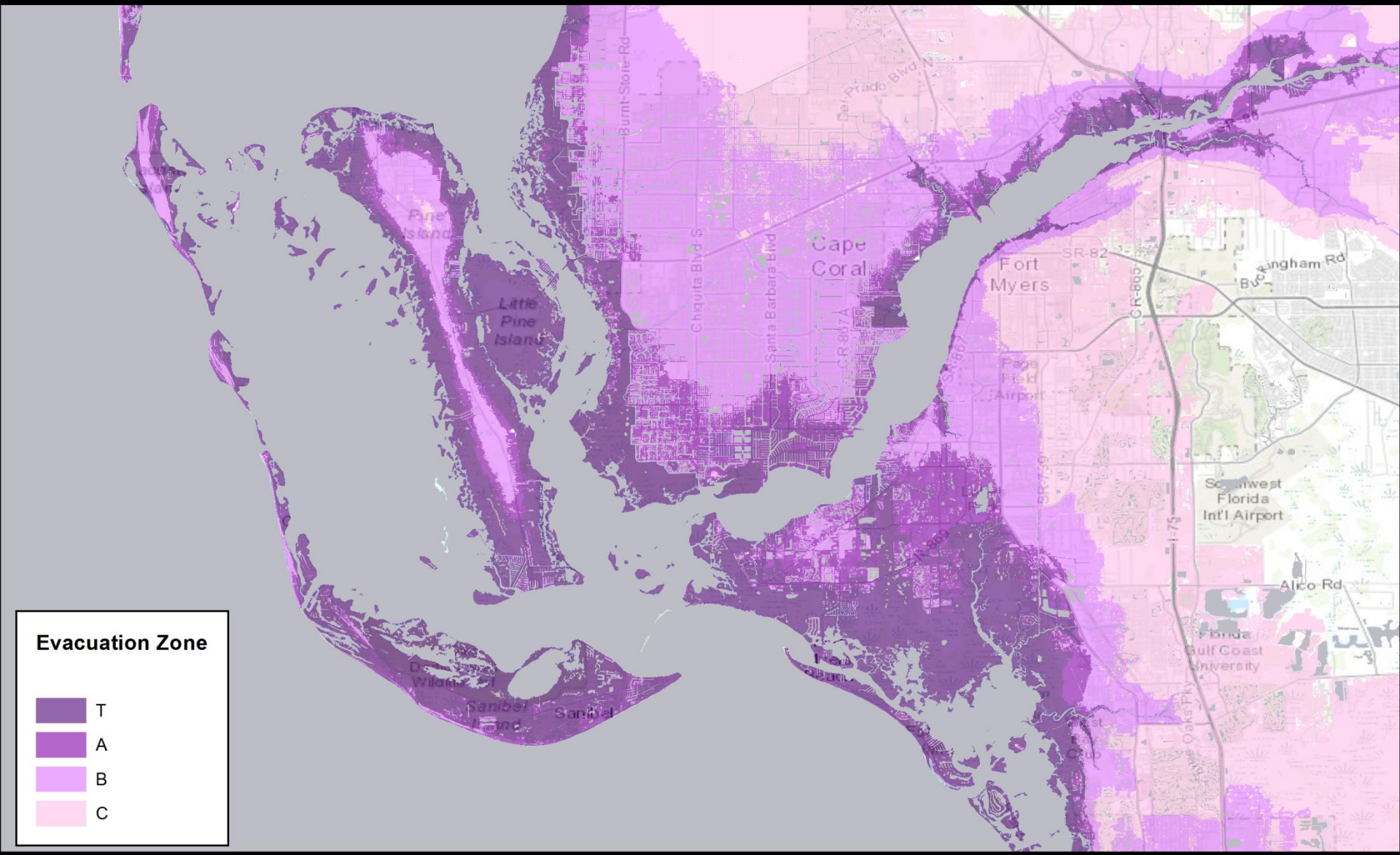


Hurricane X

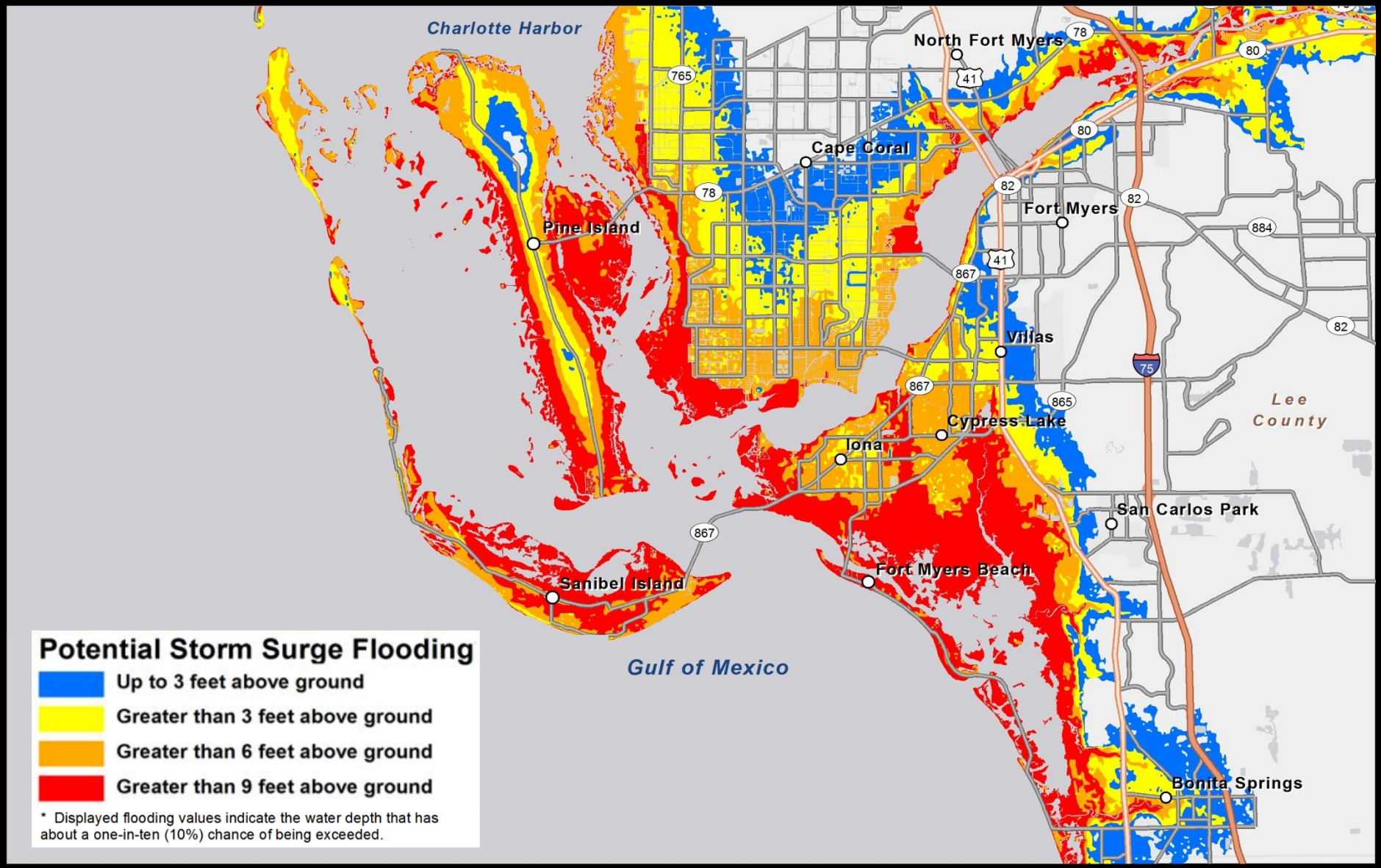


National Hurricane Center
Storm Surge Unit

Southwest Florida Evacuation Zones - T, A, B, C

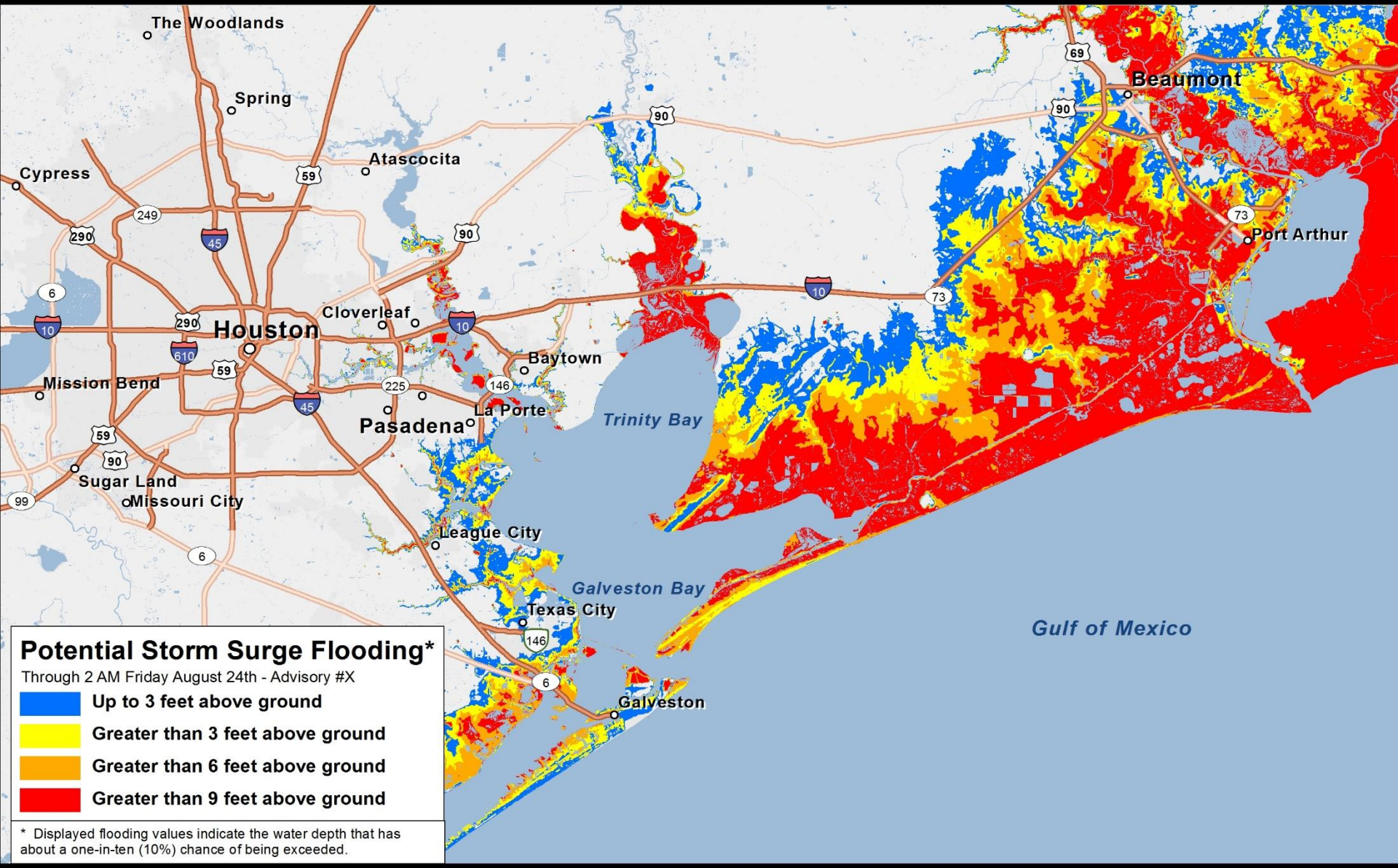


Hurricane X



National Hurricane Center
Storm Surge Unit

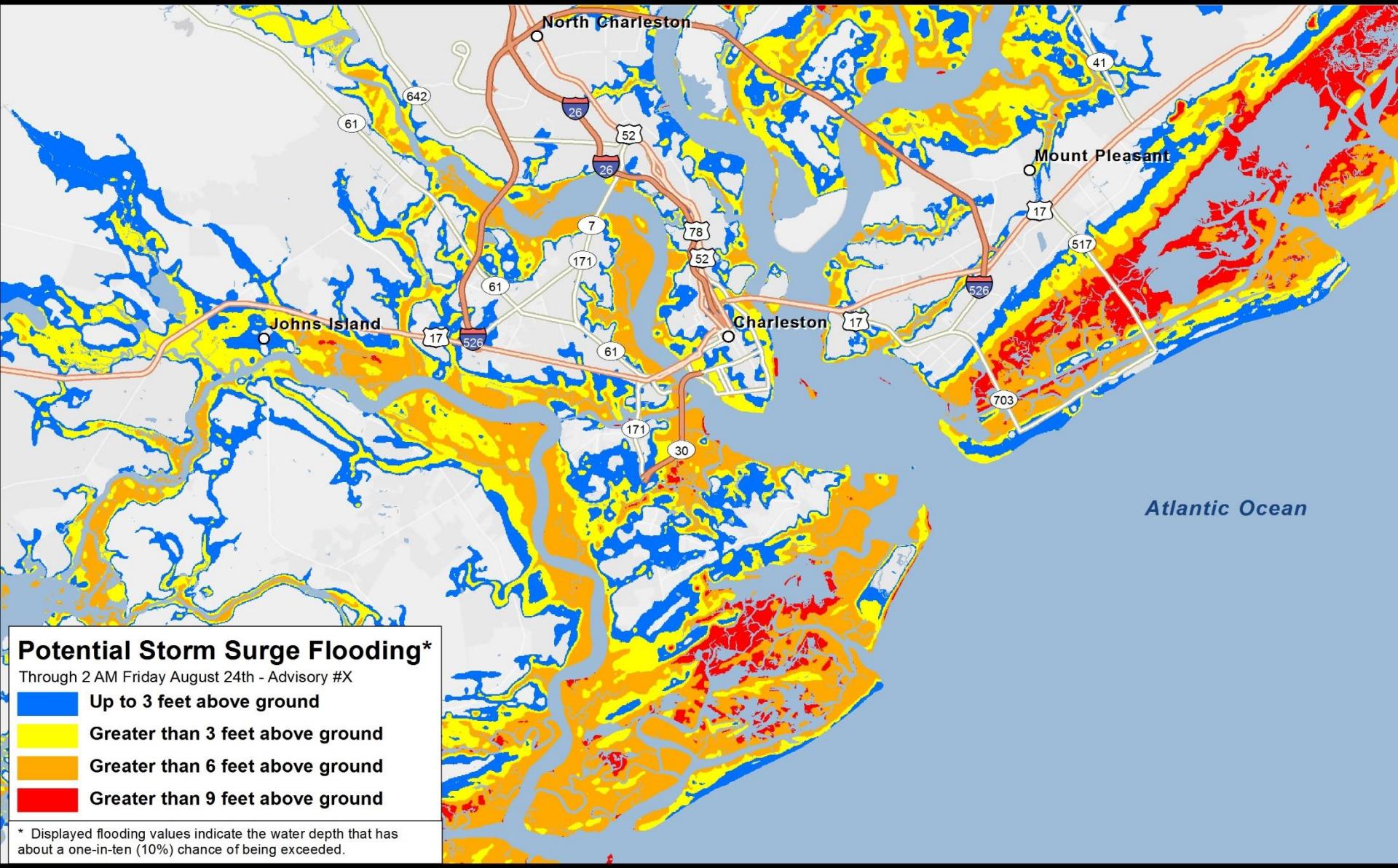
Hurricane X



National Hurricane Center
Storm Surge Unit

Hurricane X

0 2 4 Miles



Potential Storm Surge Flooding*

Through 2 AM Friday August 24th - Advisory #X

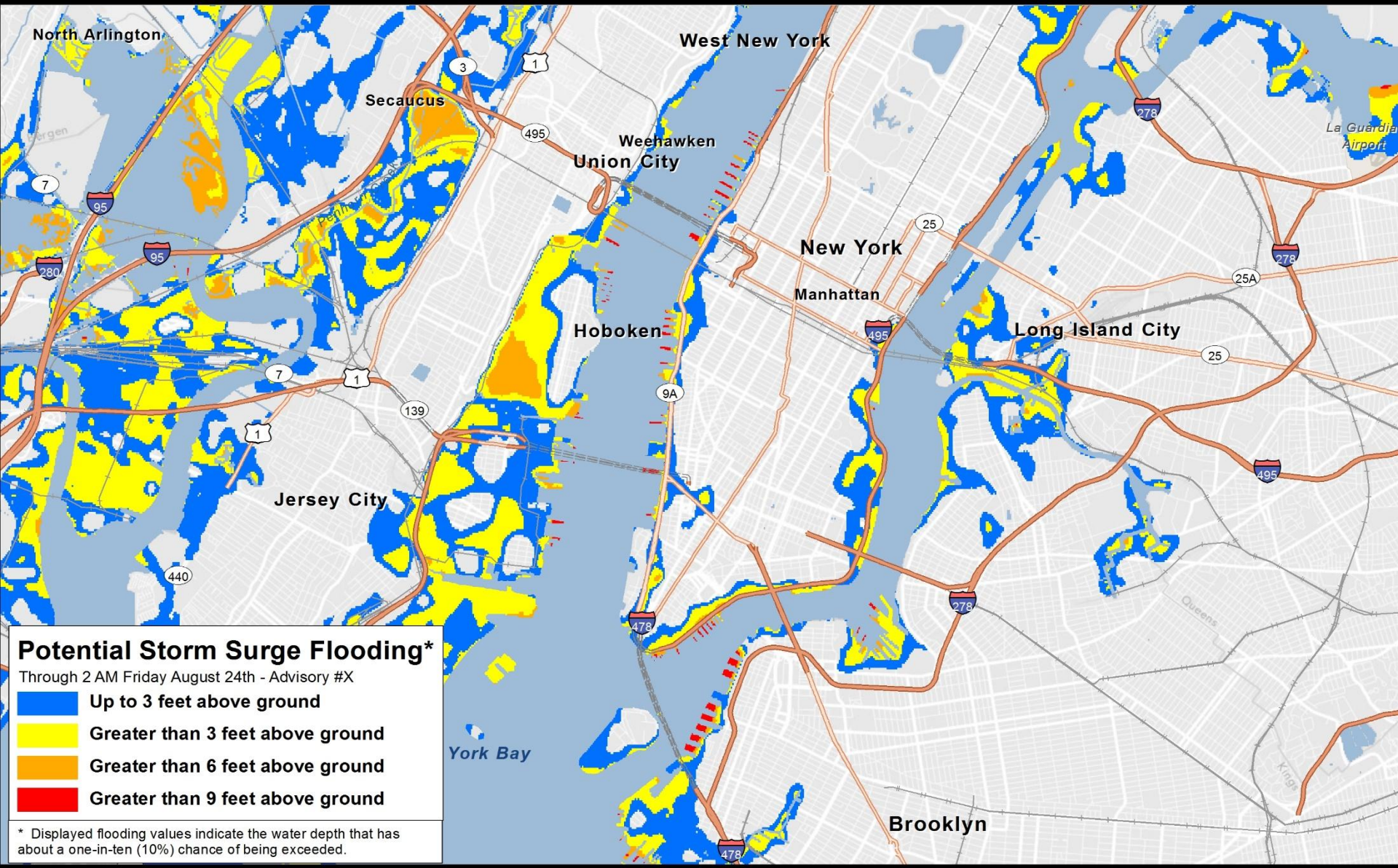
- Up to 3 feet above ground
- Greater than 3 feet above ground
- Greater than 6 feet above ground
- Greater than 9 feet above ground

* Displayed flooding values indicate the water depth that has about a one-in-ten (10%) chance of being exceeded.

National Hurricane Center
Storm Surge Unit

Hurricane X

0 1 2 Miles



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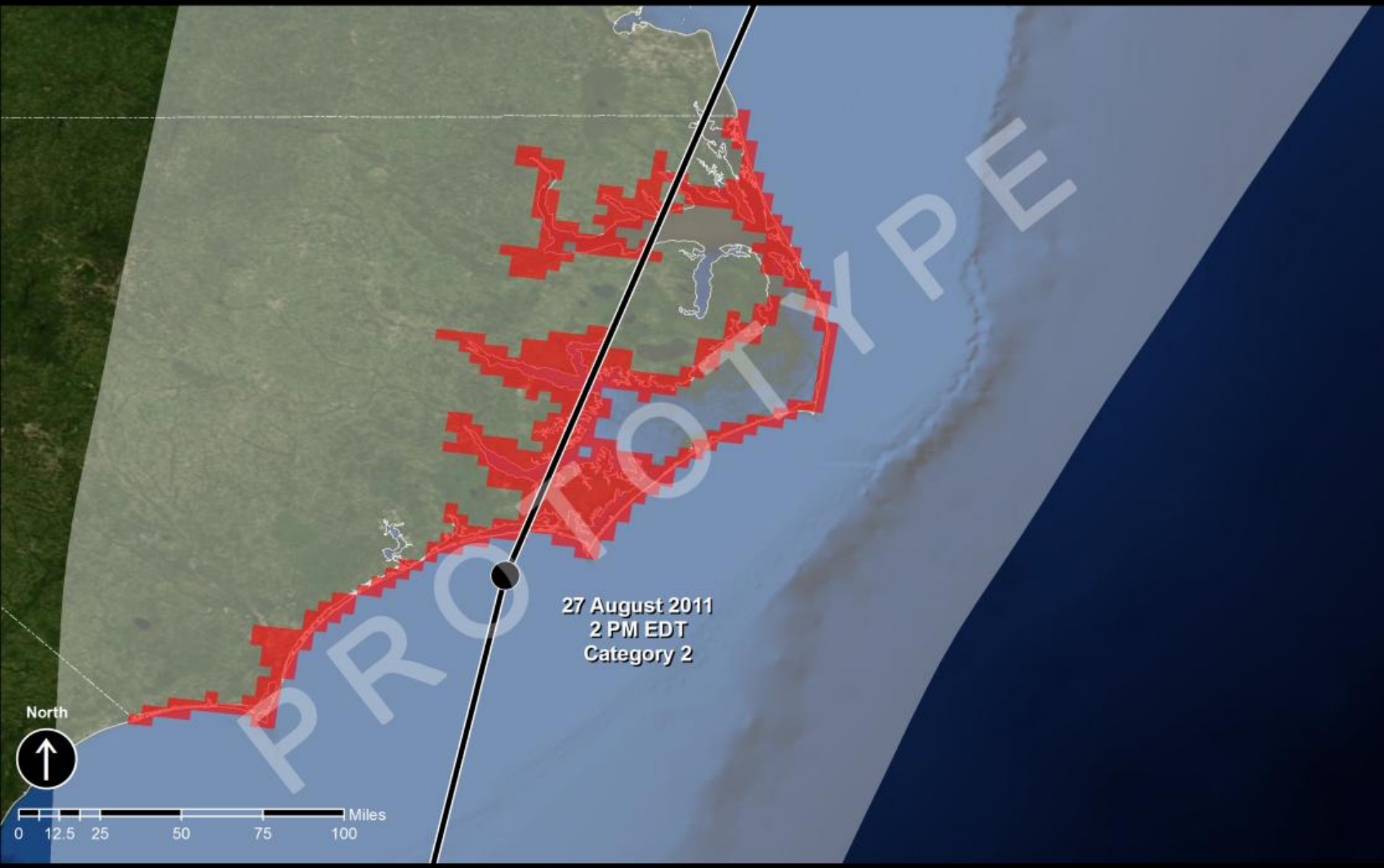
National Hurricane Center
Storm Surge Unit

Takeaways

- Available during the 2014 hurricane season experimentally via the NHC website
  - No data dissemination during experimental phase
- User-friendly graphic of *potential* storm surge

Hurricane Irene, Advisory #22

Storm Surge Warning PROTOTYPE



National Hurricane Center
Storm Surge Unit

Hurricane Irene Adv #22 Forecast Track

NWS/NHC Storm Surge Warning