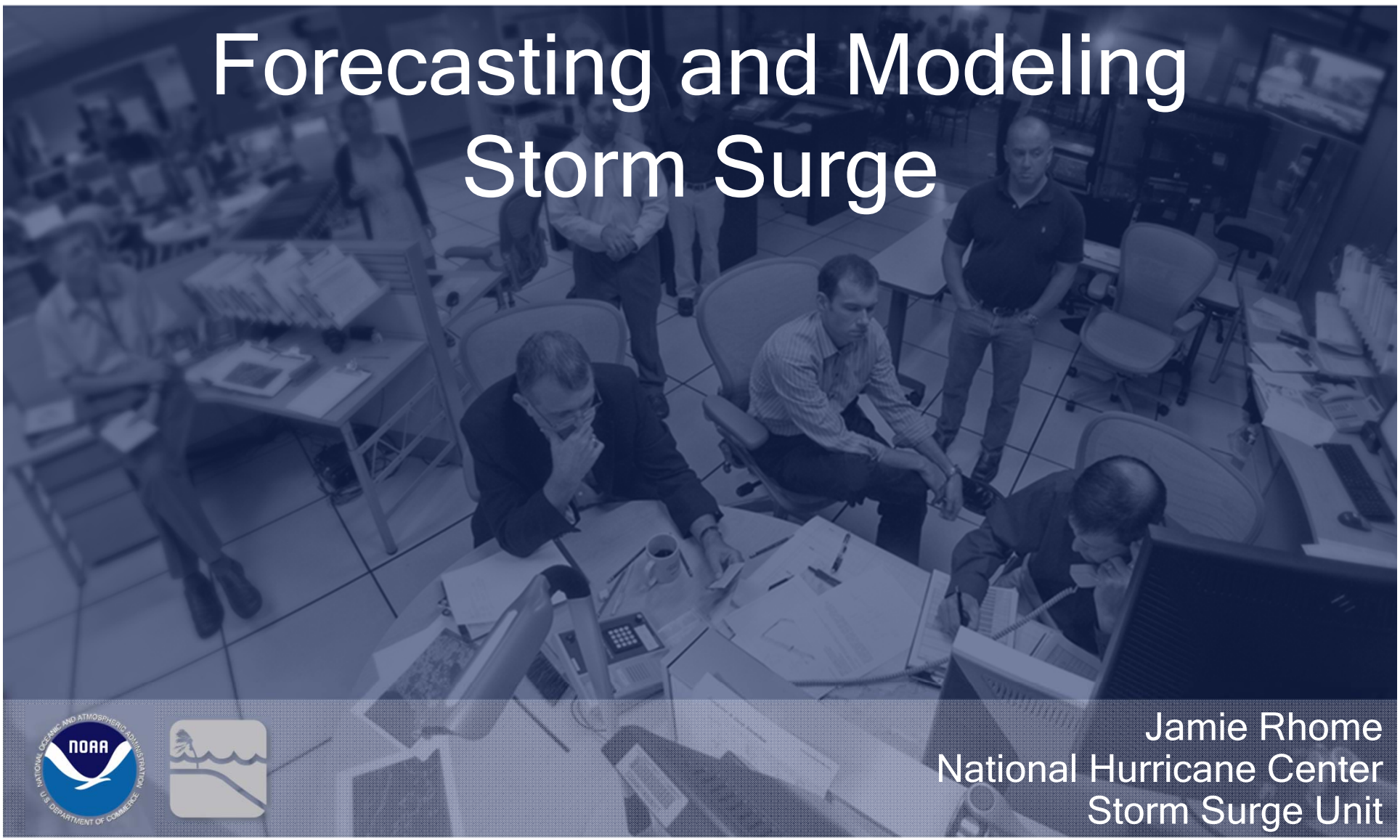
Forecasting and Modeling Storm Surge



Jamie Rhome
National Hurricane Center
Storm Surge Unit

Interpreting Surge Forecasts

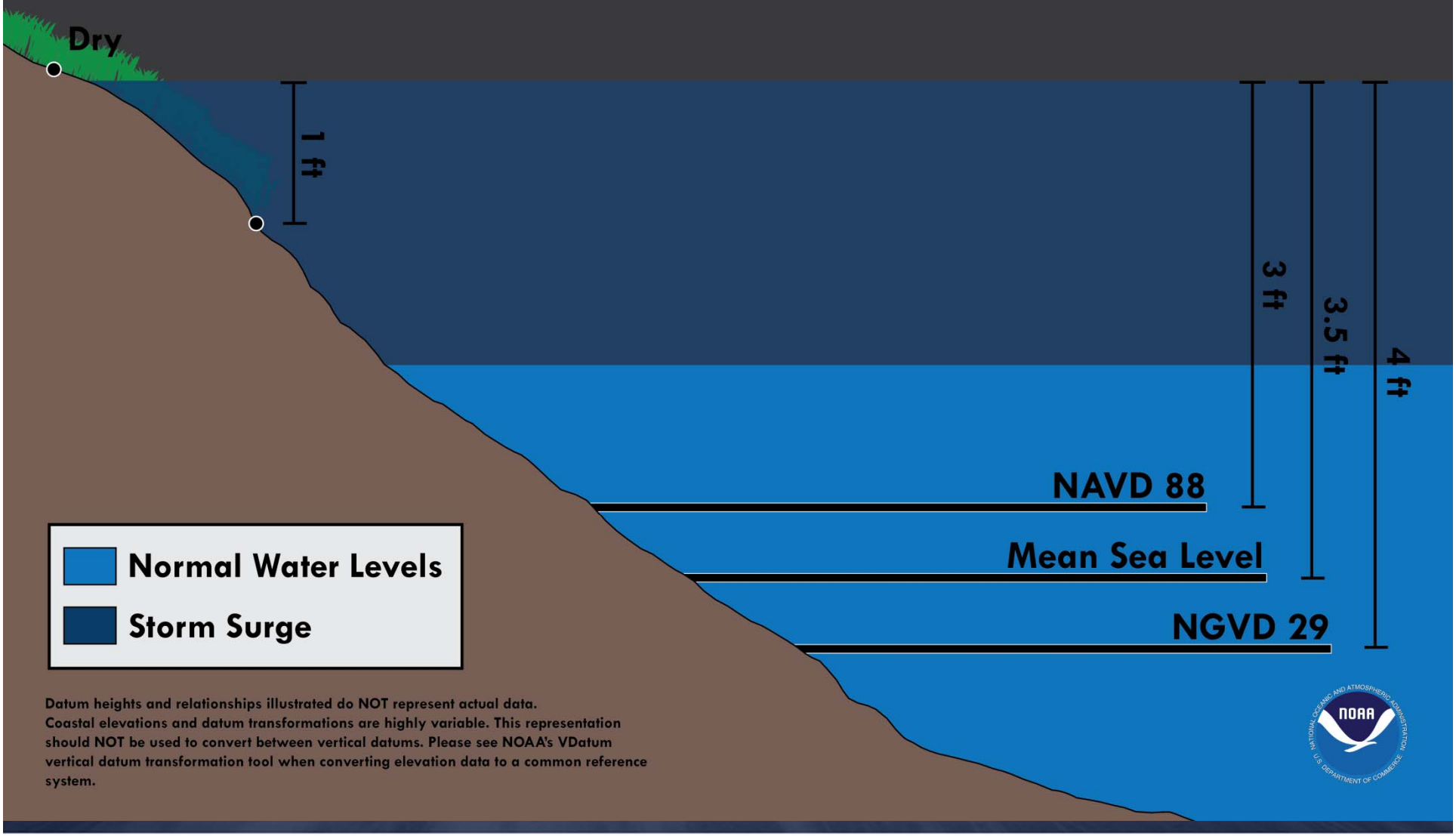
- What does 20 feet of storm surge mean?

  20 feet of storm surge above ground?
  20 feet of storm surge above mean sea level?
  What is mean sea level?

- All water level observations and models referenced as height above a vertical datum

- A vertical datum is simply a reference level, a zero surface to which storm surge heights are referred

Illustration of Vertical Datums



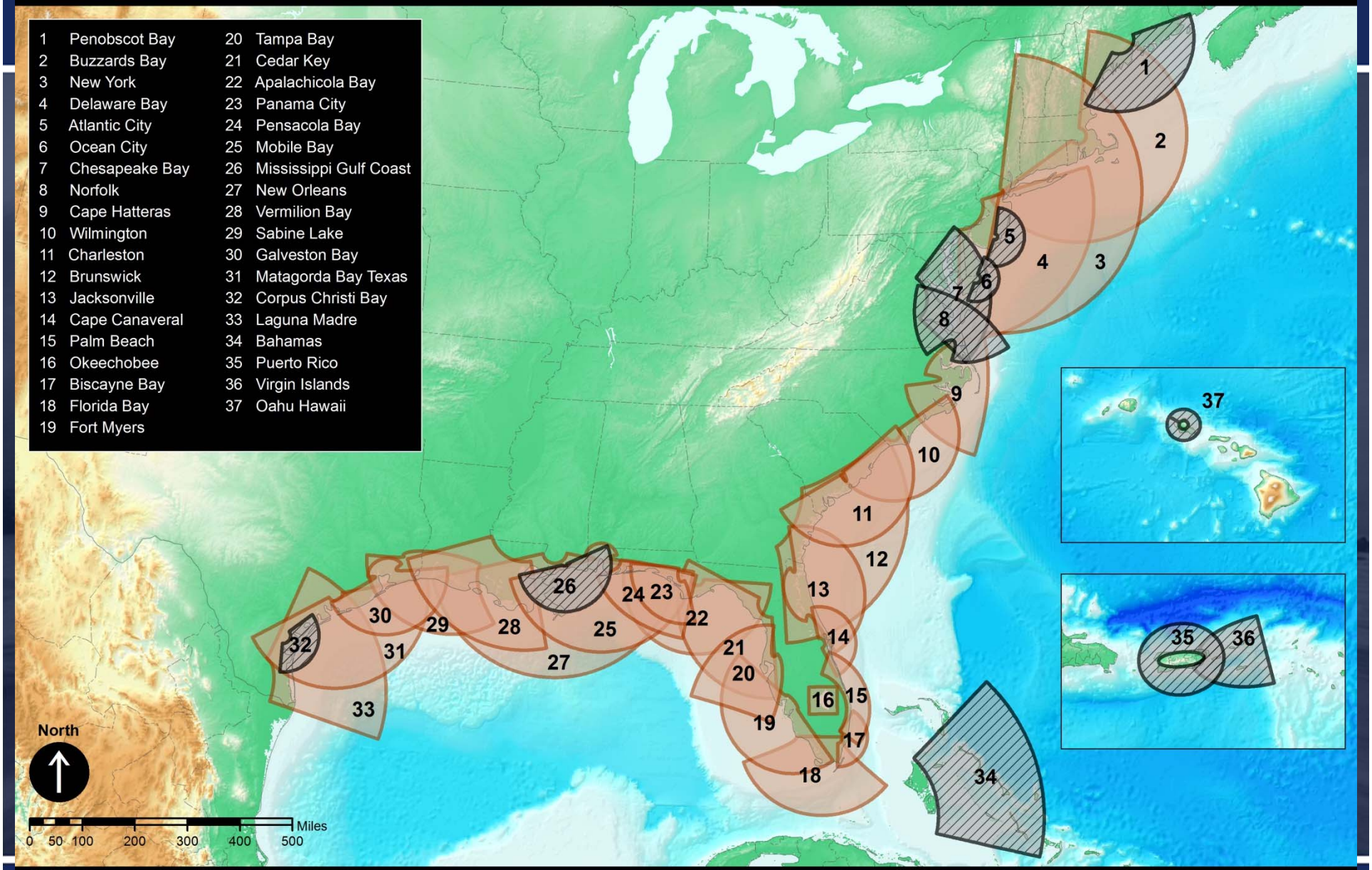
Datum heights and relationships illustrated do NOT represent actual data. Coastal elevations and datum transformations are highly variable. This representation should NOT be used to convert between vertical datums. Please see NOAA's VDatum vertical datum transformation tool when converting elevation data to a common reference system.

Vertical Datums

- Tidal datums reference water levels defined by a phase of the tide
  - Mean Sea Level (MSL)
  - Mean Lower Low Water (MLLW)
- Geodetic datums based on a simplified surface that represents the Earth's shape and size
  - National Geodetic Vertical Datum of 1929 (NGVD 29)
  - North American Vertical Datum of 1988 (NAVD 88)
- SLOSH references NAVD 88 and NGVD 29
- NAVD 88 is a newer, more accurate geodetic datum than NGVD 29

Operational SLOSH Basins by Vertical Datum

Updated February 2012



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NAVD88 SLOSH Basin

NGVD29 SLOSH Basin

Vertical Datums

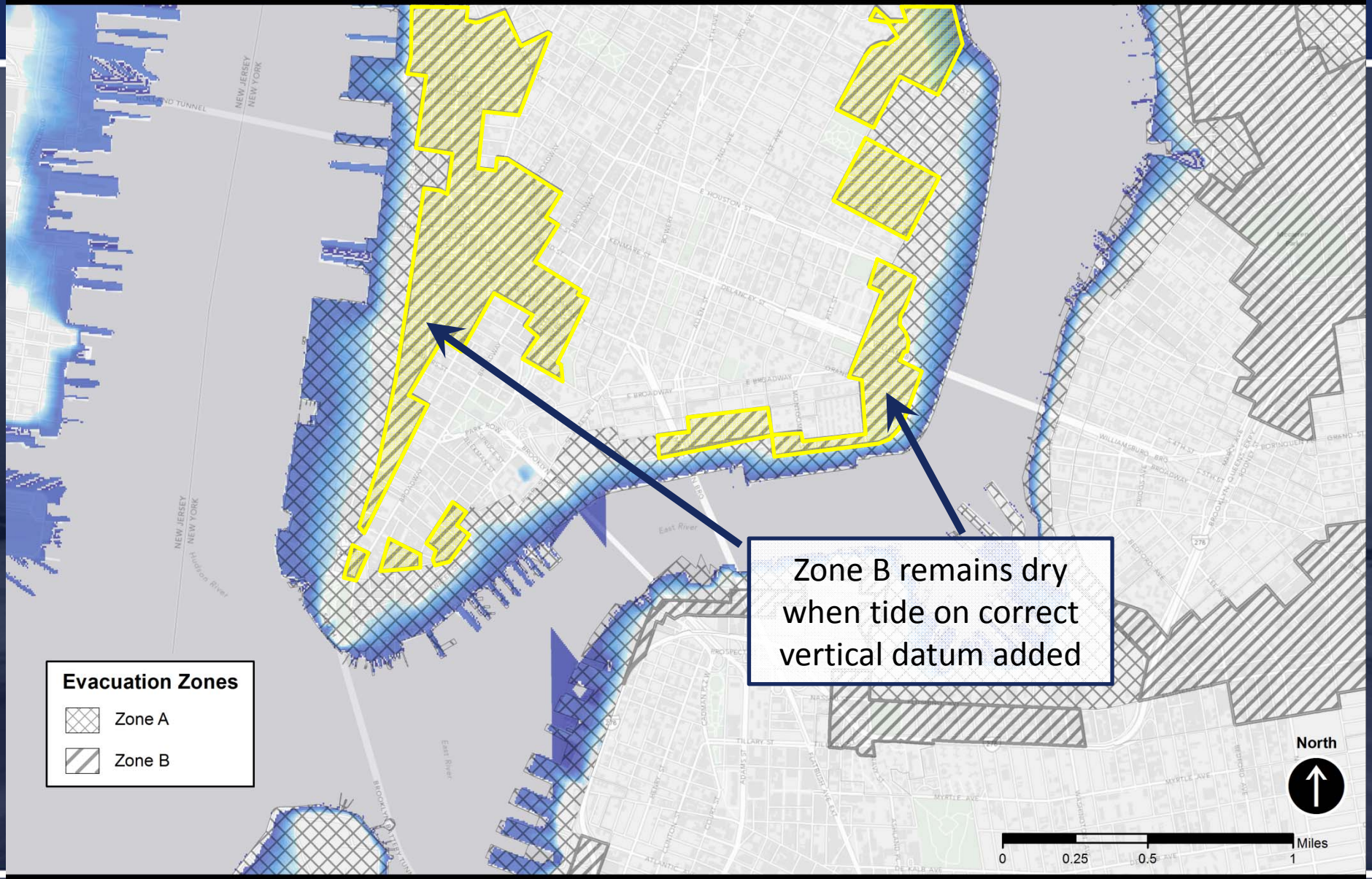
- What is the relationship between NAVD88, NGVD29 and MLLW?
  - Complex
  - Conversion tools exist but must be used carefully
  - Cannot extrapolate between locations
  - Real-time tide data available online in MLLW and NAVD88 (tidesandcurrents.noaa.gov)

Vertical Datums
Bottom Line

- Know your vertical datum (20 feet of surge above…)
- NEVER attempt to add tide to a storm surge forecast
- ALWAYS use consistent vertical datums when comparing water levels
- One cannot use a given conversion factor for datums conversion
- Datums conversion tools do exist but they are complicated
- When in doubt, don't go it alone. Rely on your local NWS office for assistance!

Hurricane Irene, Advisory #27

Potential Storm Tide Inundation, Correct Datum



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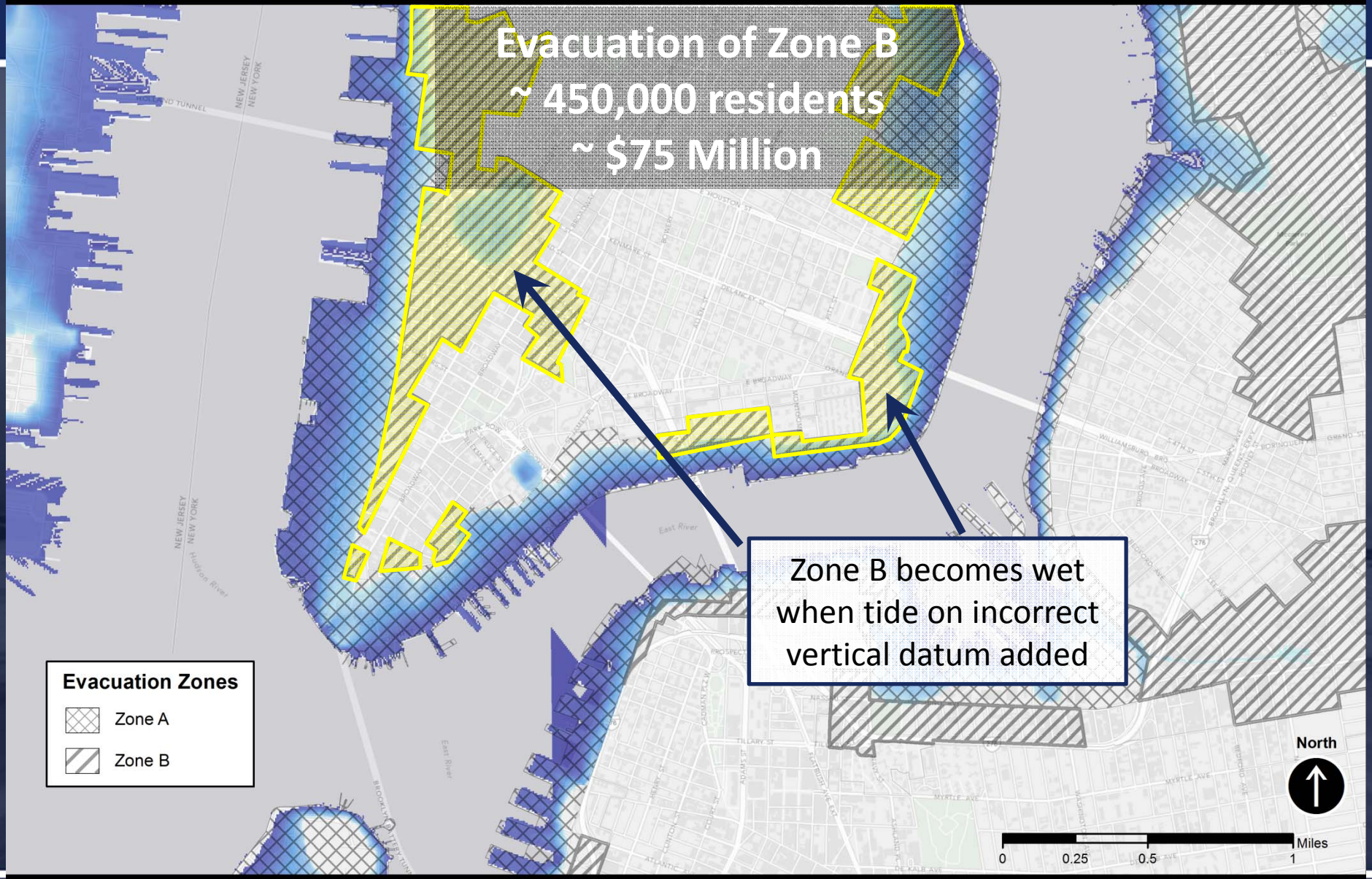
Hurricane Irene, Advisory #27

Potential Storm Tide Inundation, Incorrect Datum



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Modeling Surge

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

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  - 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

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Deterministic Numerical Models

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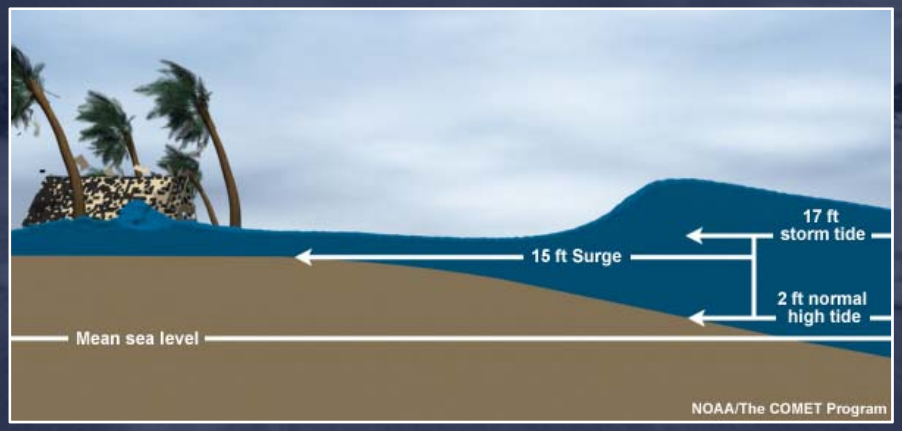
- Numerical Model Ensemble
  - Many different runs of the same model but with different conditions (family of storms)
  - Best approach for determining storm surge vulnerability for an area since it takes into account forecast uncertainty

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



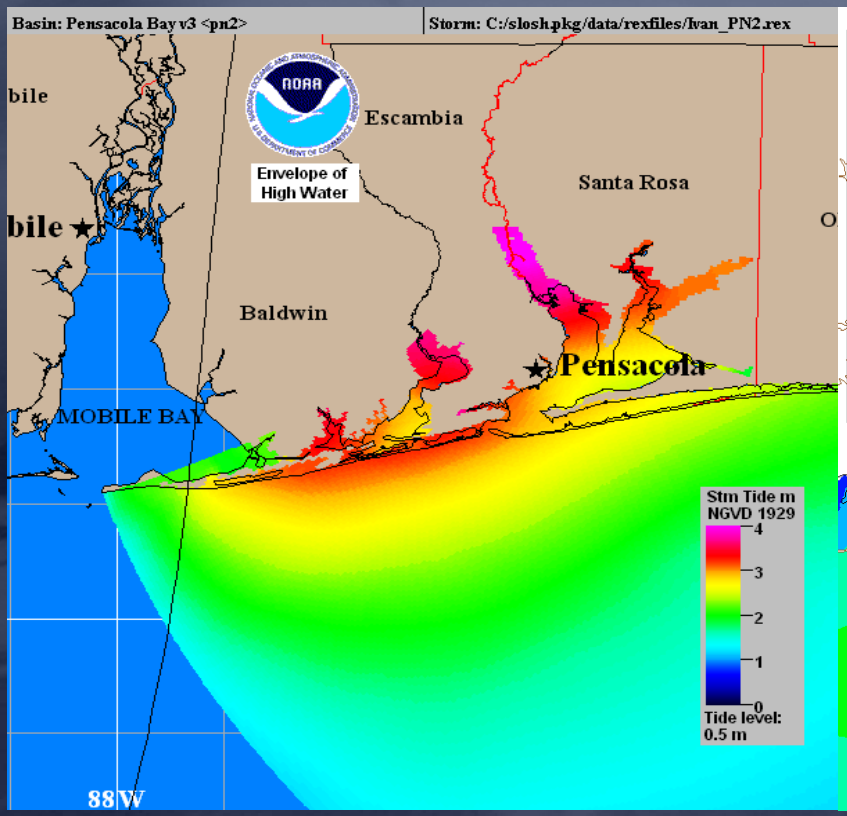
SLOSH
Strengths and Limitations

- 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)

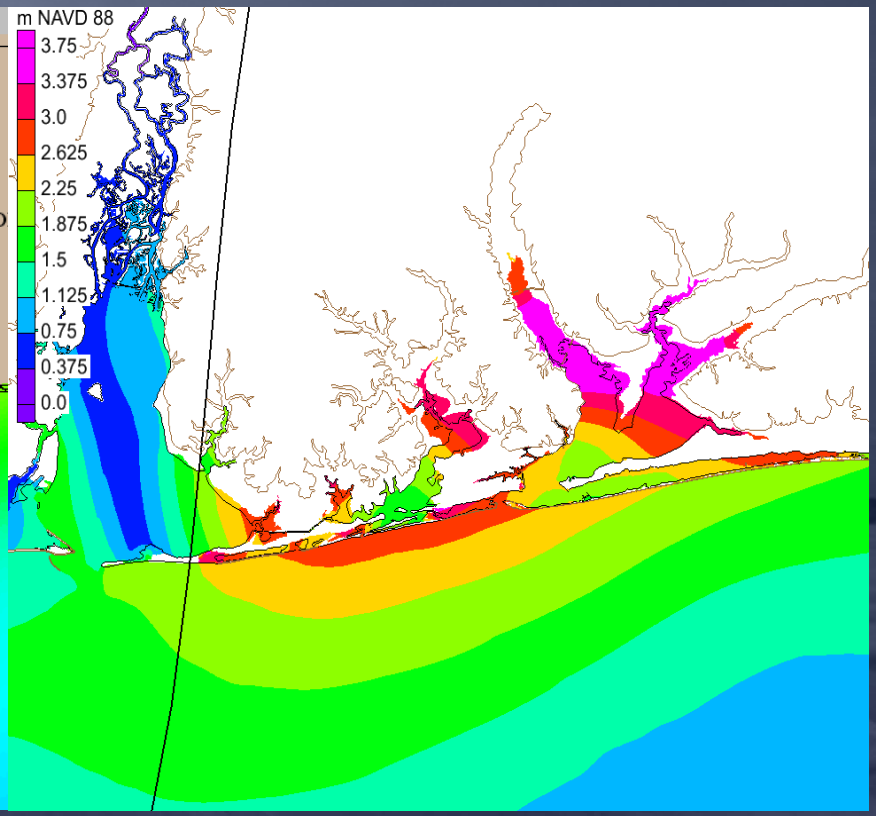
- SLOSH does not include:
  - Breaking waves/wave run-up
  - Astronomical tide
  - Operational runs can be run at different tide levels via an initial water level (anomaly)
  - Normal river flow and rain

SLOSH and ADCIRC

Overall flooding pattern very similar



SLOSH run, Hurricane Ivan



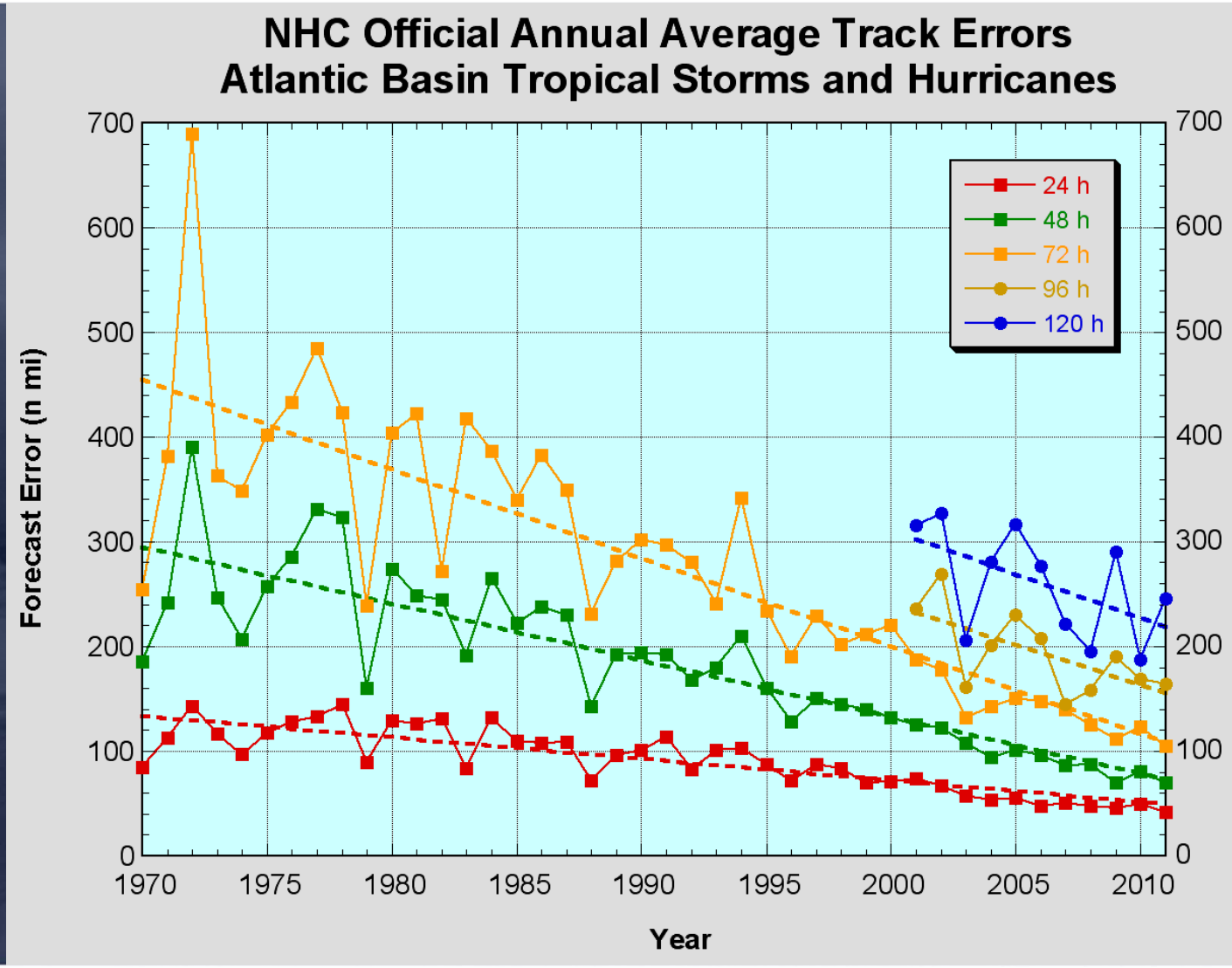
ADCIRC run, Hurricane Ivan

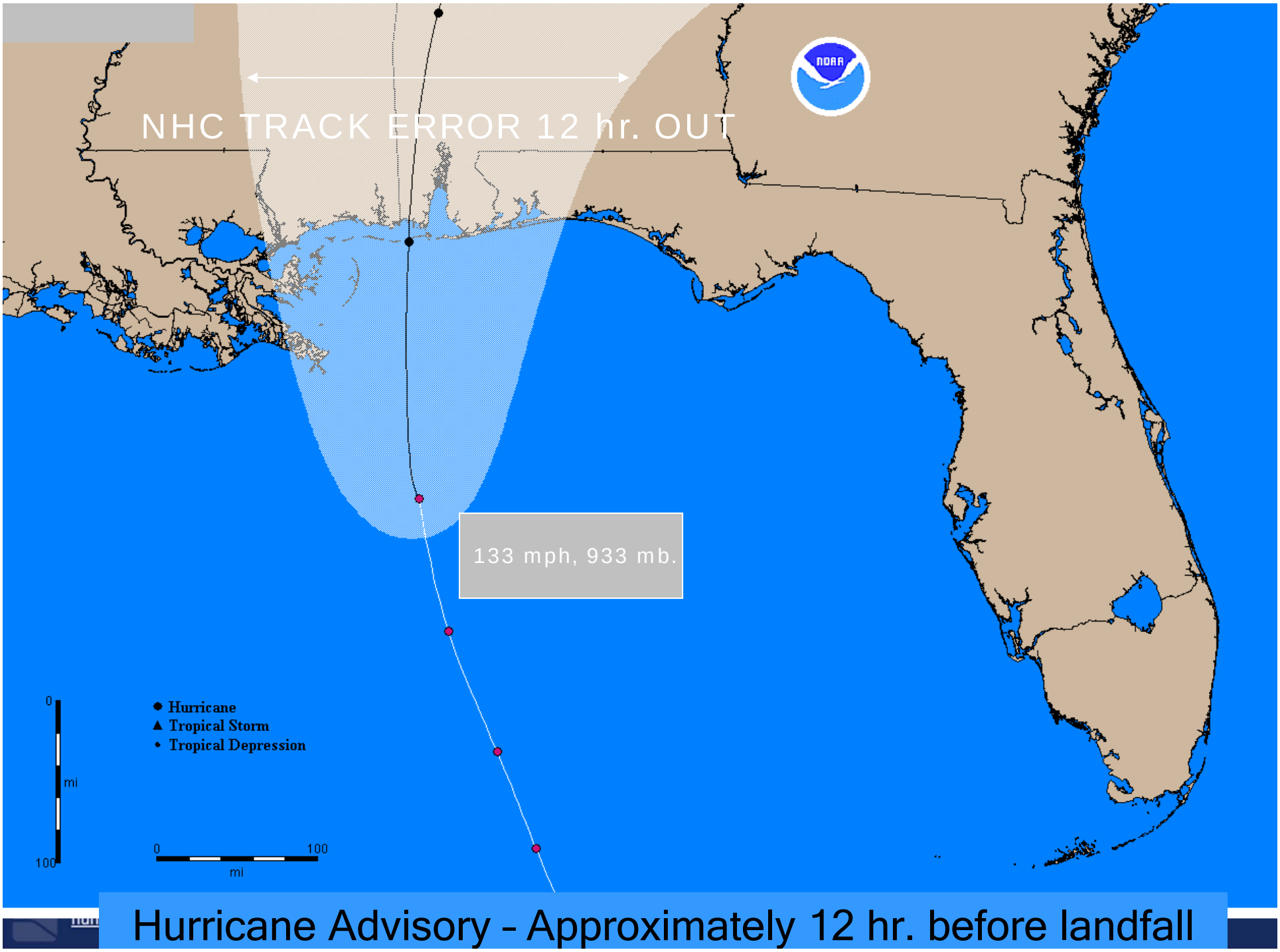
Forecasting Storm Surge

- 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

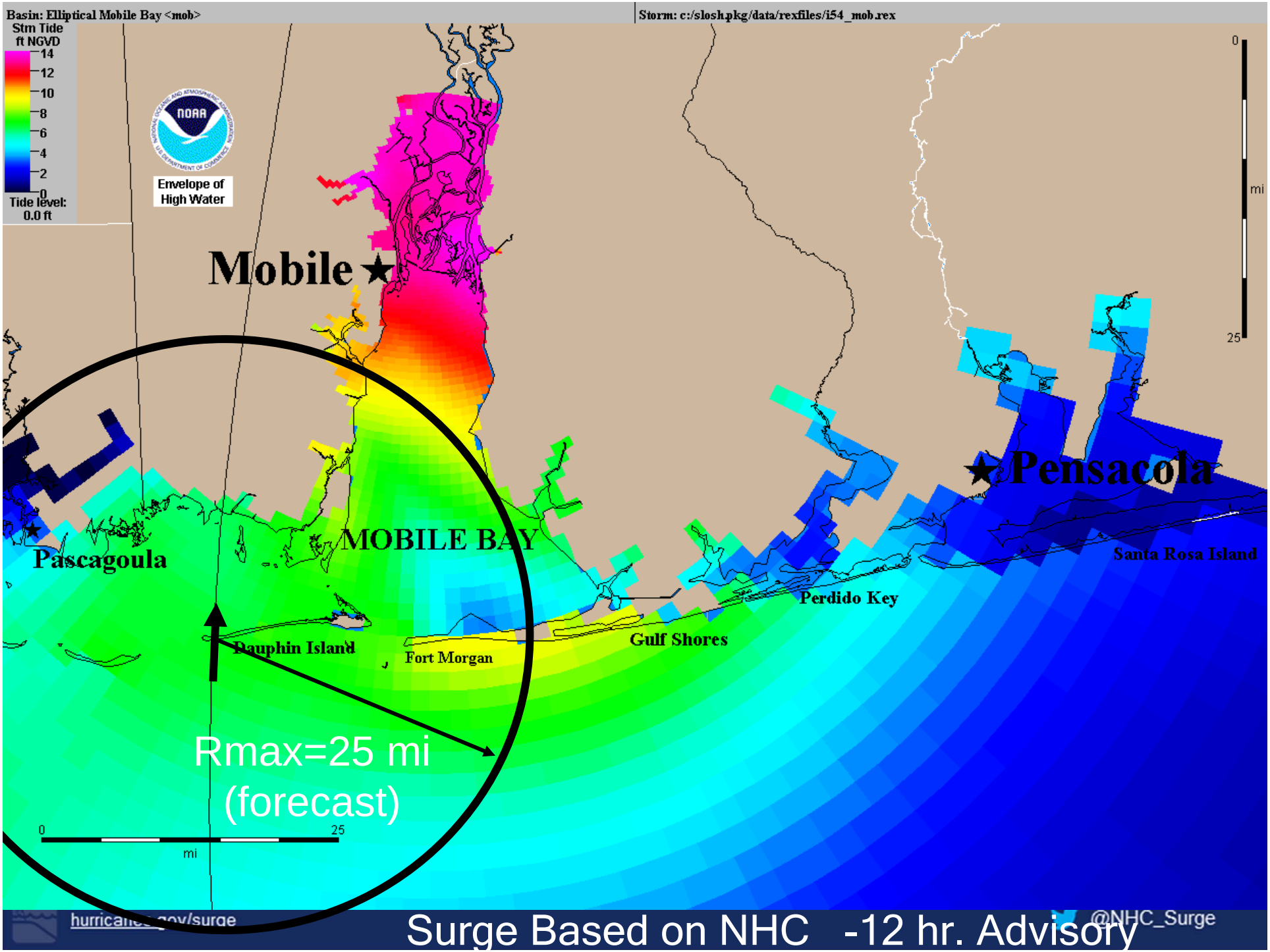
Total water rise = surge + tides + waves + freshwater flow

Track Forecast Uncertainty

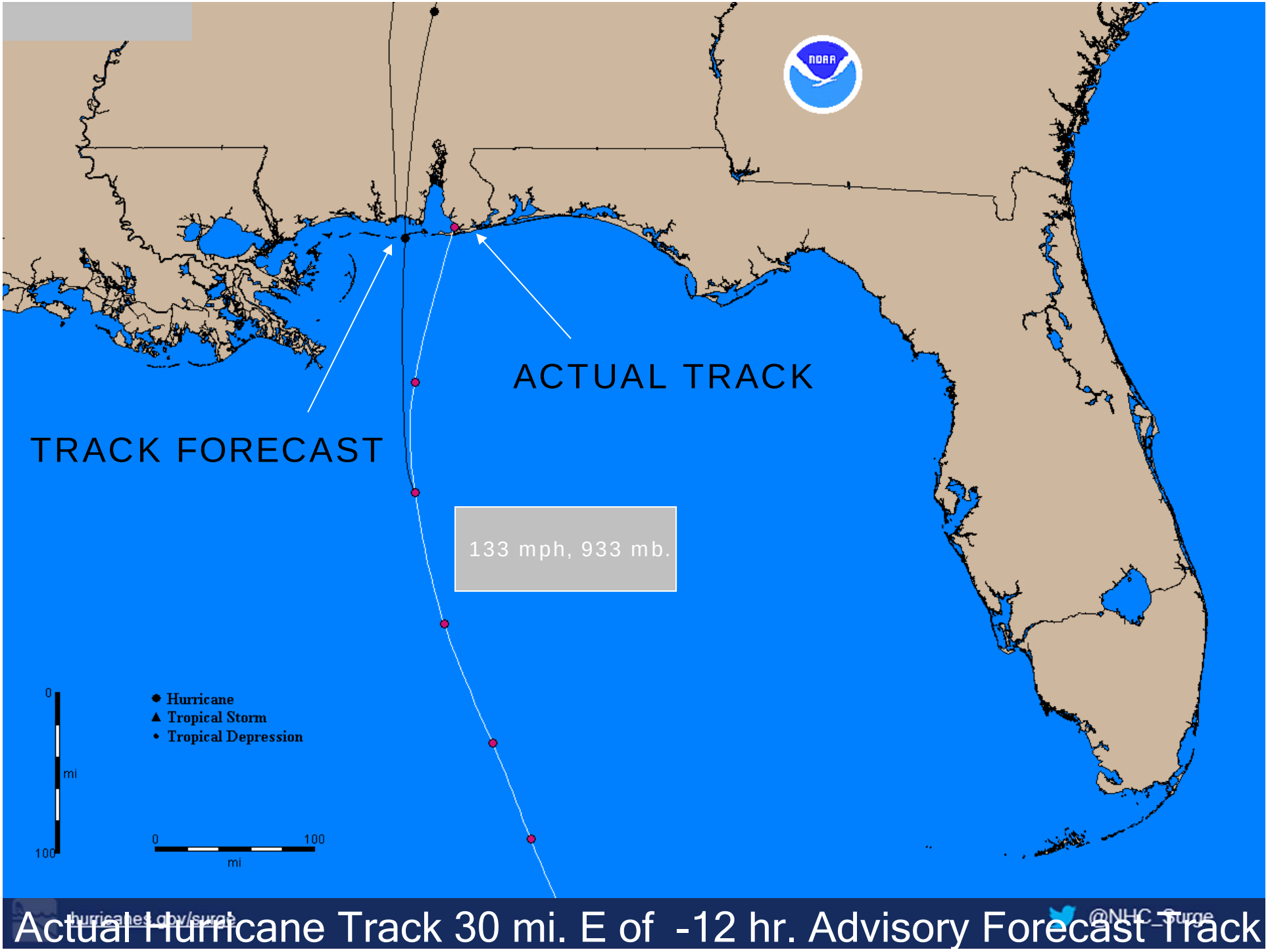




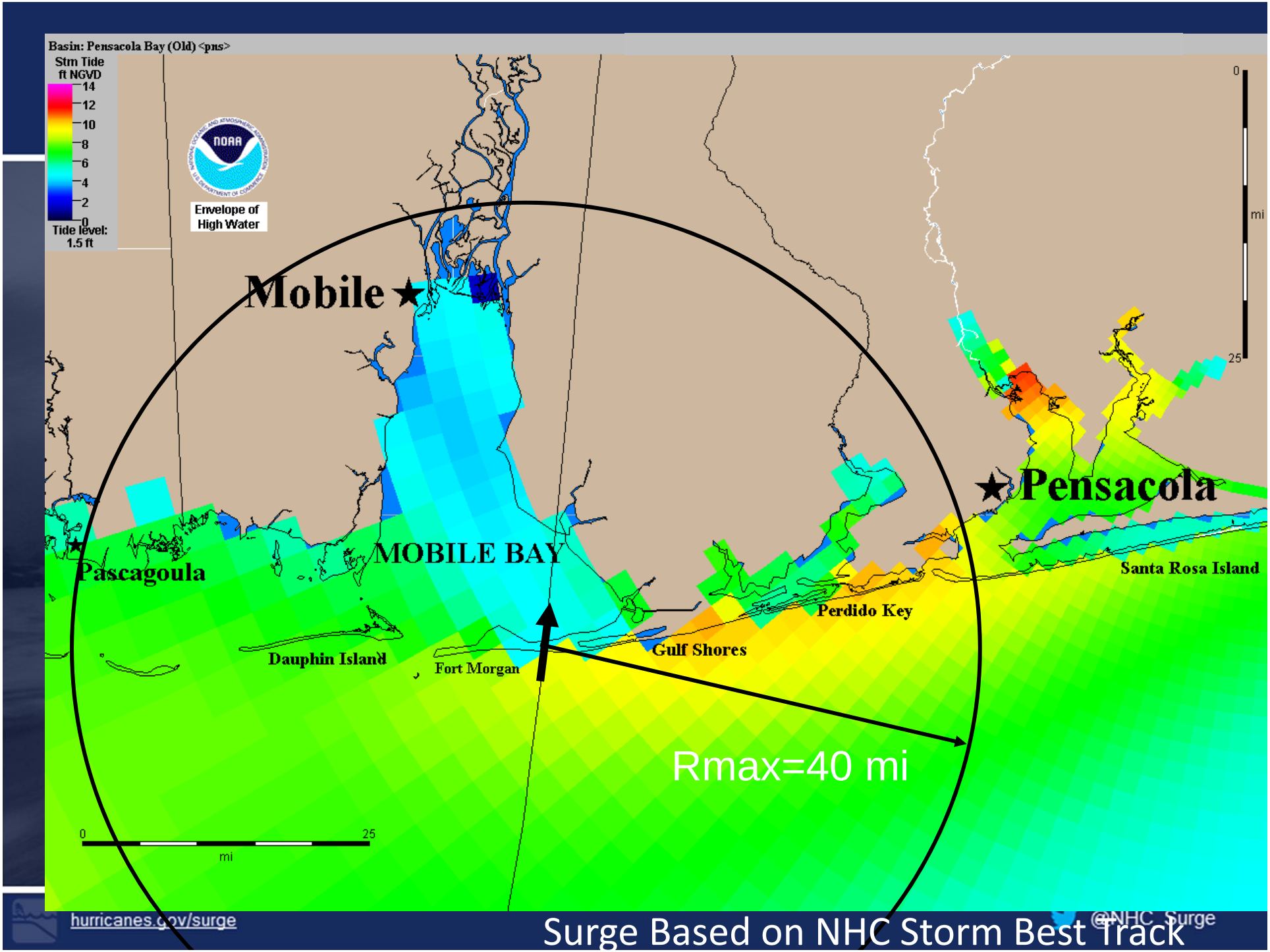
Hurricane Advisory - Approximately 12 hr. before landfall



Surge Based on NHC -12 hr. Advisory

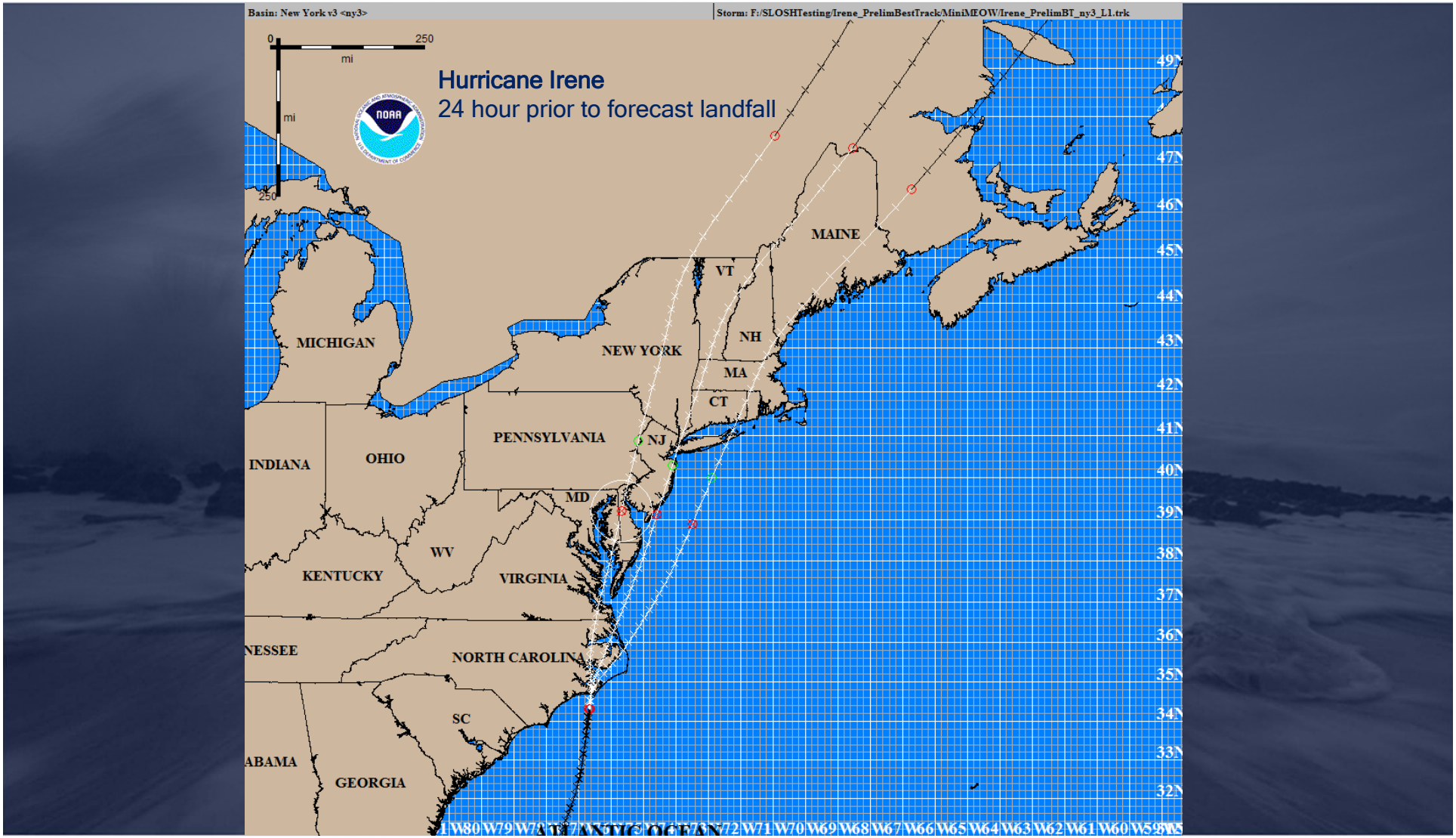


Actual Hurricane Track 30 mi. E of -12 hr. Advisory Forecast Track



Surge Based on NHC Storm Best Track

Perils of Using a Single Track Forecast
Hurricane Irene (2011)



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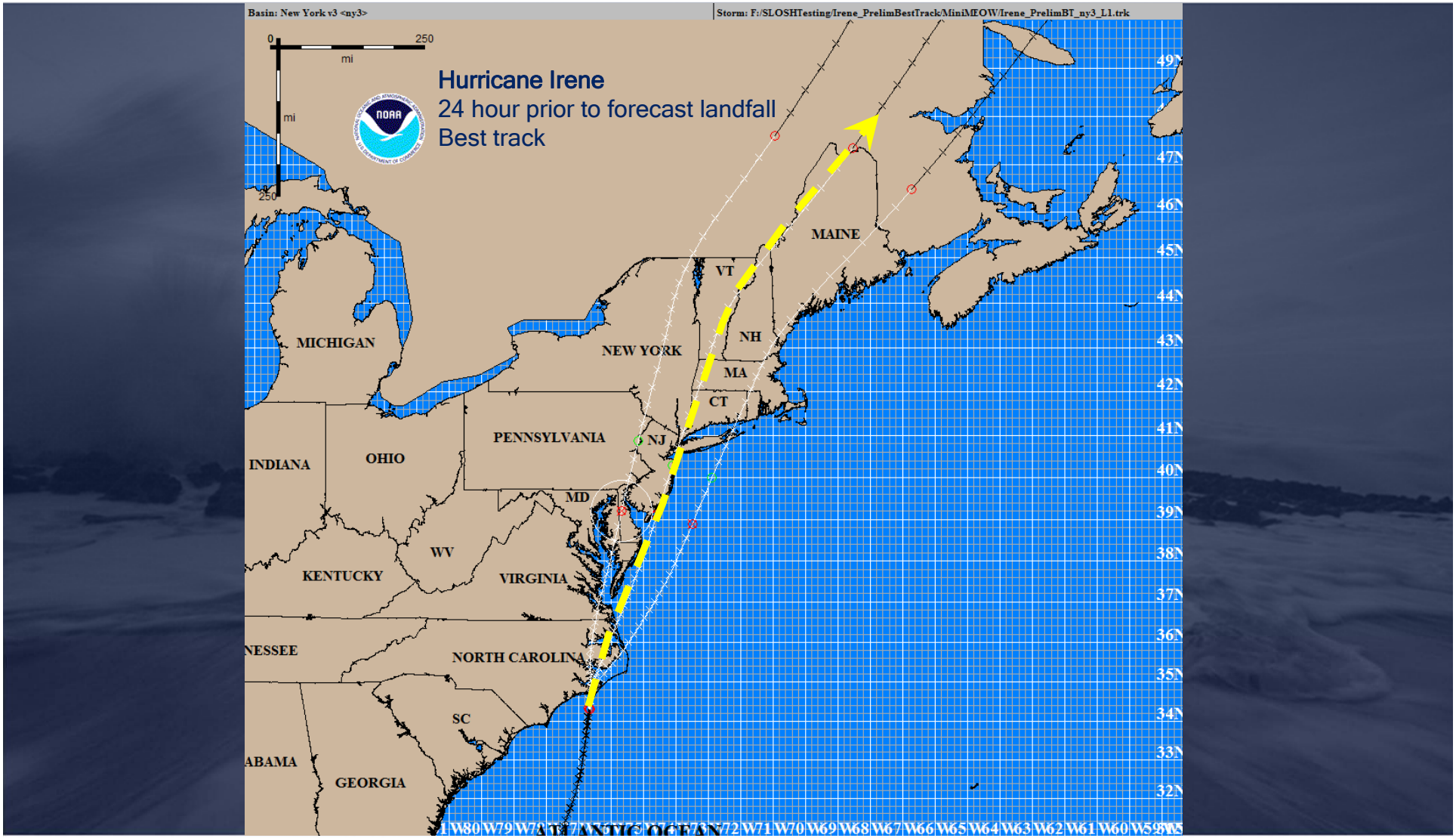

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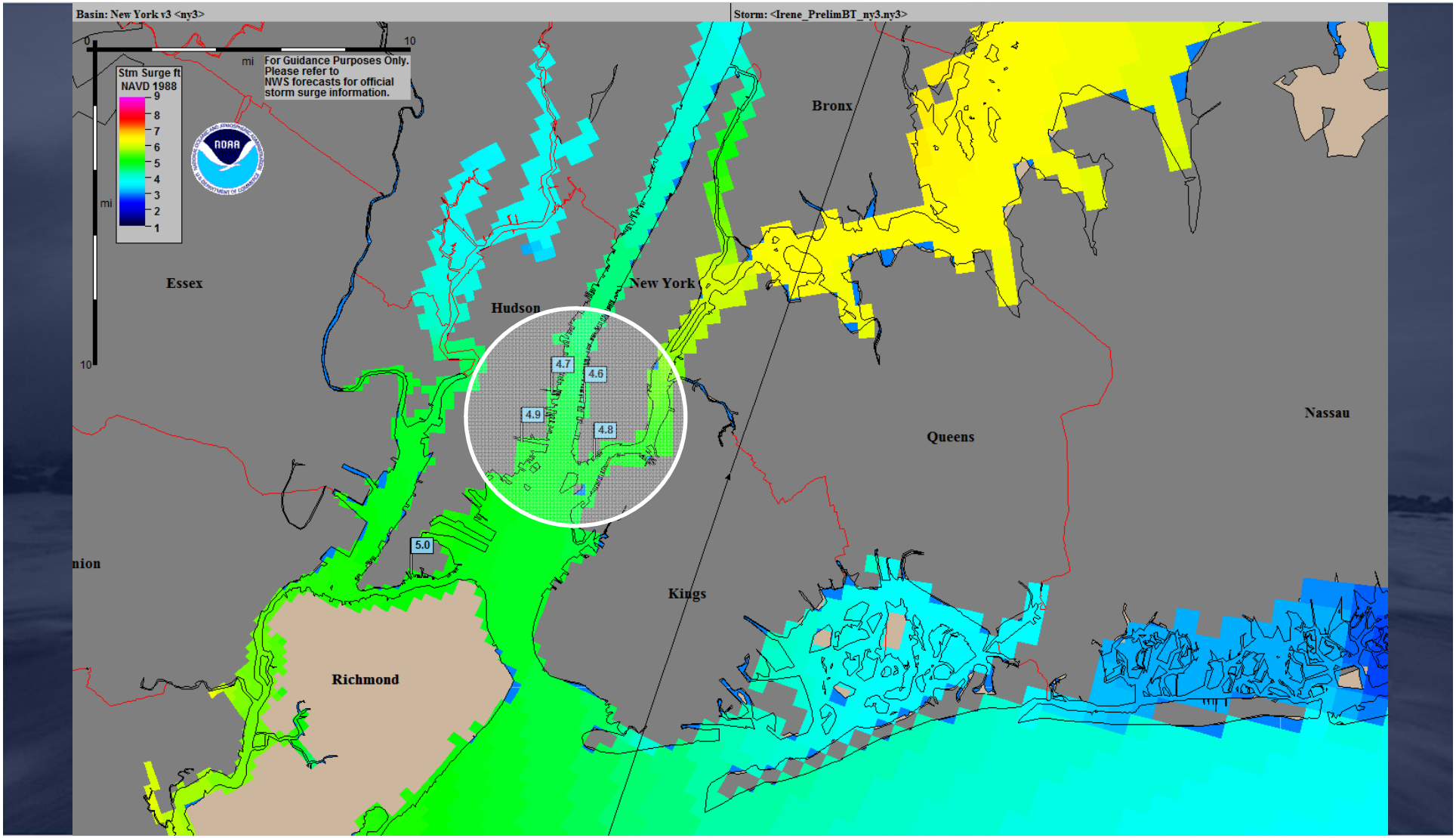

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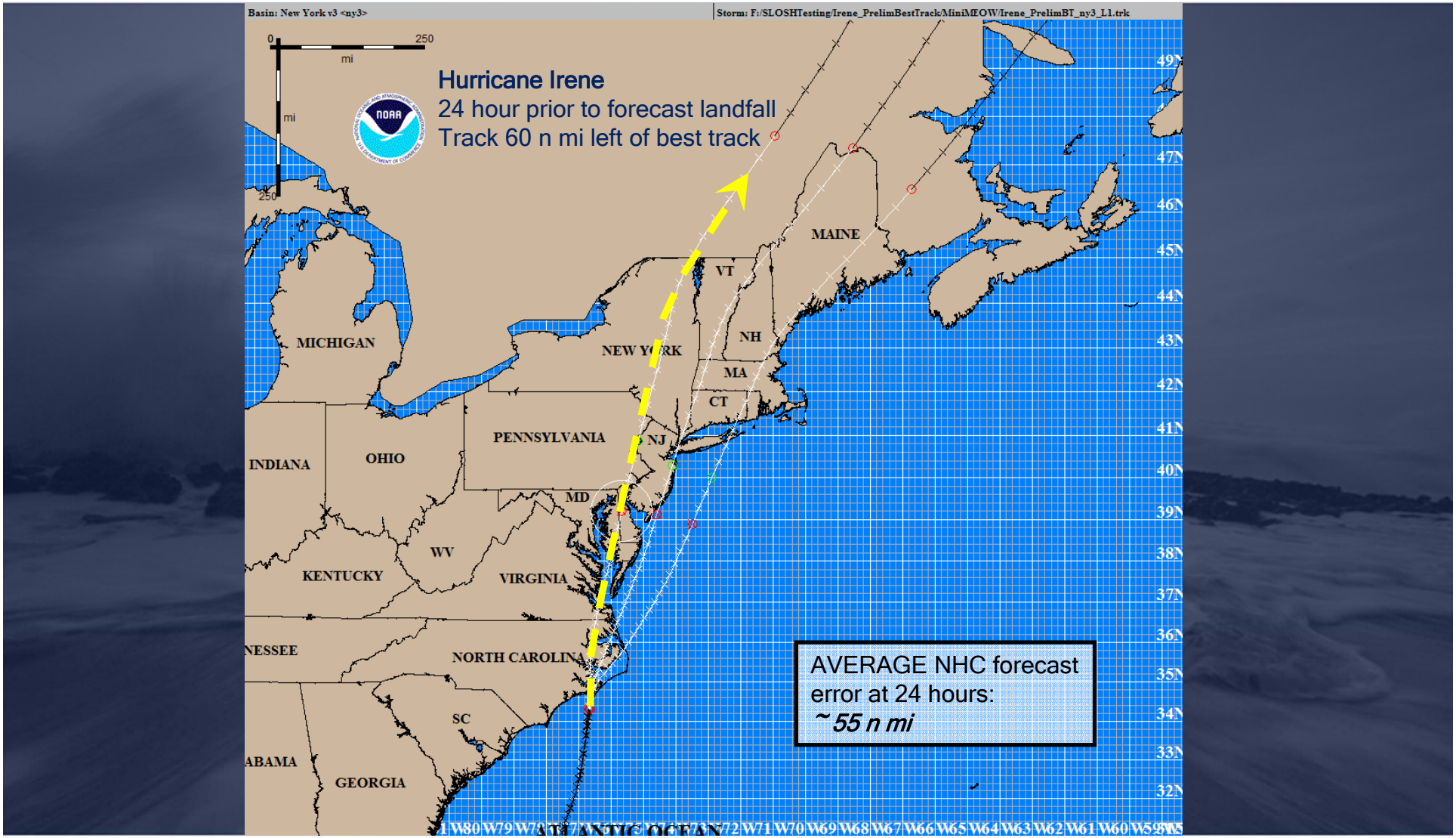

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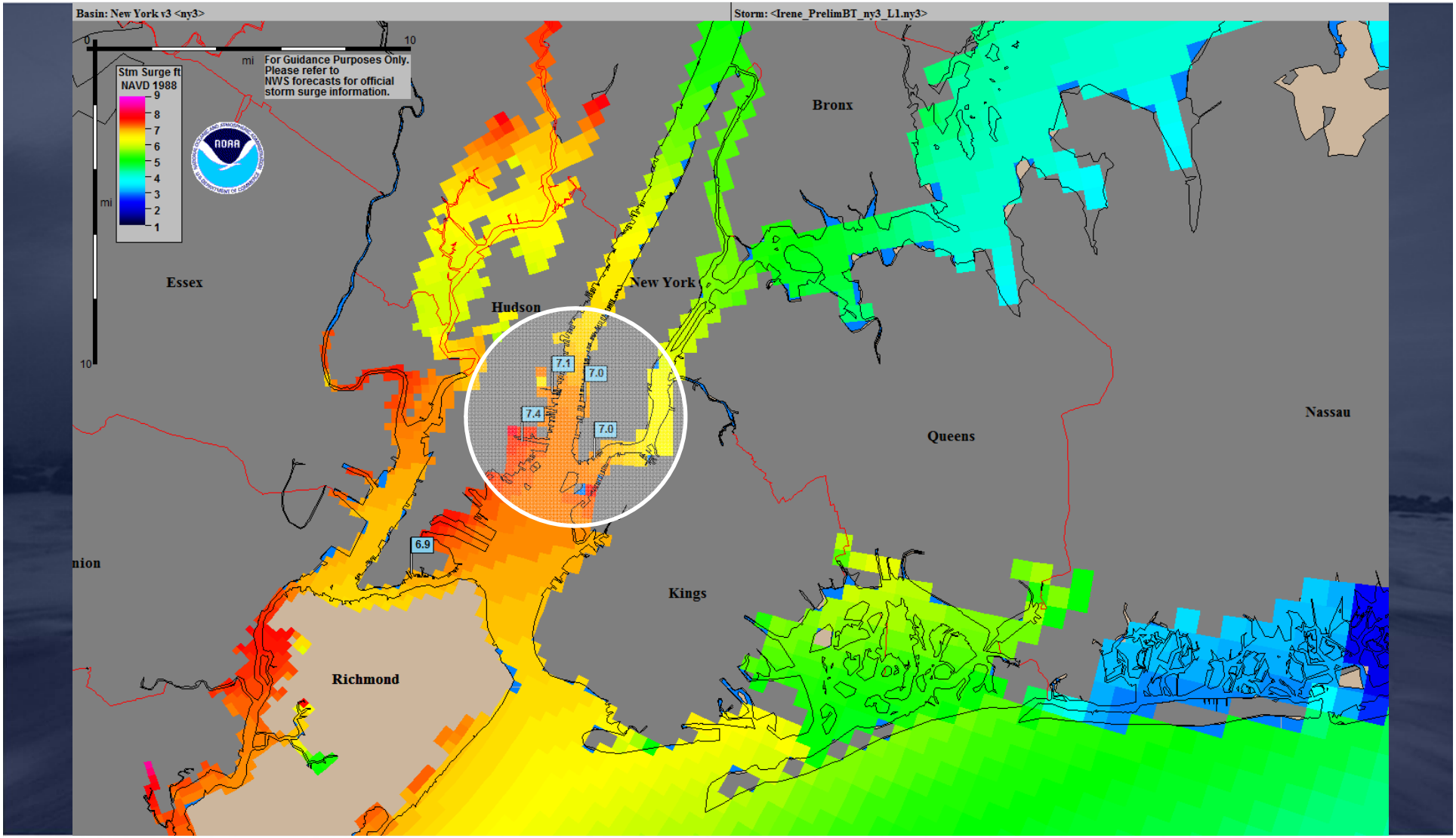


Alternative to Single Runs

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

MEOWs

Maximum Envelopes Of Water

MOMs

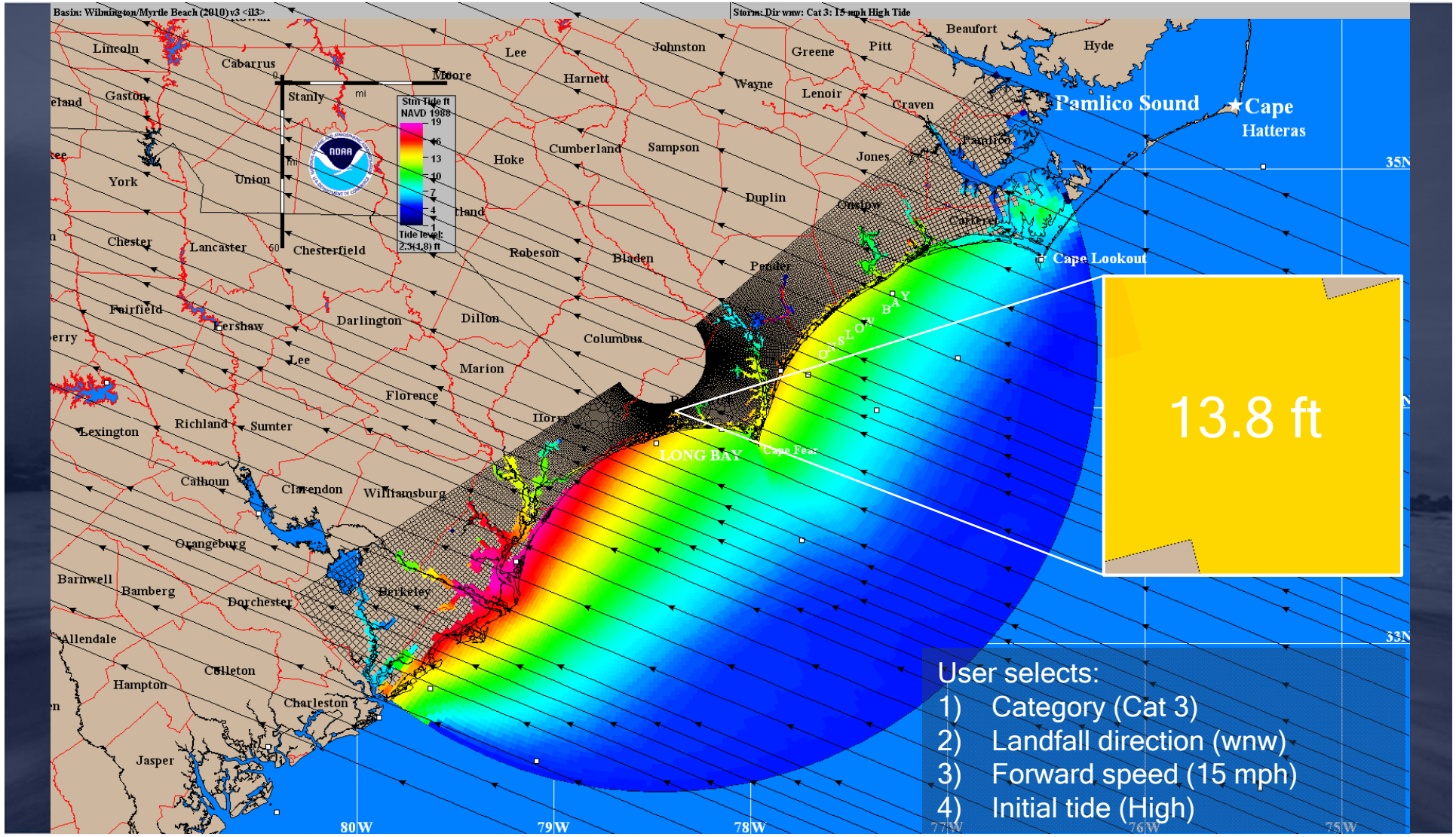
Maximum Of the MEOWs

P-surge

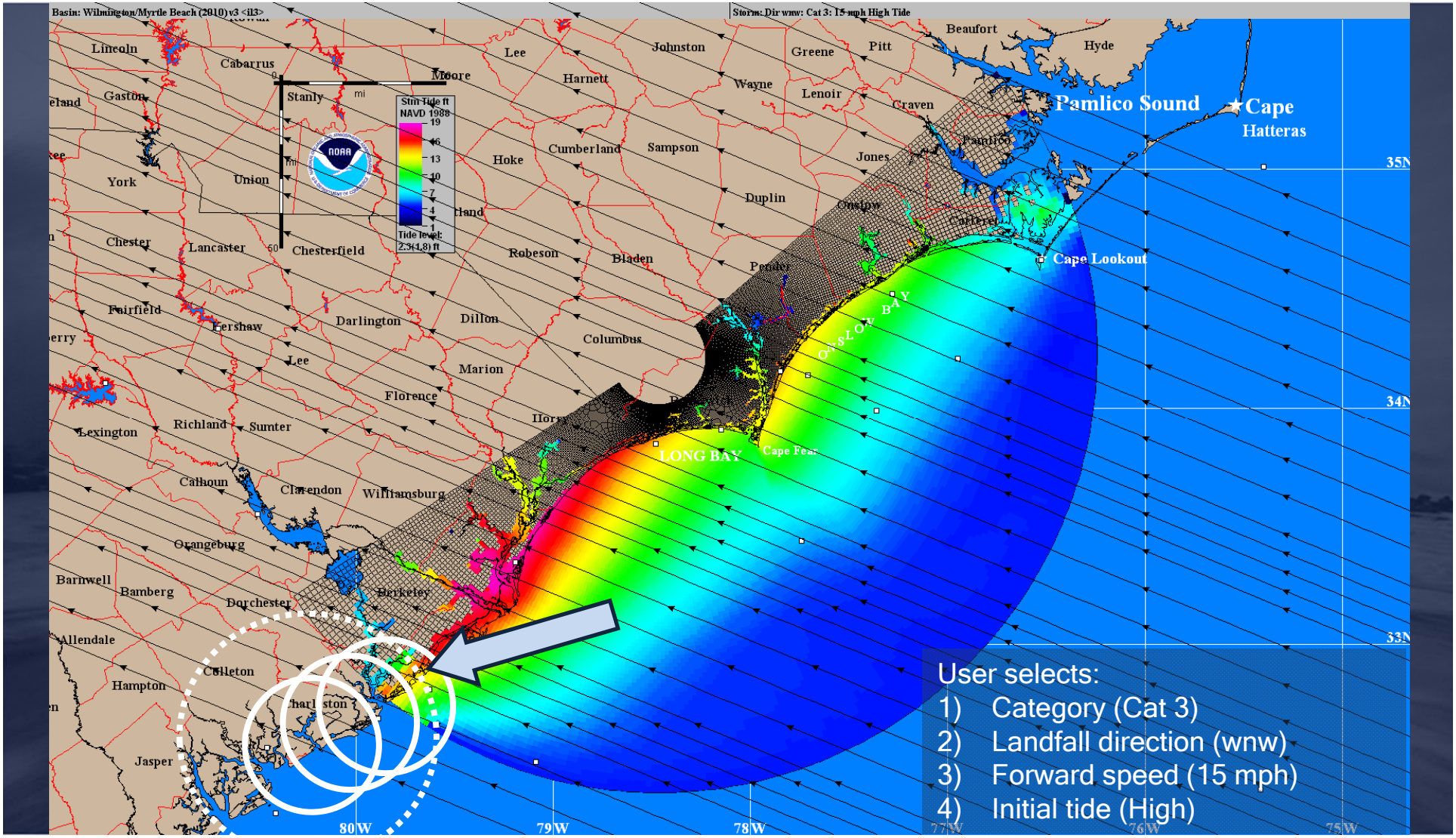
Probabilistic Storm Surge

MEOW
Maximum Envelope Of Water

Maximum Envelope of Water (MEOW)



Ensemble Guidance



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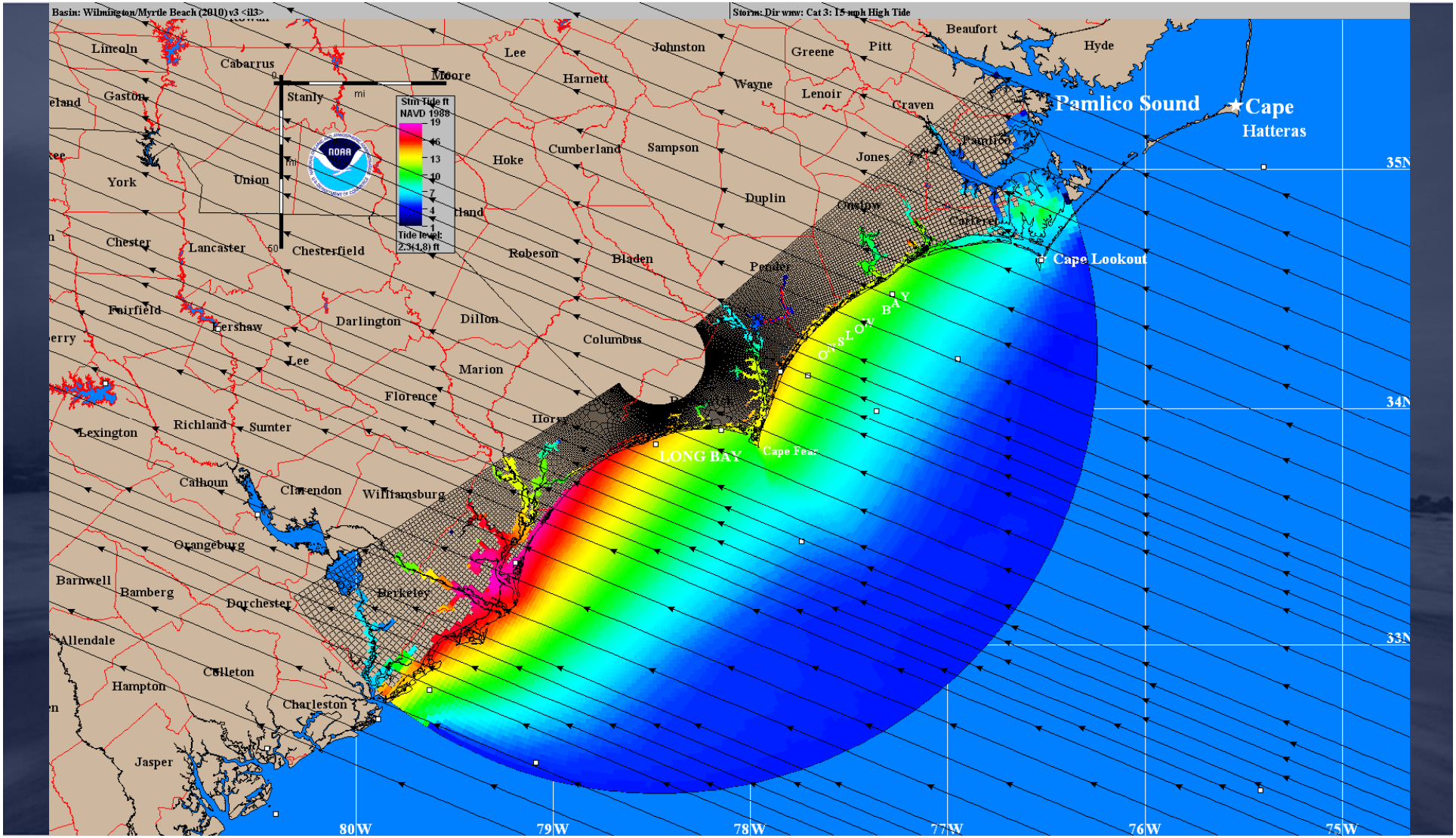
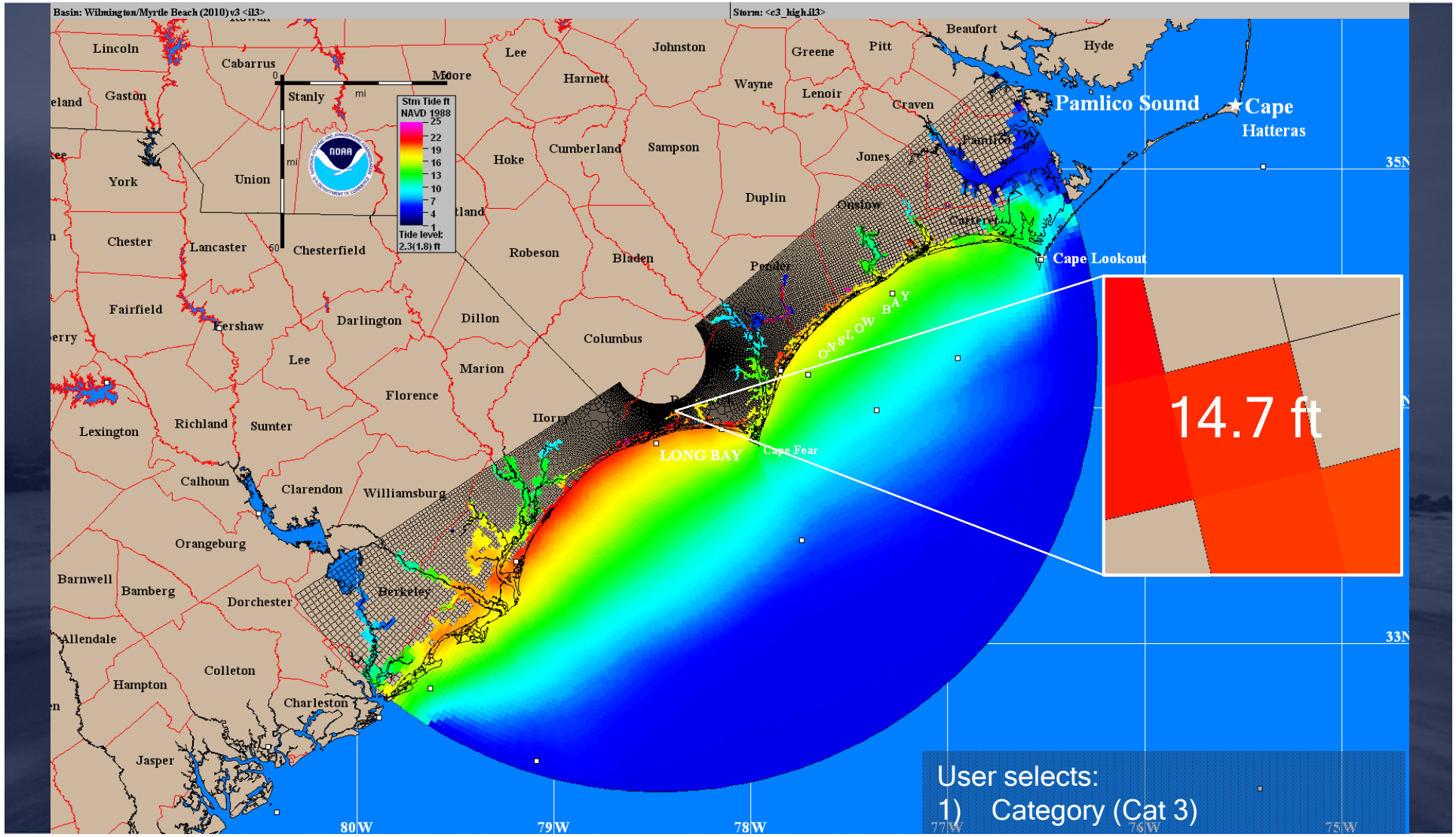


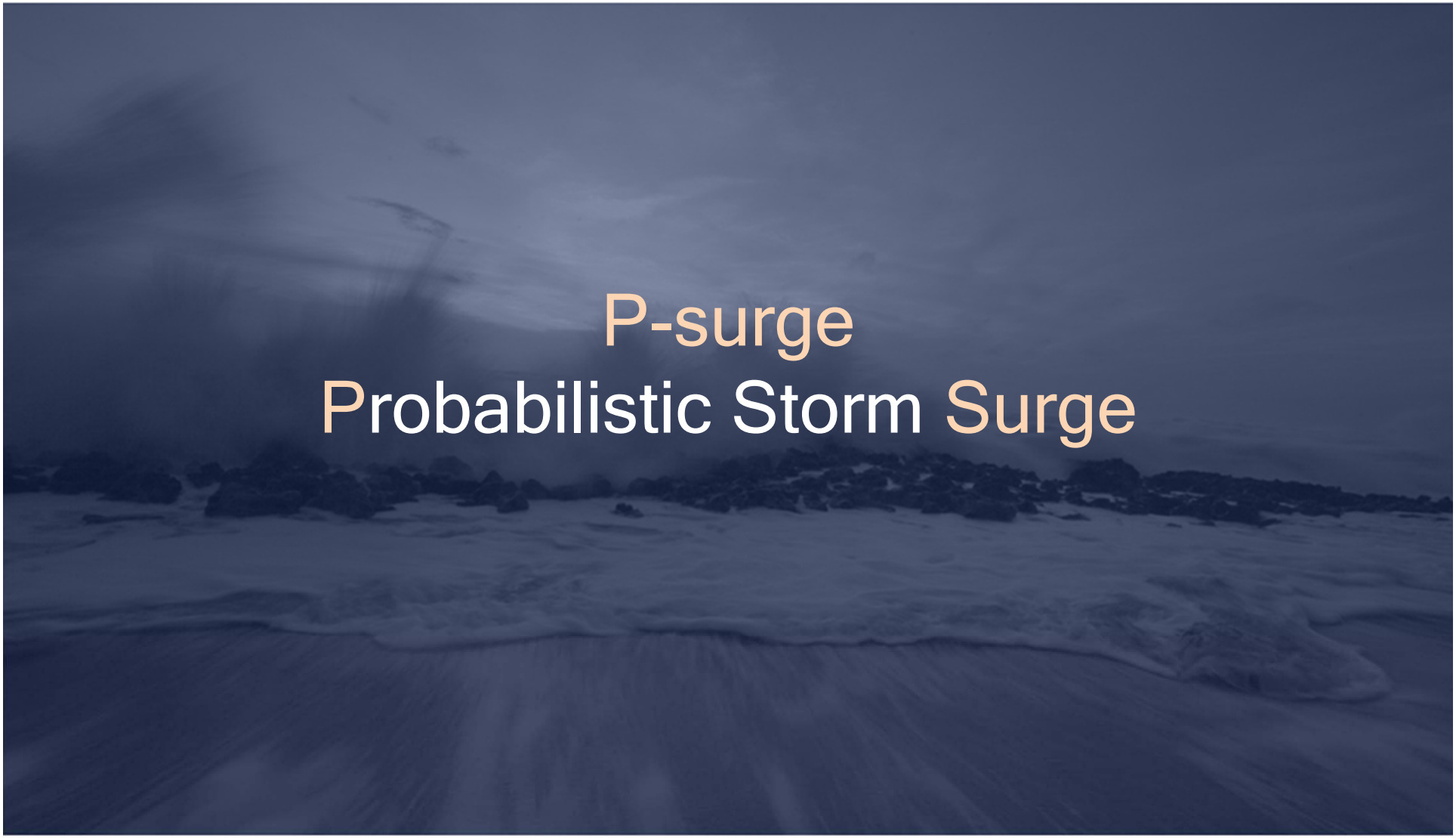
MOM

- Maximum of MEOWs
- Composite of the maximum storm surge height for all hurricanes of a given category
- Disregards forward speed, landfall direction, landfall location, etc.
- Only 1 MOM per storm category

MOM
Maximum Of the MEOWs

Maximum of the MEOWs (MOMs)



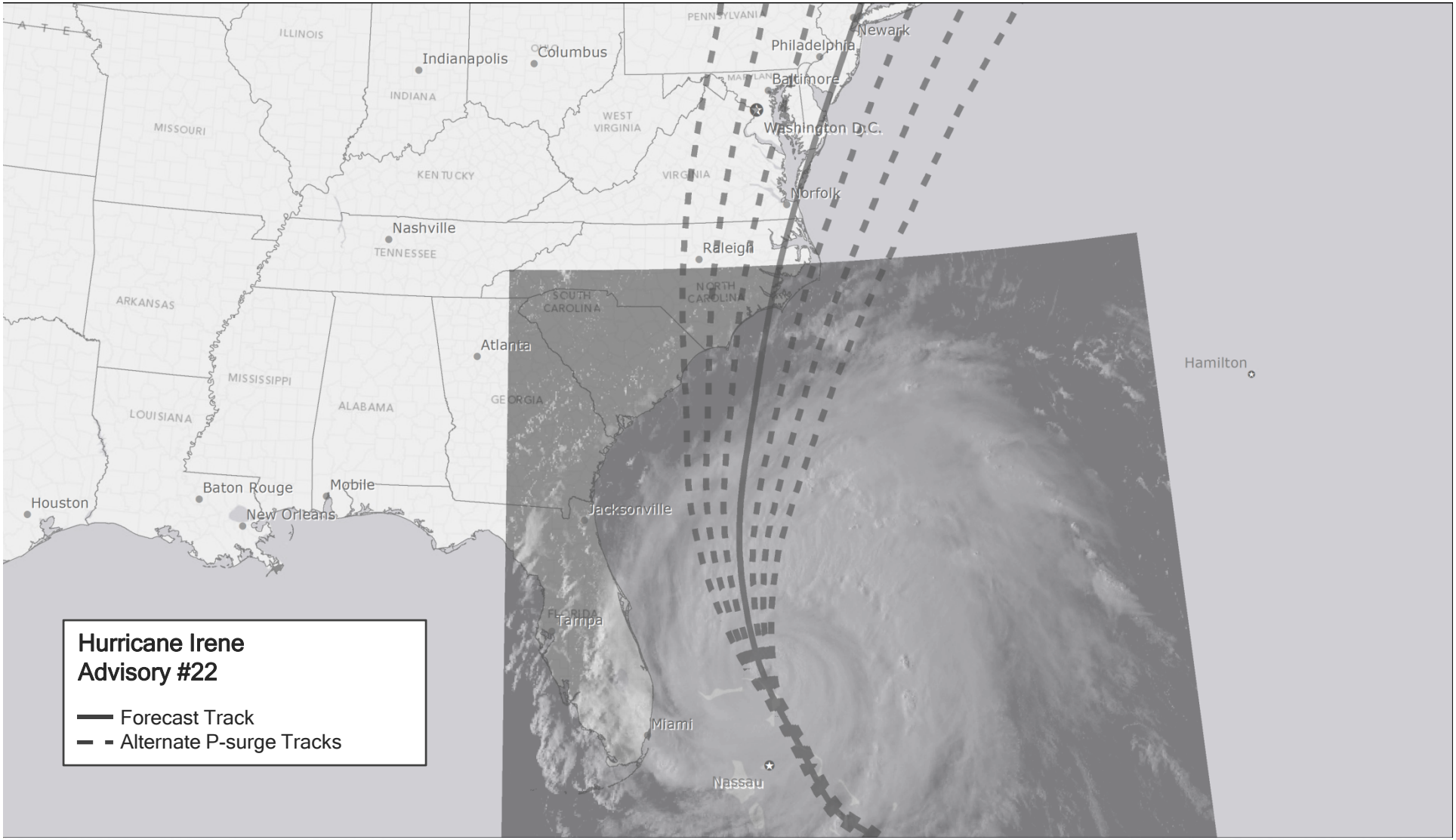


P-surge
Probabilistic Storm Surge

Probabilistic Storm Surge (P-surge)

- Storm surge probabilities based on NHC official advisory
- Available approximately 48 hours prior to hurricane landfall
- Accounts for uncertainty in:
  - Track / landfall location
  - Size
  - Forward speed
  - Intensity
- Uncertainties based on historical errors

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



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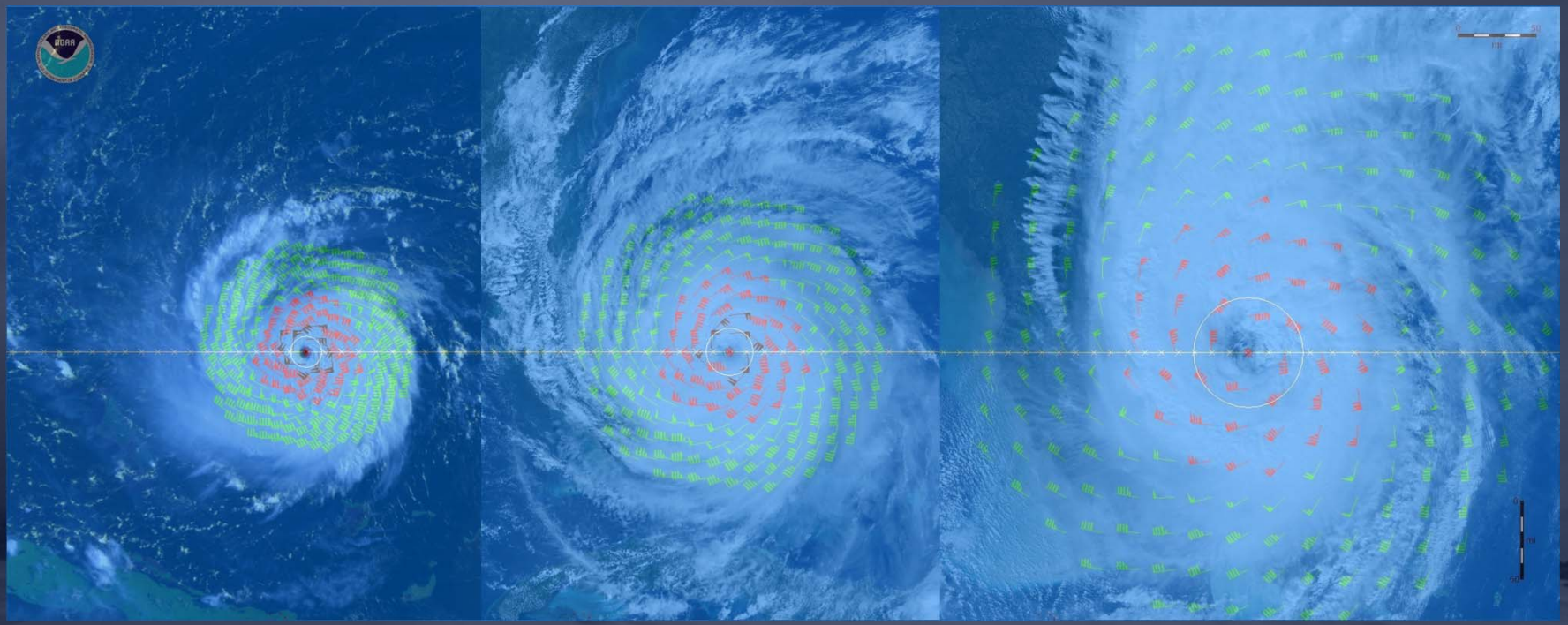


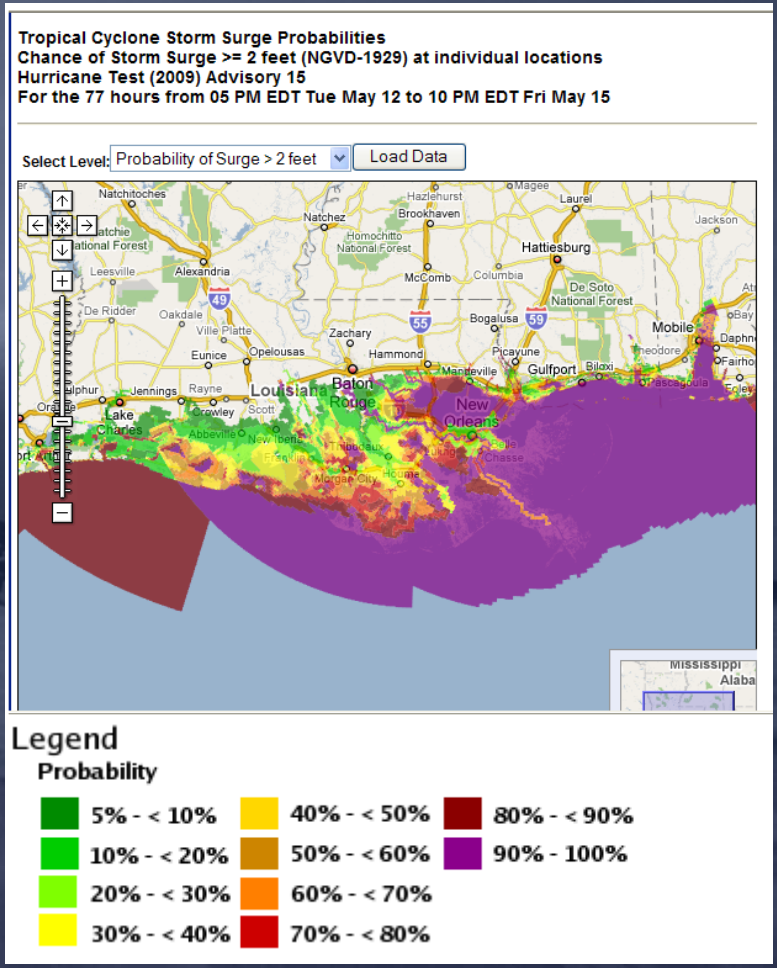
Size: Small, Medium, Large

Forward Speed: Fast, Medium, Slow

Intensity: Strong, Medium, Weak

Probabilistic Storm Surge (P-surge)
When is it available?

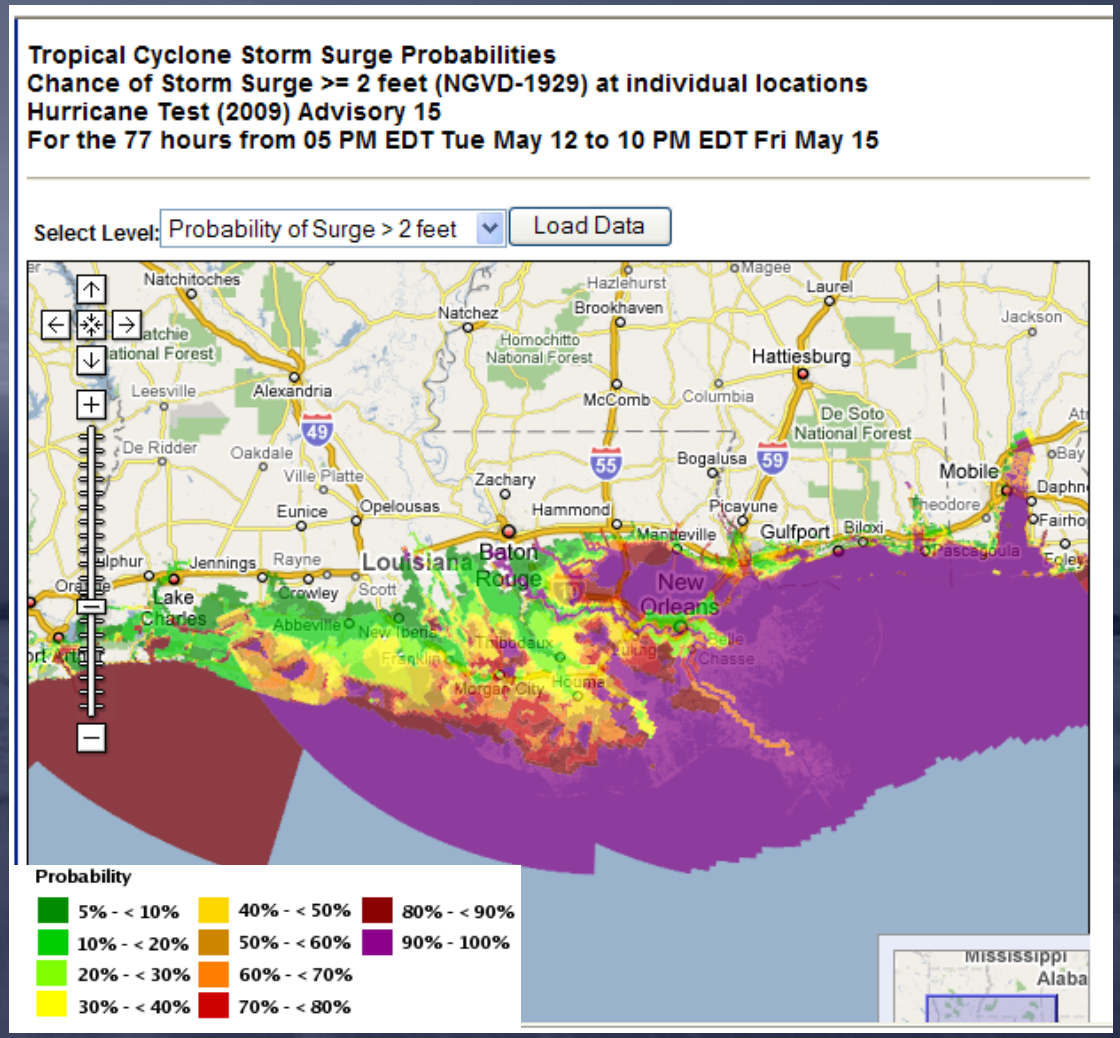
- Whenever a hurricane watch or warning is in effect
  - Approximately 48 hours prior to landfall
- Available approximately 30 minutes after full advisory release time
  - 05:30 EDT
  - 11:30 EDT
  - 17:30 EDT
  - 23:30 EDT

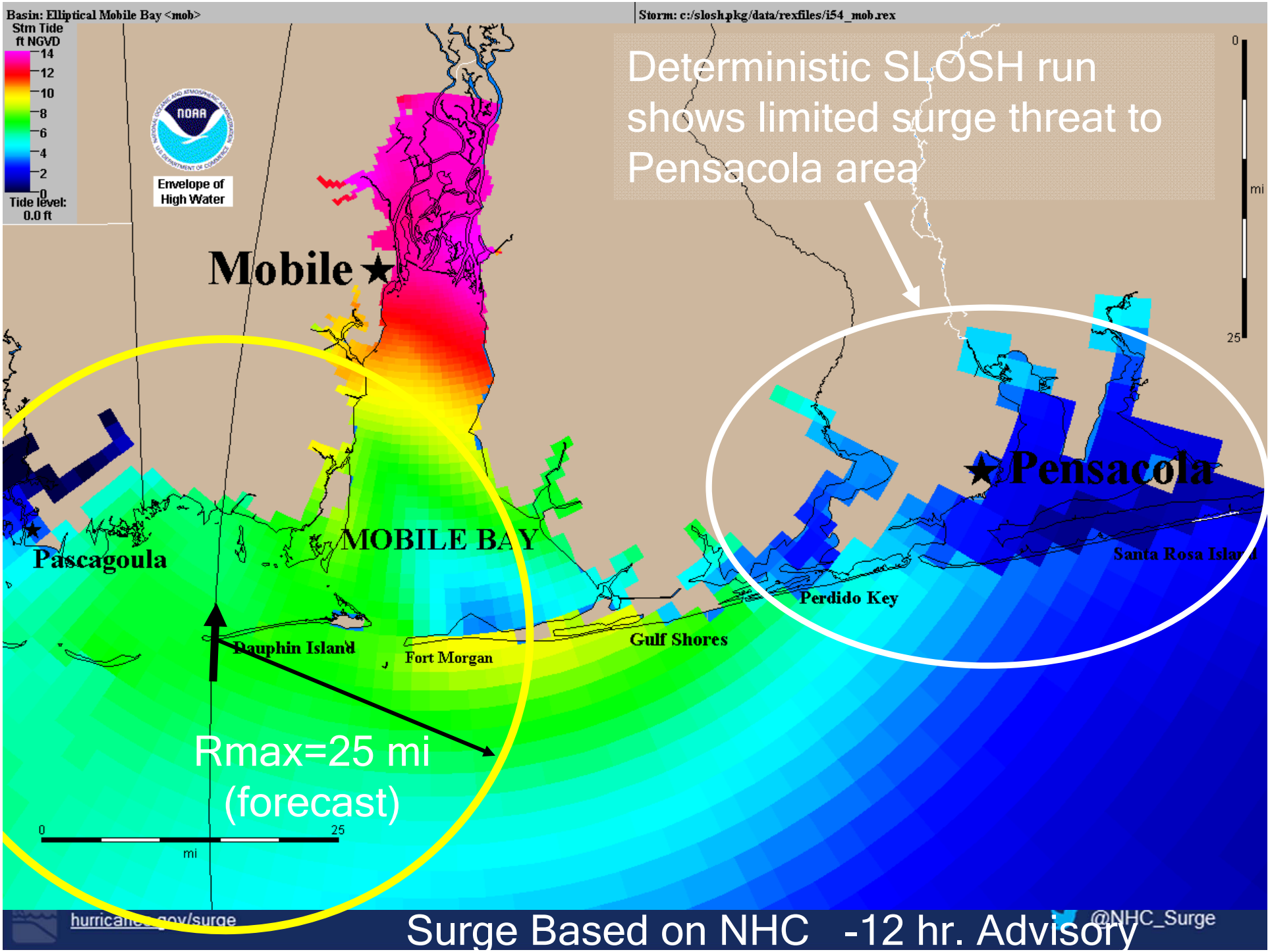


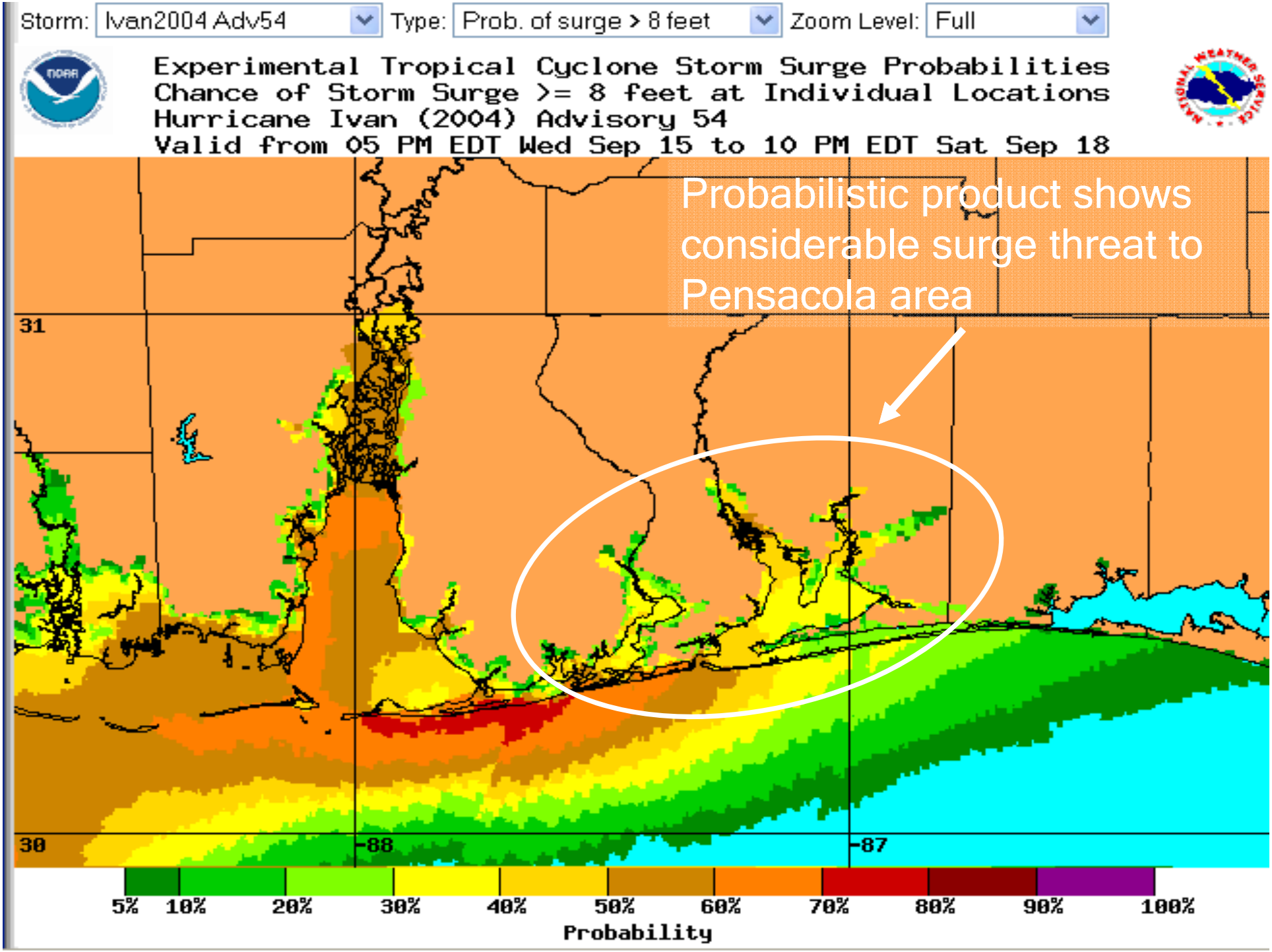
Understanding and Using Probabilities

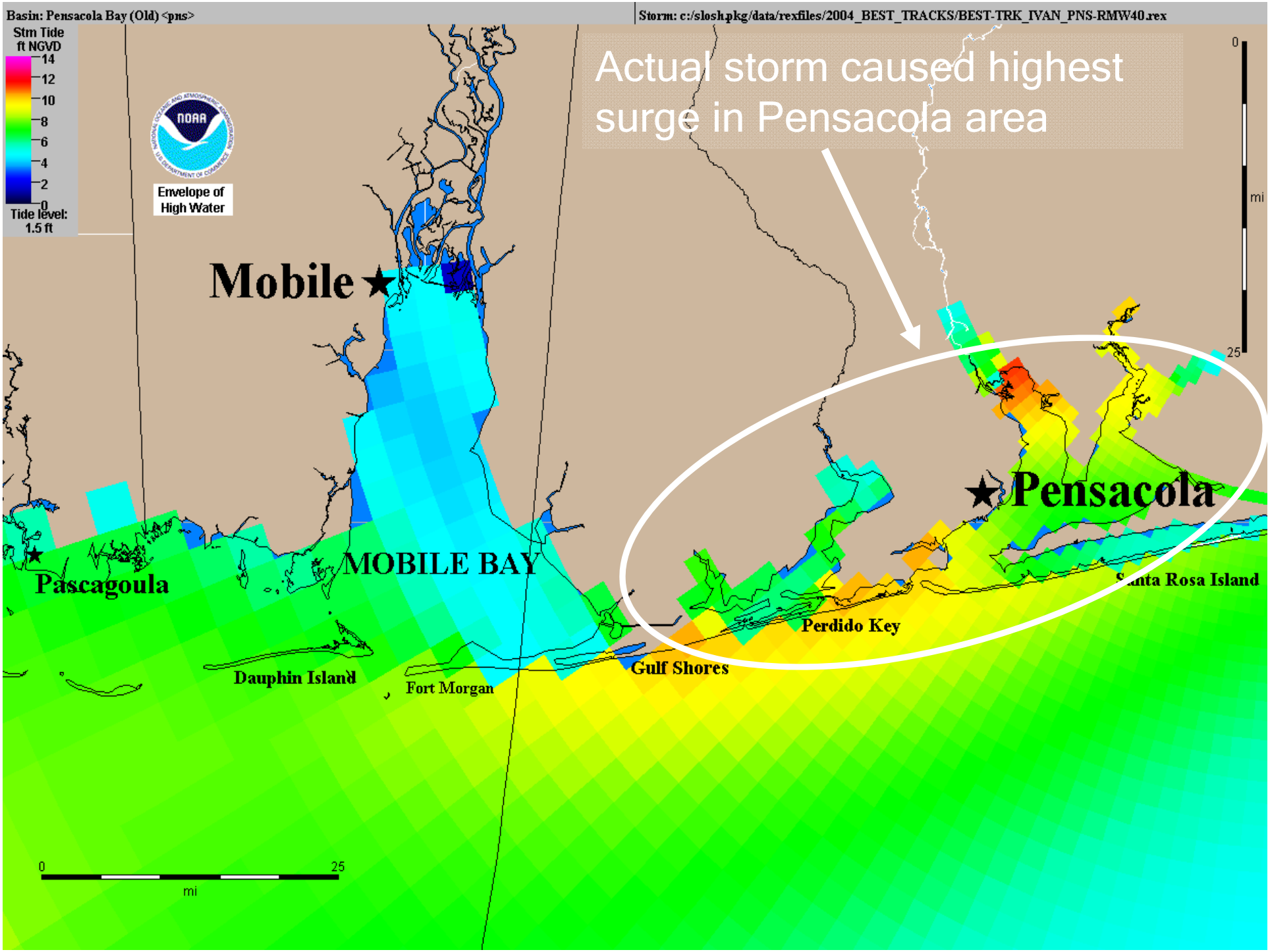
The number one argument against using probability is that users do not understand how to interpret low probabilities of an extreme event.

Would you offer to pick up free lunch if there is a 20% chance of you being involved in a fatal car accident along the way?

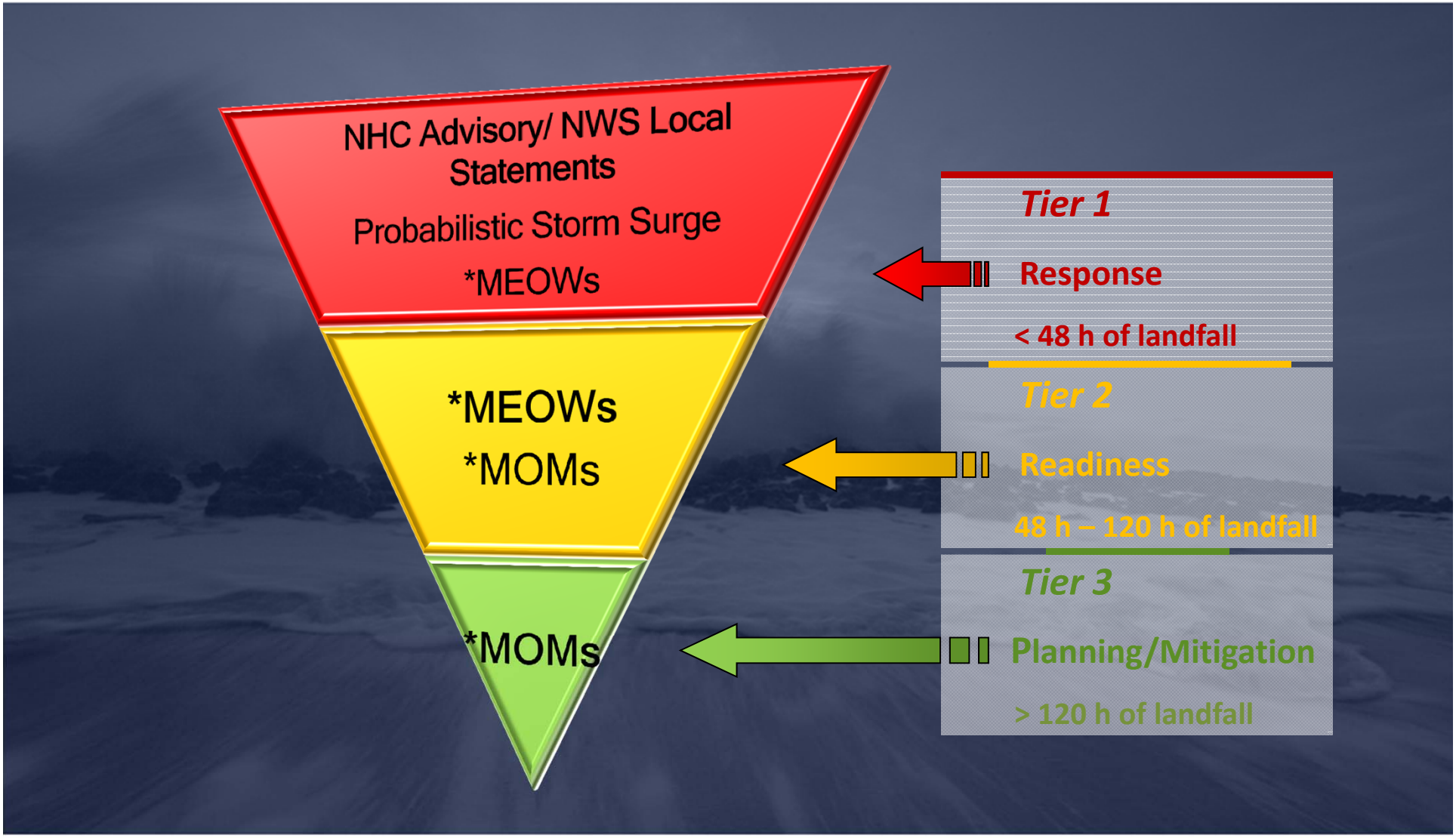



Basin: Elliptical Mobile Bay <mob>
Storm: c:/slosh.pkg/data/rexfiles/i54_mob.rex
Stm Tide
ft NGVD
14
12
10
8
6
4
2
0
Tide level:
0.0 ft
Envelope of
High Water
Deterministic SLOSH run shows limited surge threat to Pensacola area
Mobile
MOBILE BAY
Pascagoula
Pensacola
Perdido Key
Santa Rosa Island
Dauphin Island
Fort Morgan
Gulf Shores
Rmax=25 mi
(forecast)
0
25
mi
hurricane.gov/surge
@NHC_Surge
Surge Based on NHC -12 hr. Advisory

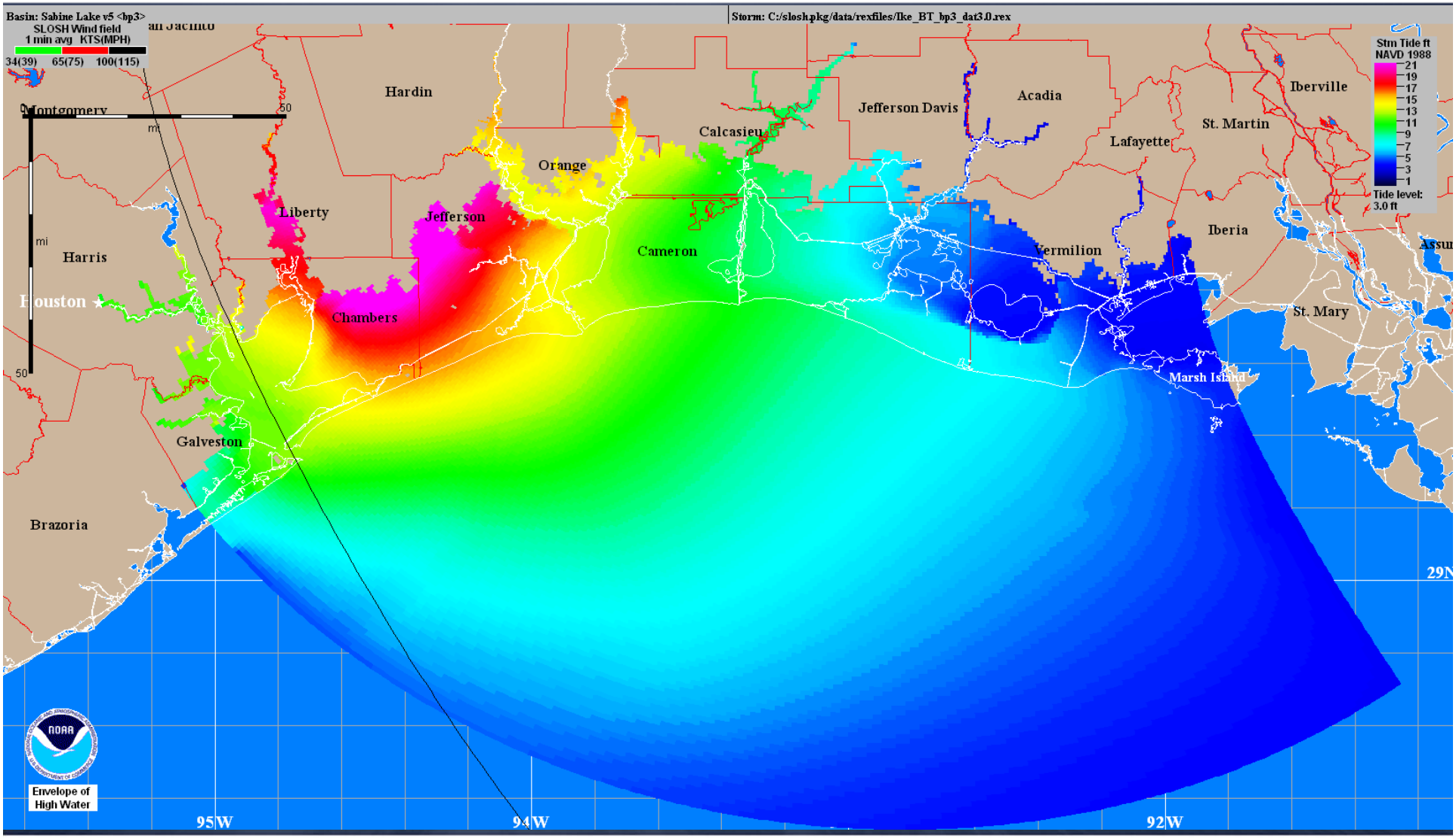

Storm: Ivan2004 Adv54
Type: Prob. of surge > 8 feet
Zoom Level: Full
Experimental Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge >= 8 feet at Individual Locations
Hurricane Ivan (2004) Advisory 54
Valid from 05 PM EDT Wed Sep 15 to 10 PM EDT Sat Sep 18
Probabilistic product shows considerable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


Basin: Pensacola Bay (Old) <pns>
Storm: c:/slosh.pkg/data/rexfiles/2004_BEST_TRACKS/BEST-TRK_IVAN_PNS-RMW40.rex
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
MOBILE BAY
Pascagoula
Dauphin Island
Fort Morgan
Gulf Shores
Perdido Key
Santa Rosa Island
0
25
mi
0
25
mi

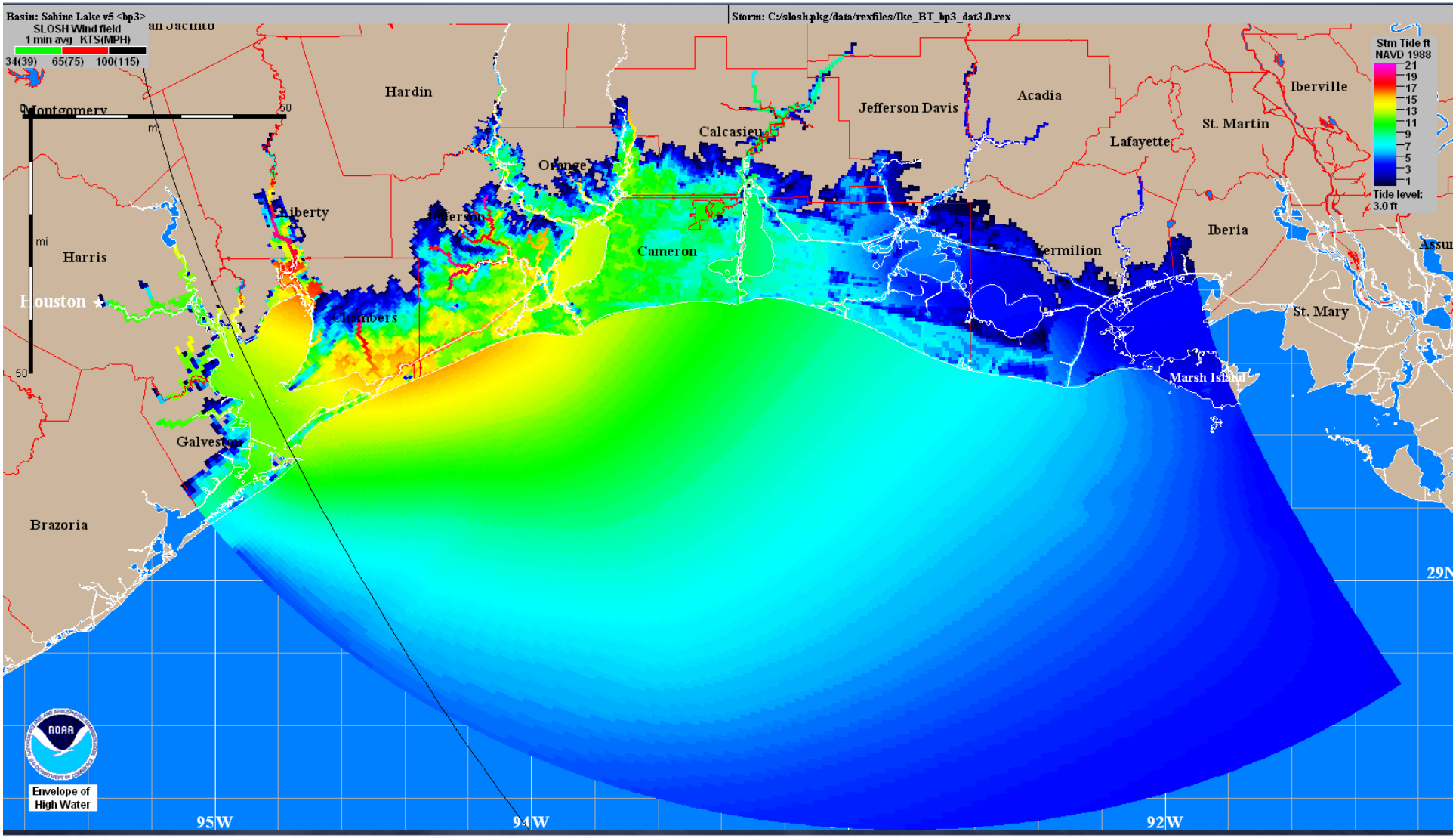
Strom Surge Guidance Timeframe
NHC Storm Surge Product Decision Support Wedge



Height Above Reference Level



Height Above Ground Level (Inundation)



Storm Surge Unit

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Dr. Cristina Forbes
Dr. Brian Zachry
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James Brinkley

hurricanes.gov/surge