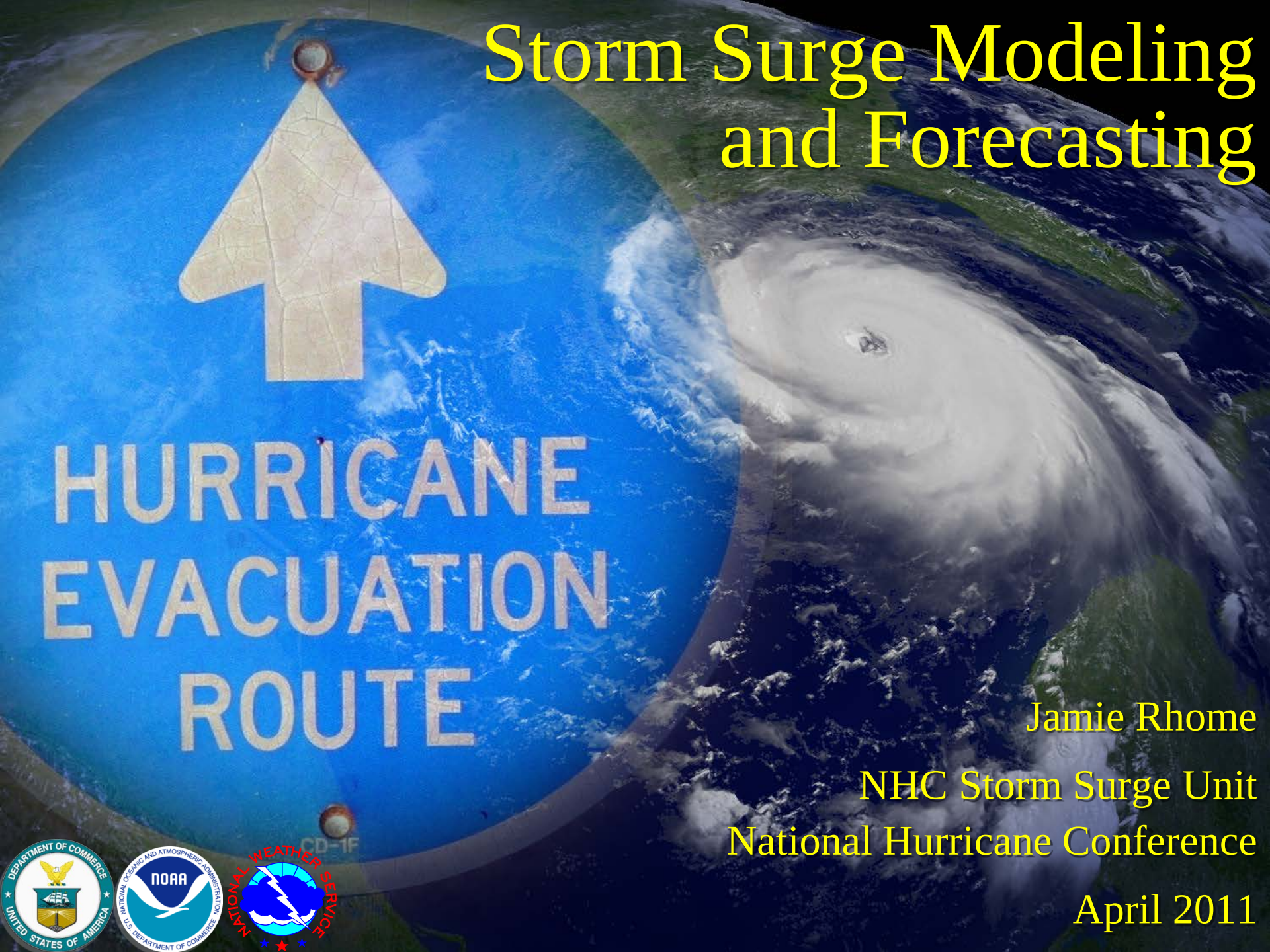
Storm Surge Modeling and Forecasting



Jamie Rhome

NHC Storm Surge Unit

National Hurricane Conference

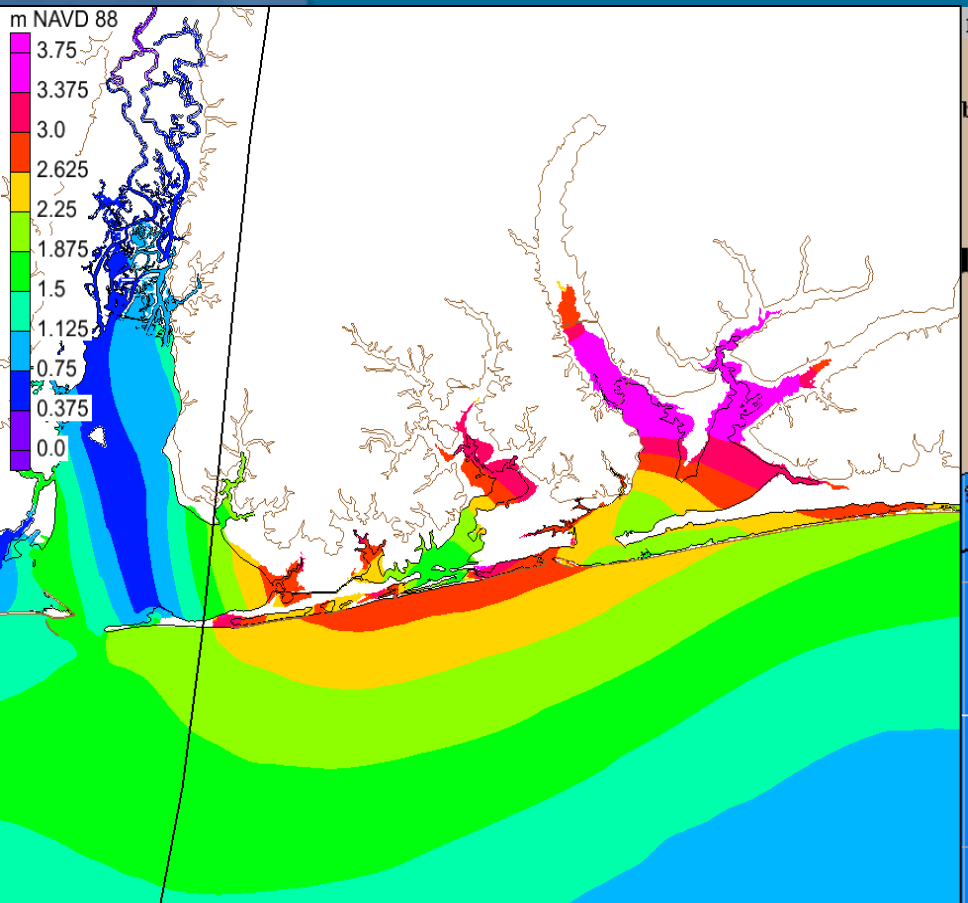
April 2011

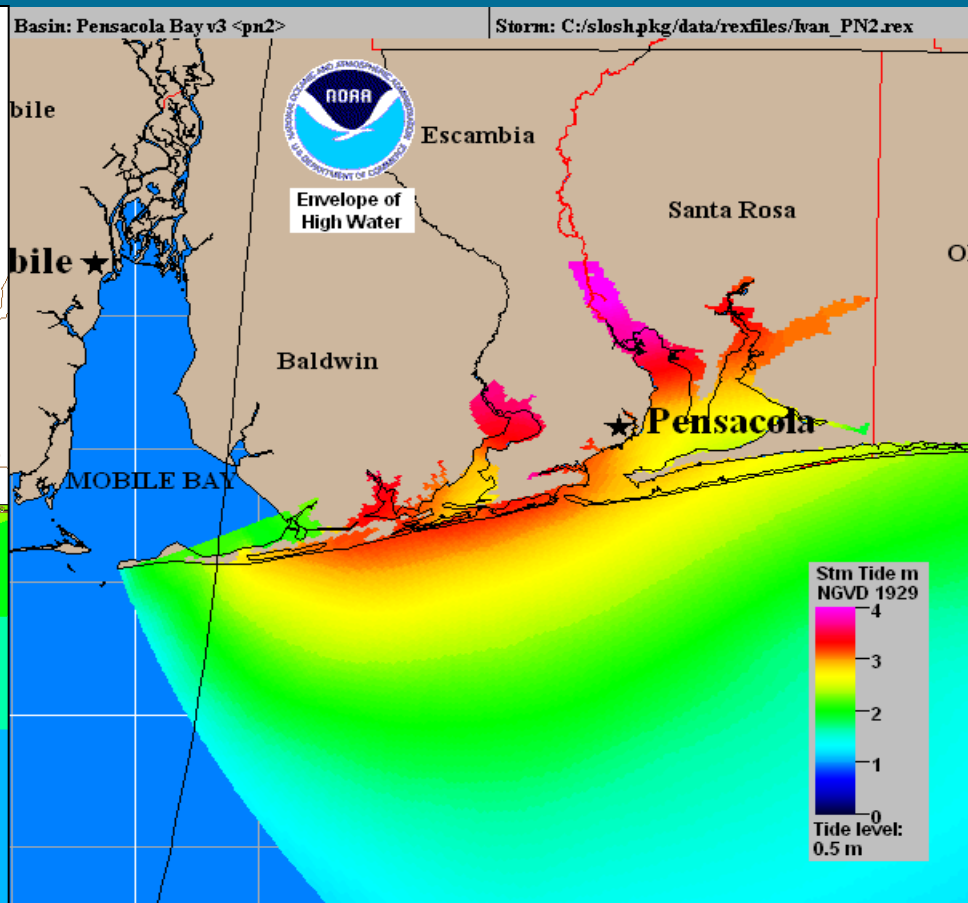
Modeling Surge

- Statistical
  - Utilize historical data to develop statistical relationships between surge and driving factors
  - 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

ADCIRC & SLOSH

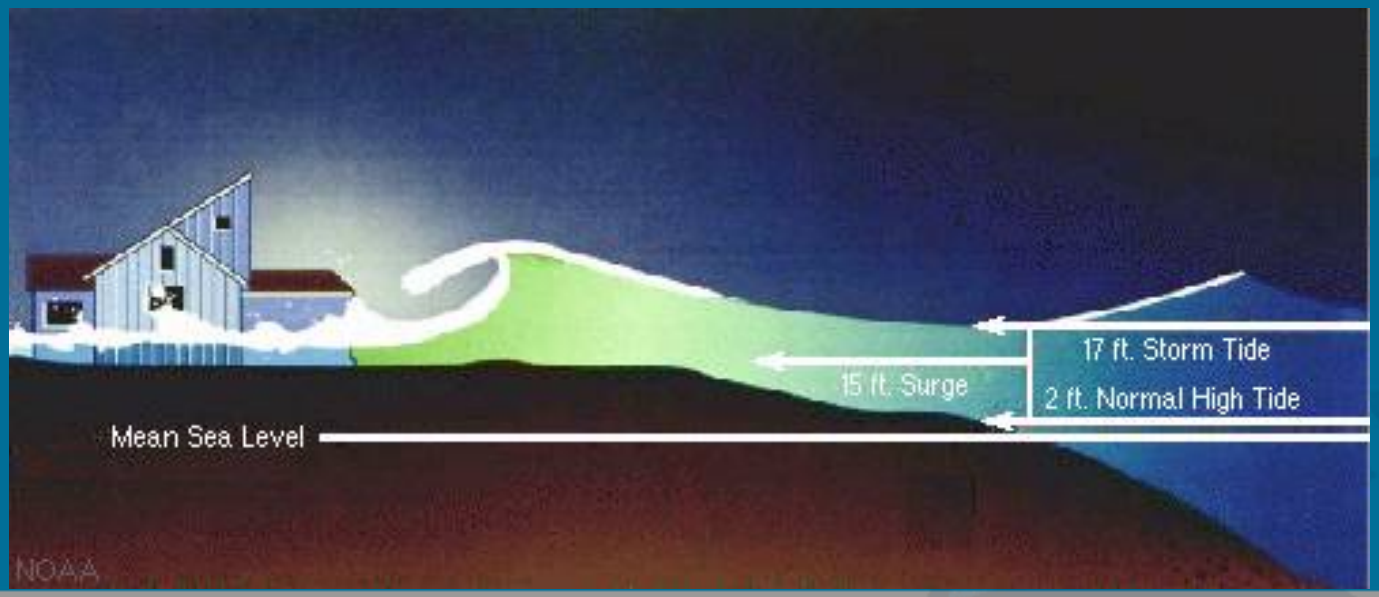
- Overall flooding pattern very similar





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

- 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

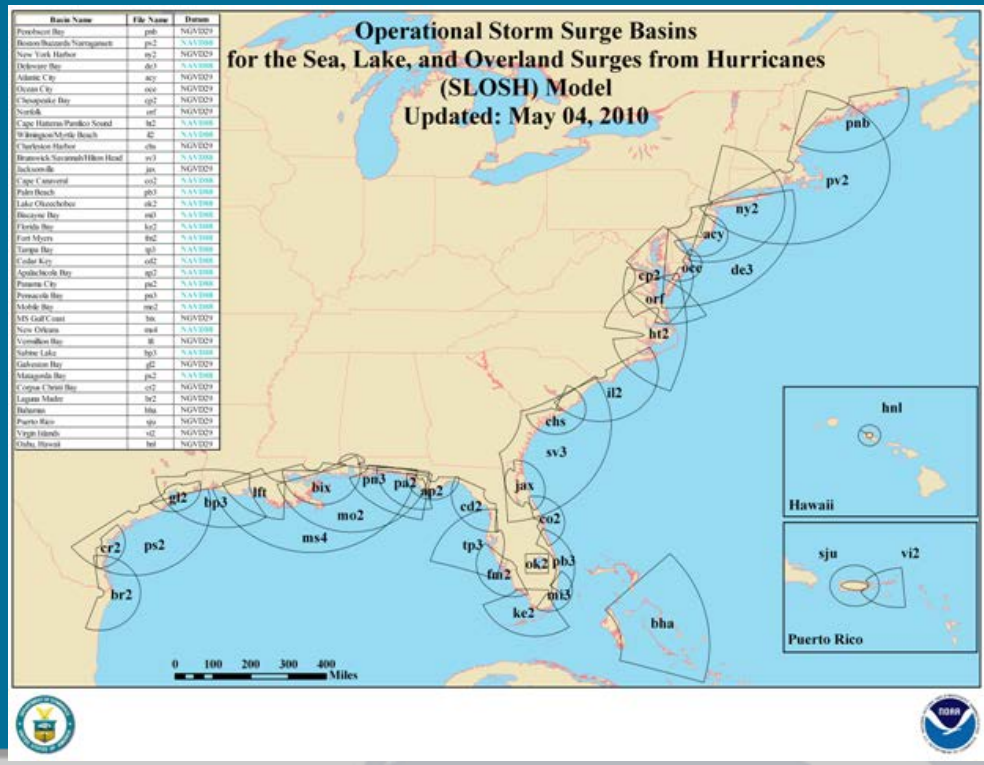
SLOSH Basin Updates

- Size/shape of basins
  - Size sometimes increased to better model surge
    - Additional hypothetical tracks to cover larger area
  - Grid shape typically unchanged
- NGVD29 → NAVD88
- Update topography/bathymetry information
  - More accurate representation of barriers, gaps, passes, and other features
- Higher resolution especially near the coast and the center of the grid
- Hypothetical tracks now include “average” AND “large” size storms

SLOSH Basin

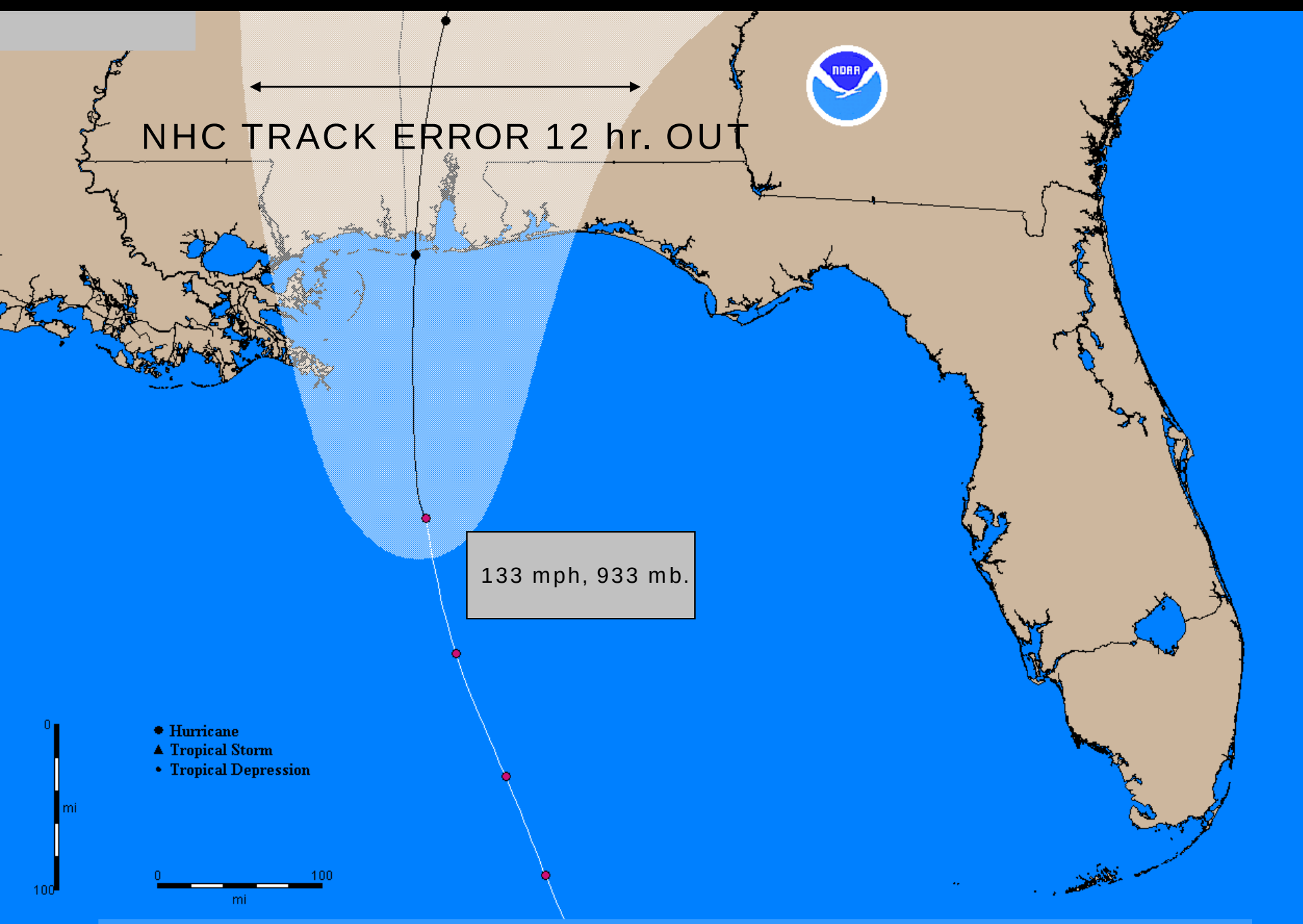
Planned basin updates for 2011

- Wilmington*
- Laguna Madre*
- New Orleans
- Jacksonville
- Vermillion
- Charleston
- Galveston

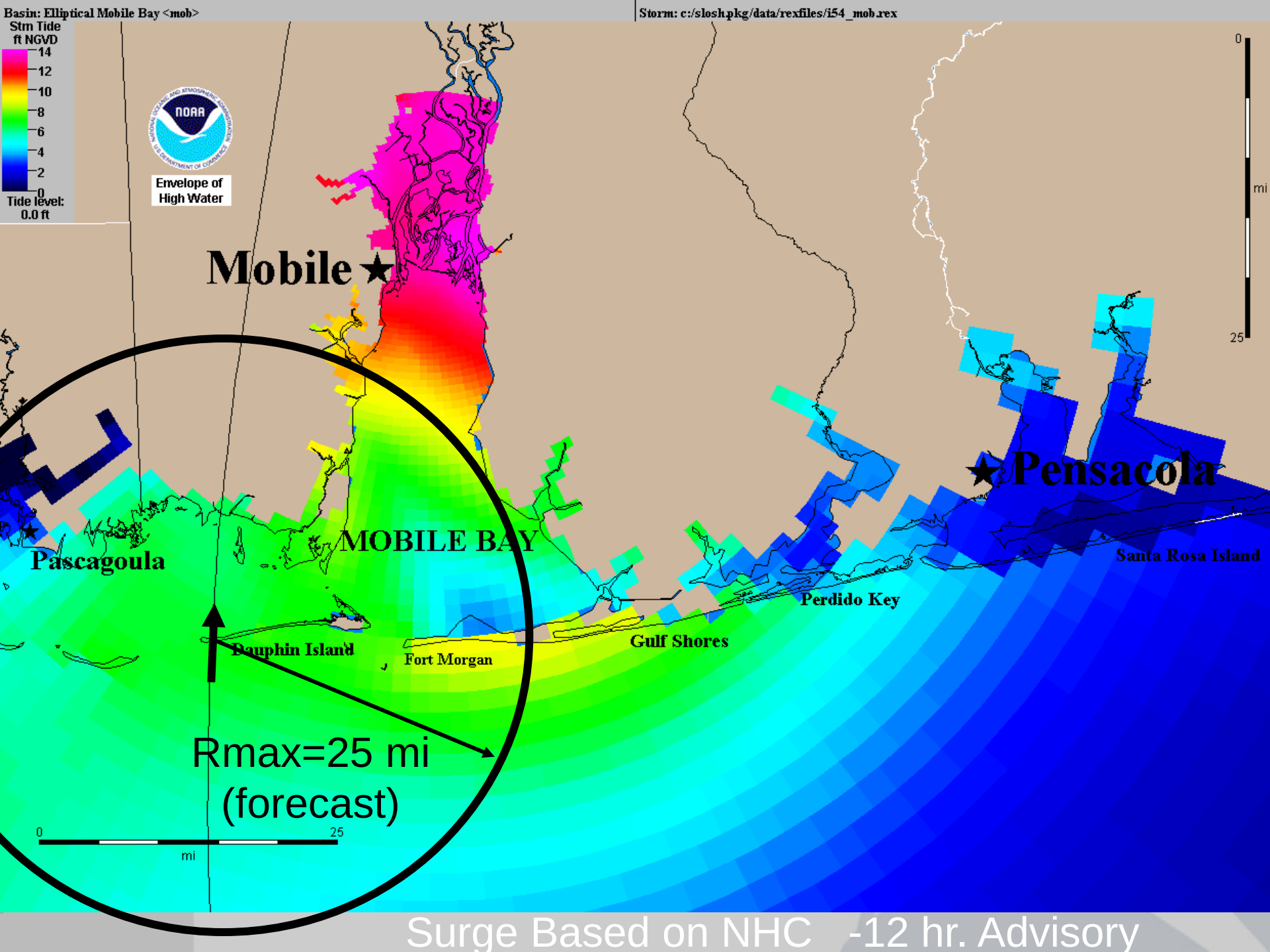


Forecasting Surge

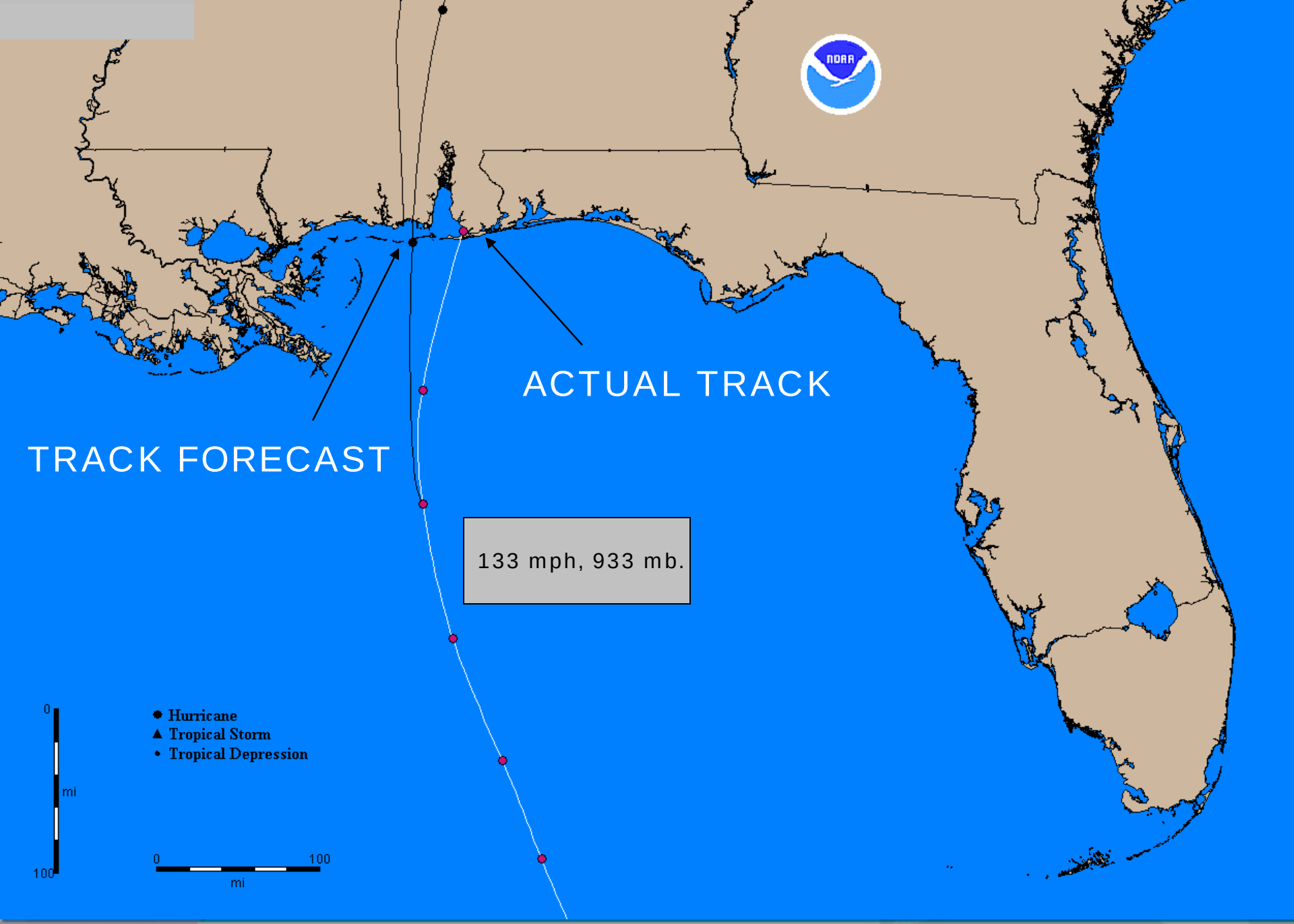
- All storm surge models are STRONGLY dependent on the accuracy of the meteorological input!!!
- Meteorological uncertainty will dominate over storm surge model specifications (physics, resolution, etc)
- Different vertical datums/reference levels
- Storm surge is only one component in the real water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



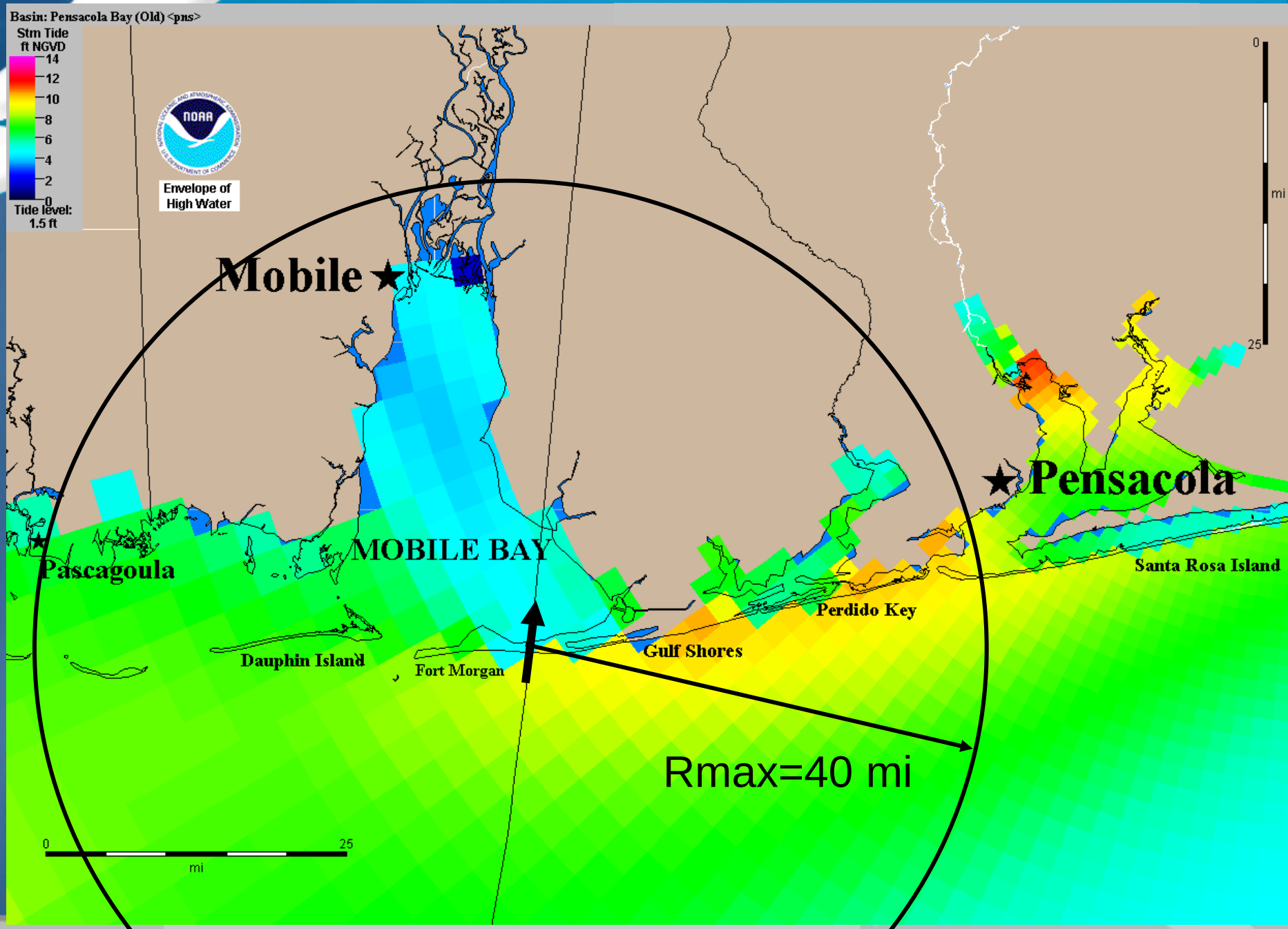
Hurricane Advisory – Approximately 12 hr. before landfall



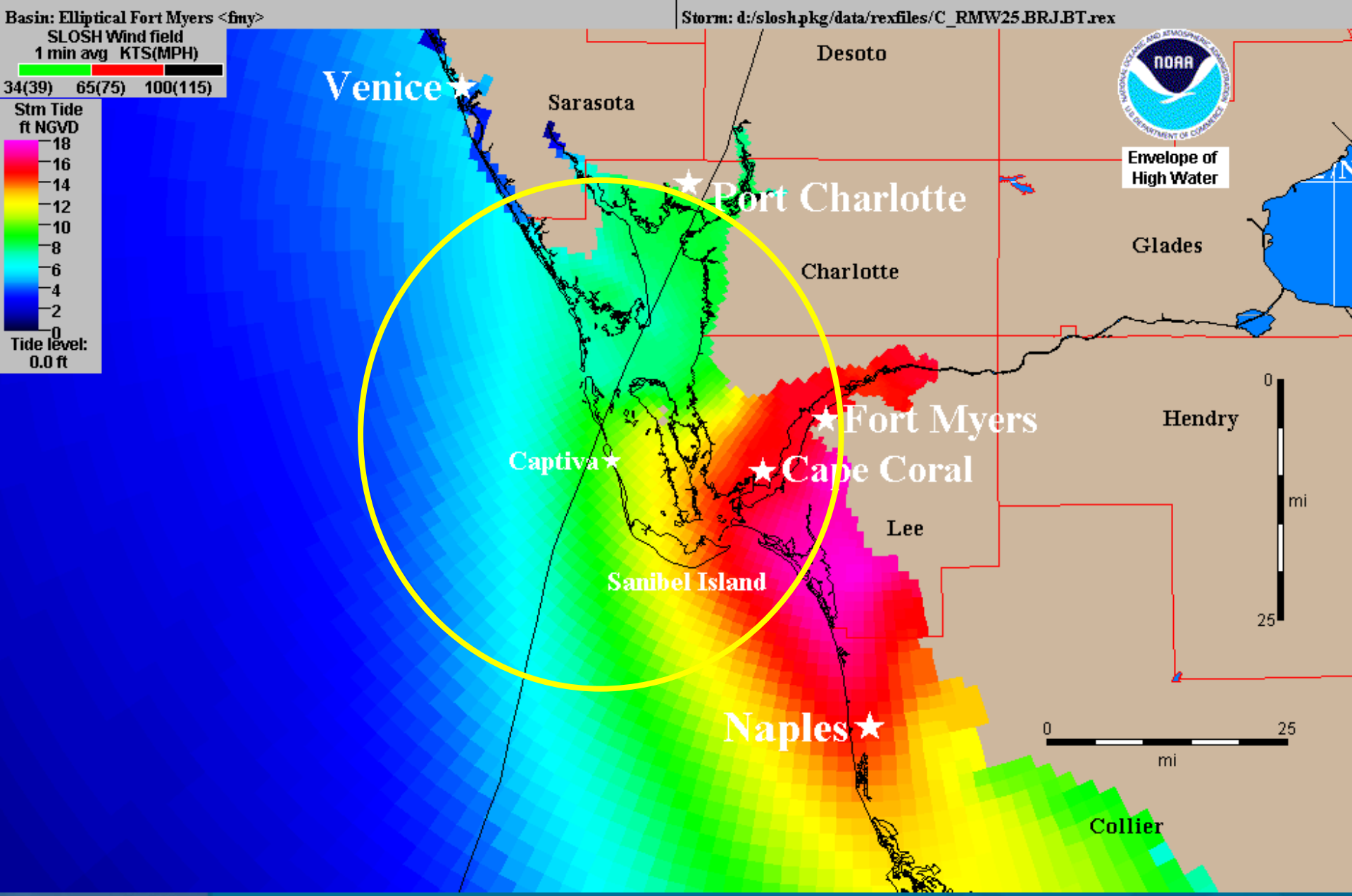
Surge Based on NHC -12 hr. Advisory



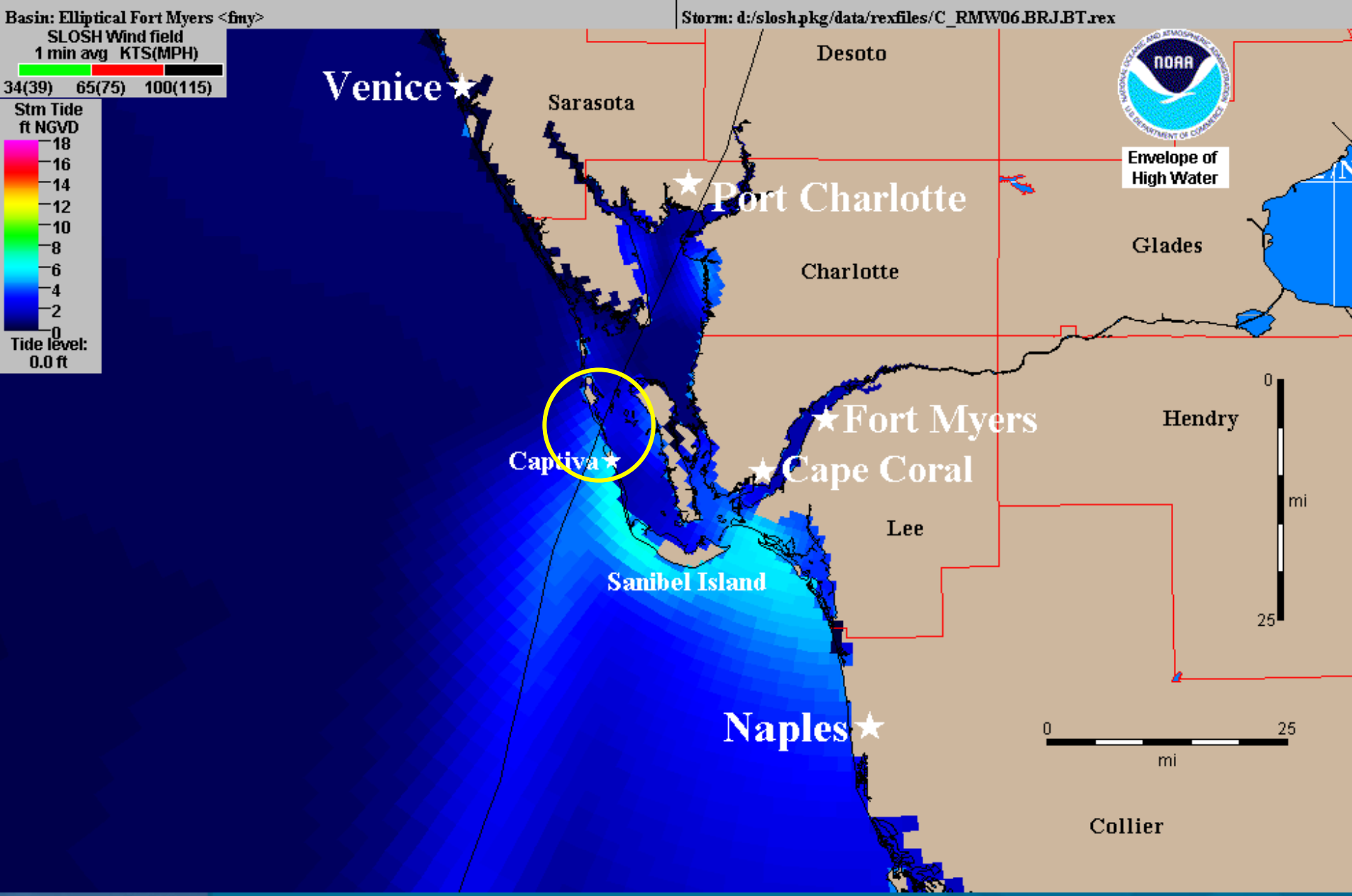
Actual Hurricane Track 30 mi. E of -12 hr. Advisory Forecast Track



Surge Based on NHC Storm Best Track



RMW = 25 mi., “Average” Size


Basin: Elliptical Fort Myers <fmy>
Storm: d:/slosh.pkg/data/rexfiles/C_RMW06.BRJ.BT.rex
SLOSH Wind field
1 min avg KTS(MPH)
34(39) 65(75) 100(115)
Stm Tide
ft NGVD
18
16
14
12
10
8
6
4
2
0
Tide level:
0.0 ft
Venice
Sarasota
Desoto
Port Charlotte
Charlotte
Glades
Envelope of
High Water
Fort Myers
Cape Coral
Captiva
Sanibel Island
Lee
Hendry
Naples
Collier
0
25
mi
0
25
mi

RMW = 6 mi.

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 Products

1. MEOWs

Maximum Envelopes Of Water

2. MOMs

Maximum Of the MEOWs

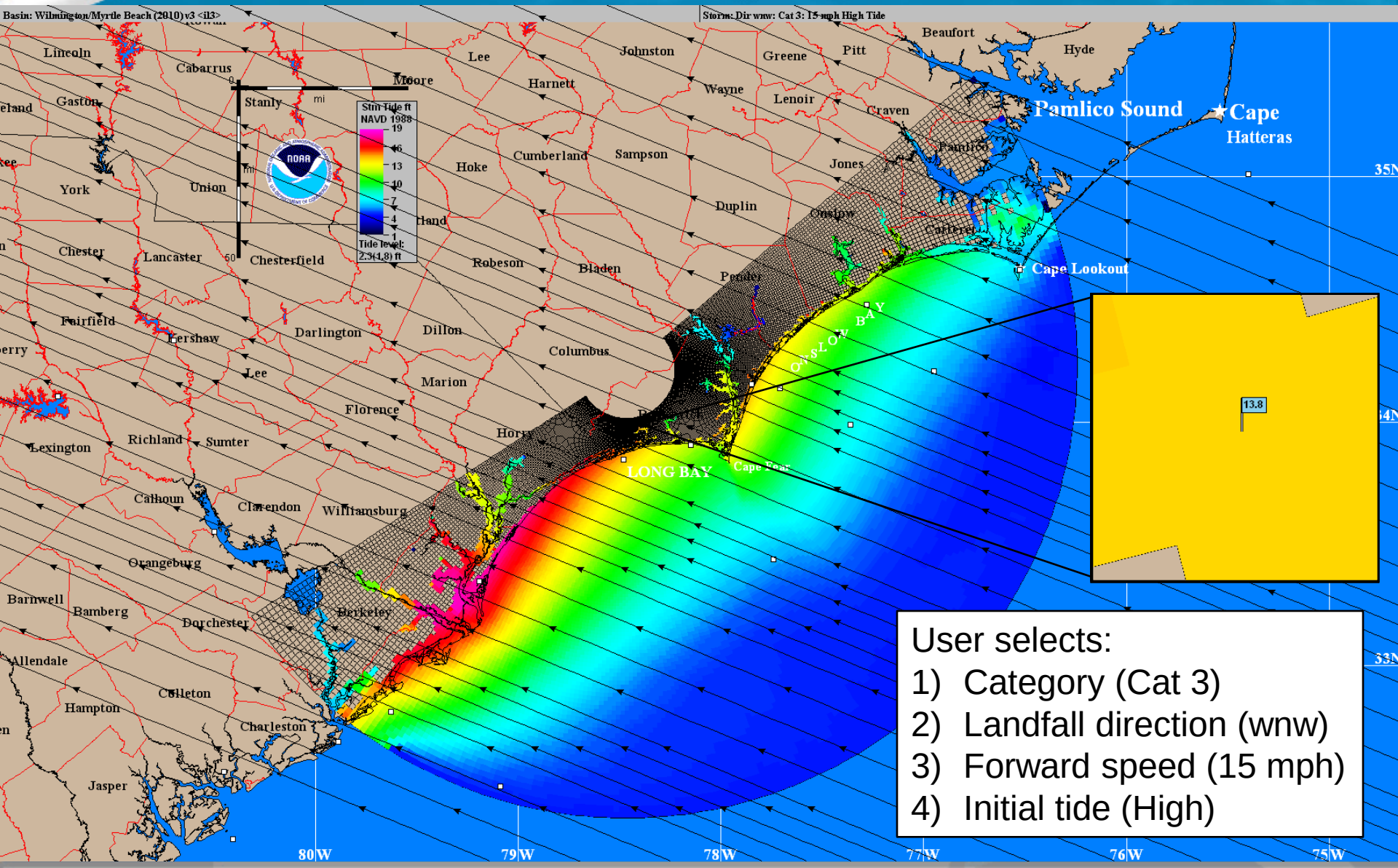
3. P-surge

Probabilistic Storm Surge

MEOW

Maximum Envelope Of Water

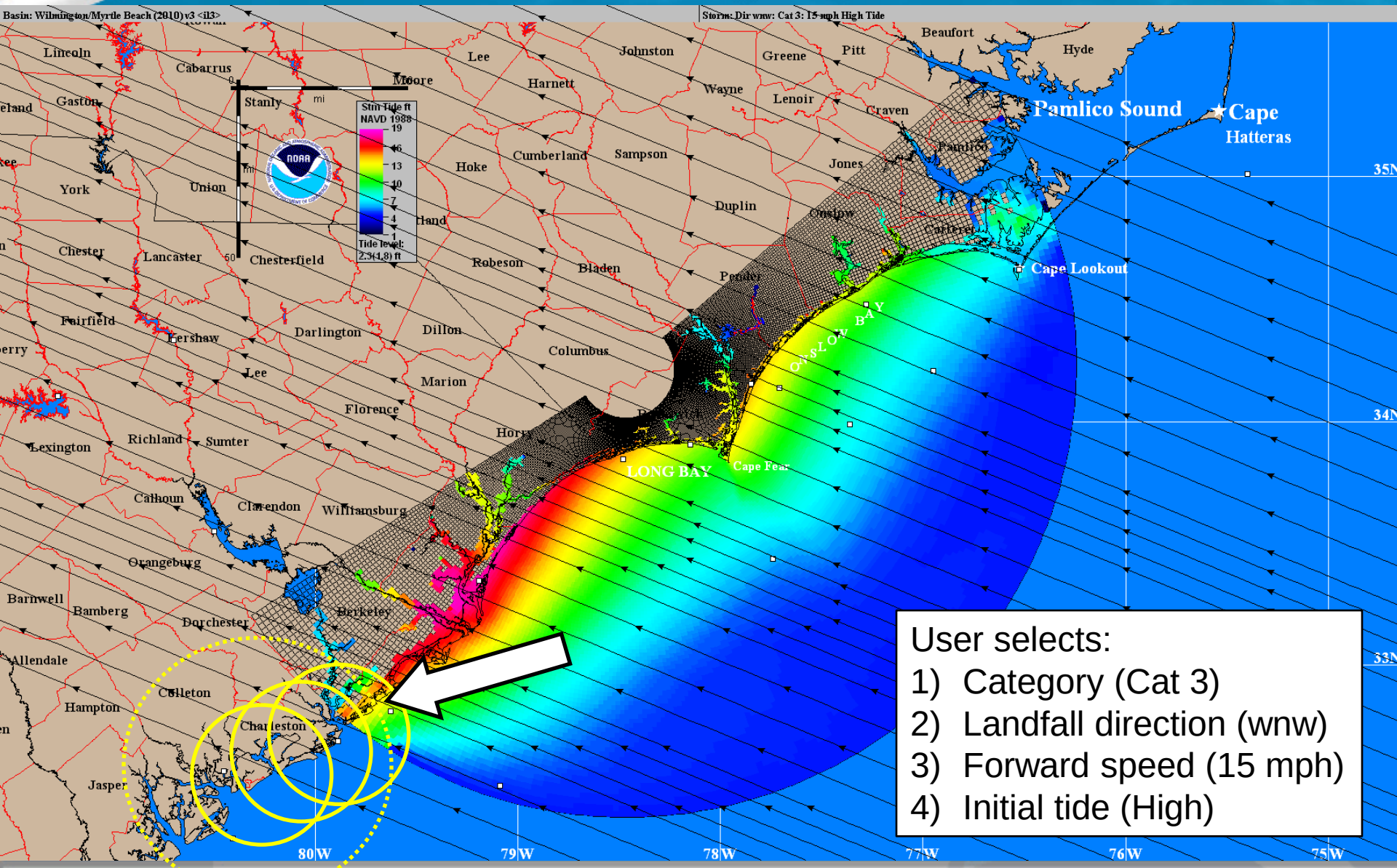
Maximum Envelope Of Water



User selects:

1) Category (Cat 3)
2) Landfall direction (wnw)
3) Forward speed (15 mph)
4) Initial tide (High)

Maximum Envelope Of Water



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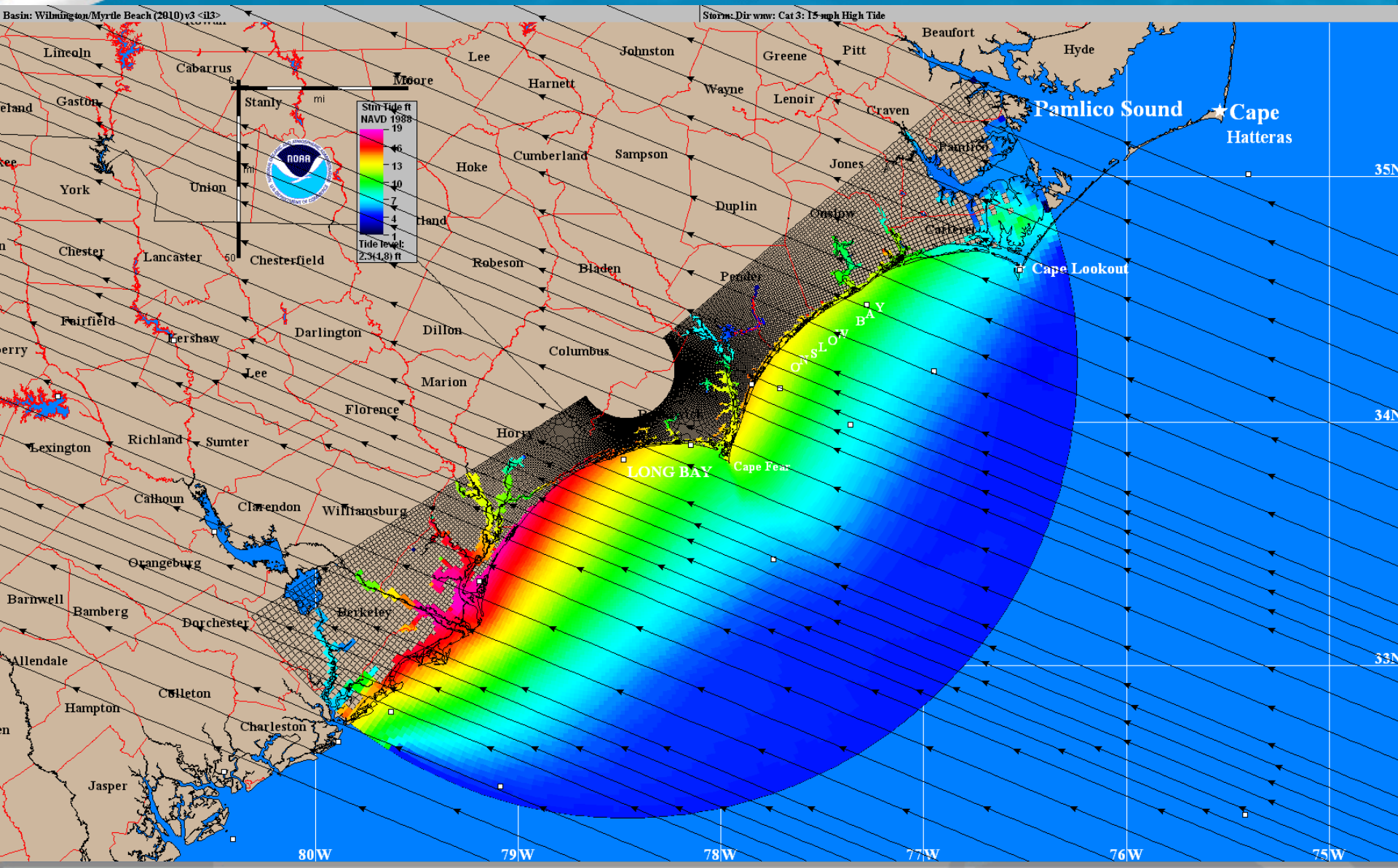
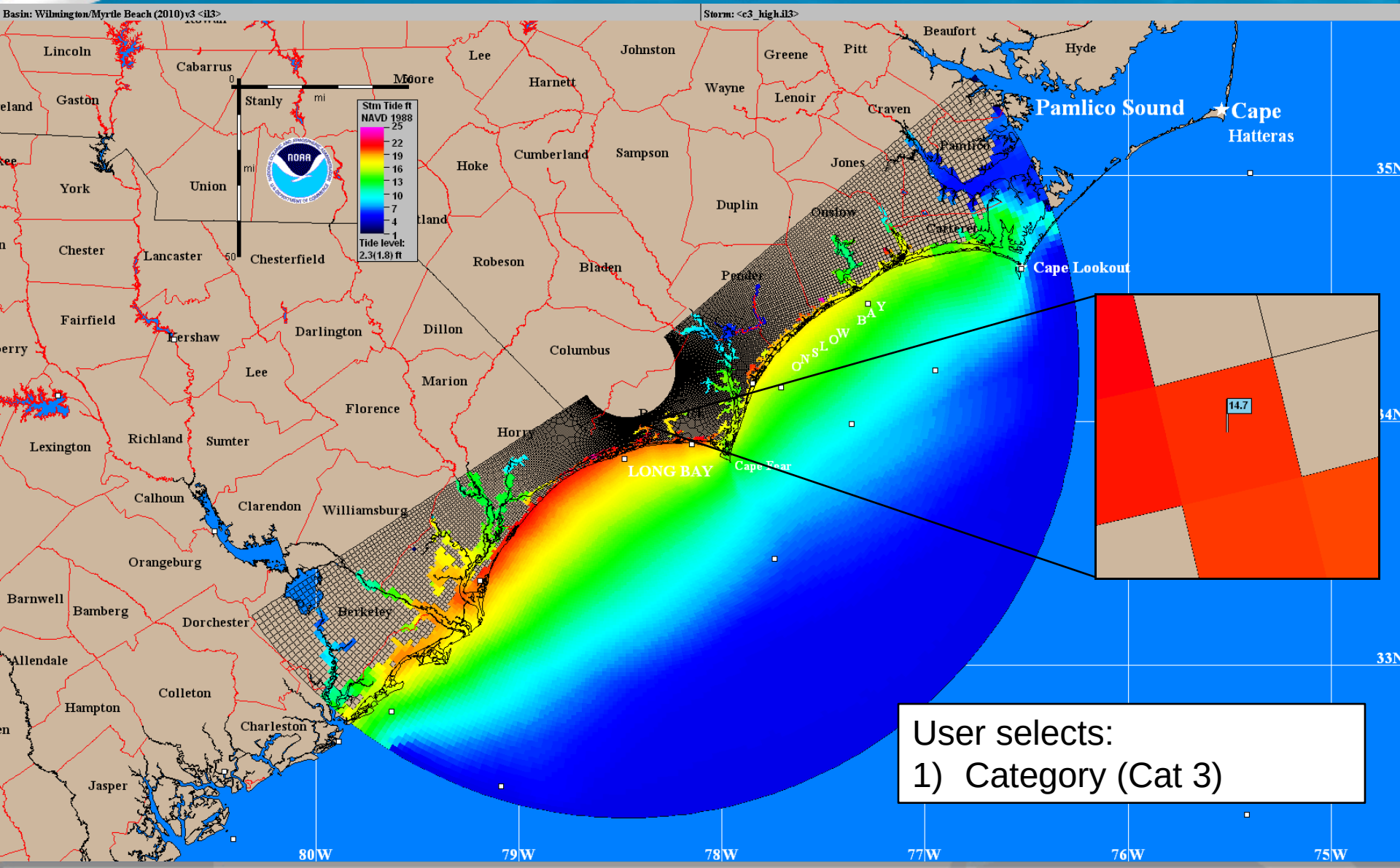
Maximum Envelope Of Water



MOM

Maximum Of the MEOWs

MOM



User selects:

1) Category (Cat 3)

Probabilistic Storm Surge

Use an ensemble of SLOSH runs to create probabilistic storm surge (p-surge)

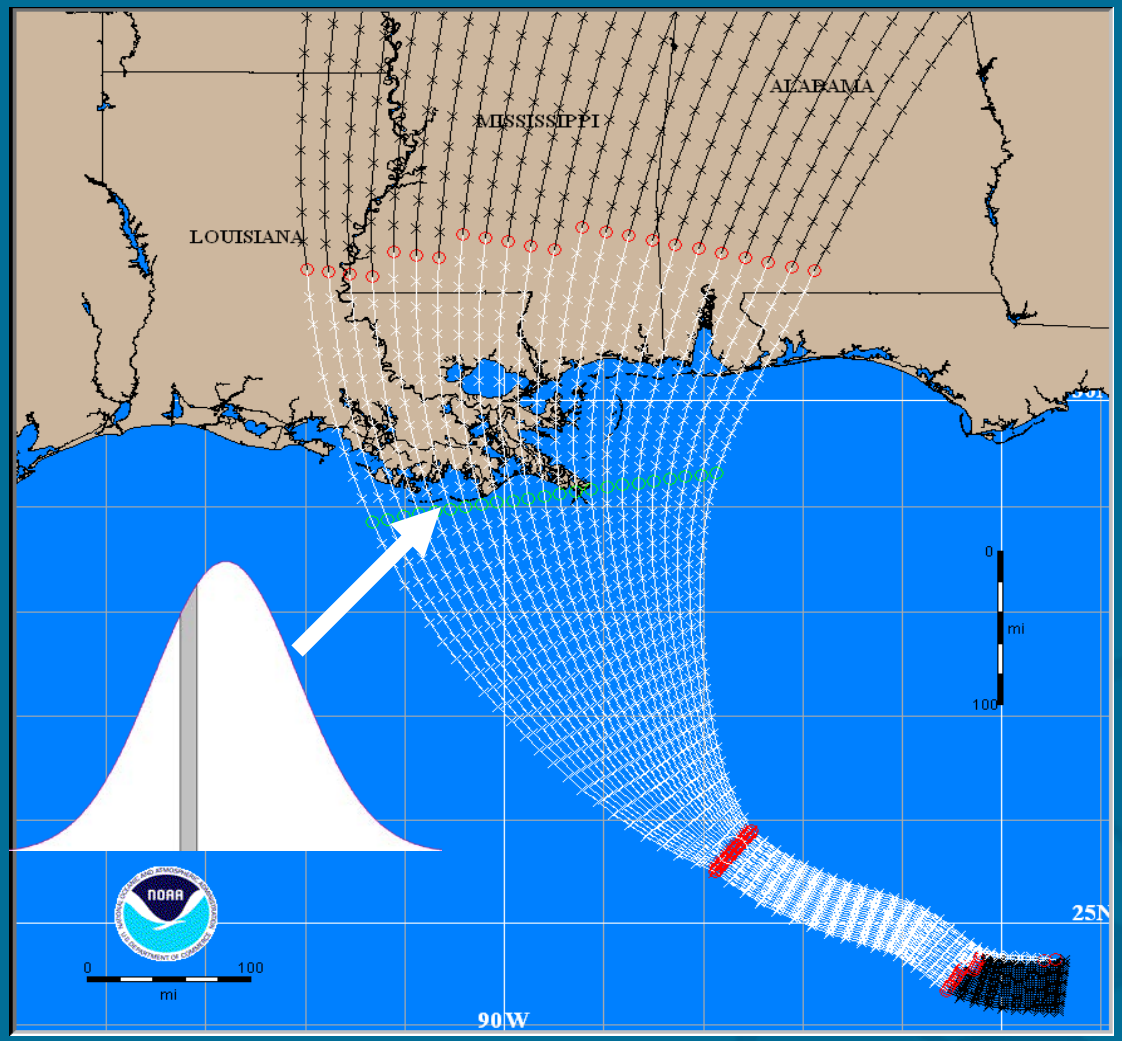
- Intended to be used operationally so it is based on NHC's official advisory
- P-surge's ensemble perturbations are determined by statistics of past performance of the advisories

Error Incorporated in P-Surge

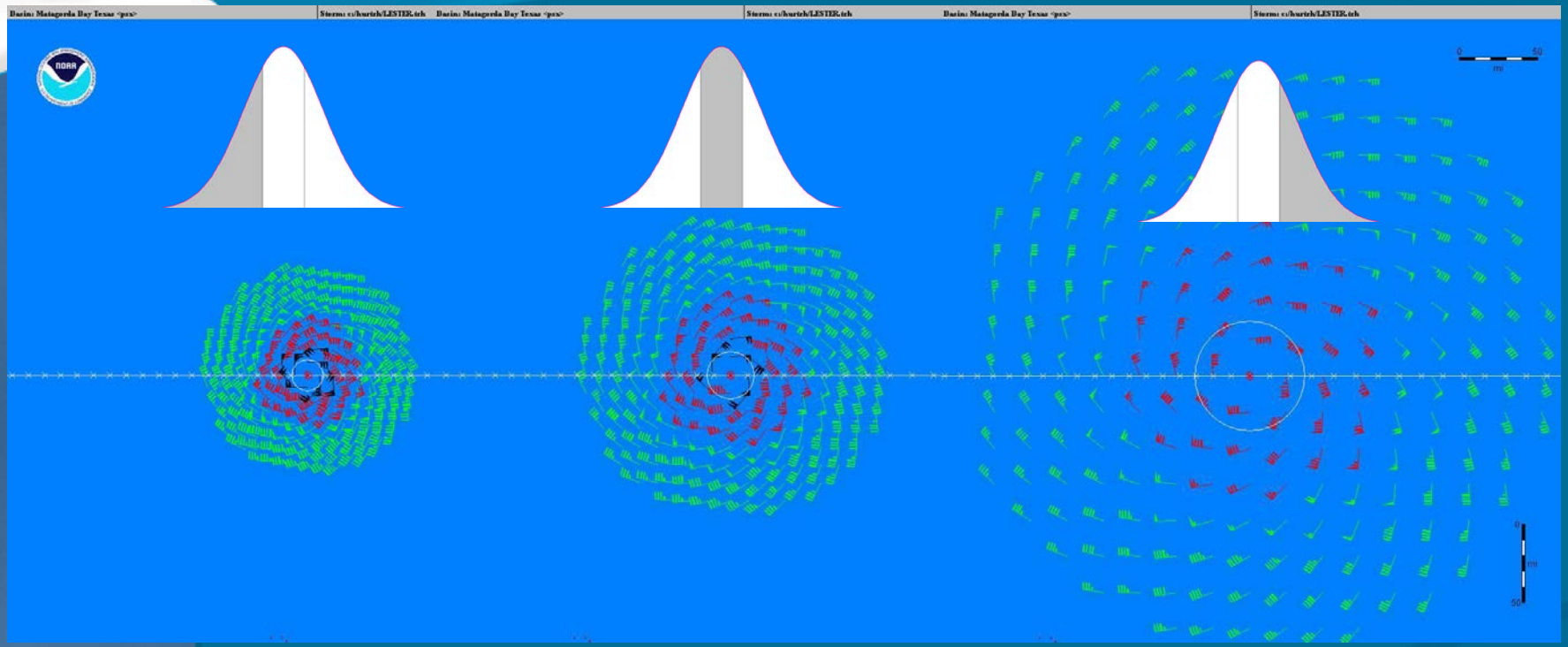
Ensemble based on distributions of:

- Cross track error (impacts Location)
- Along track error (impacts Forward Speed, Timing)
- Intensity error (impacts Pressure)
- Rmax error (impacts Size)

Cross-Track Error



Other Parameters



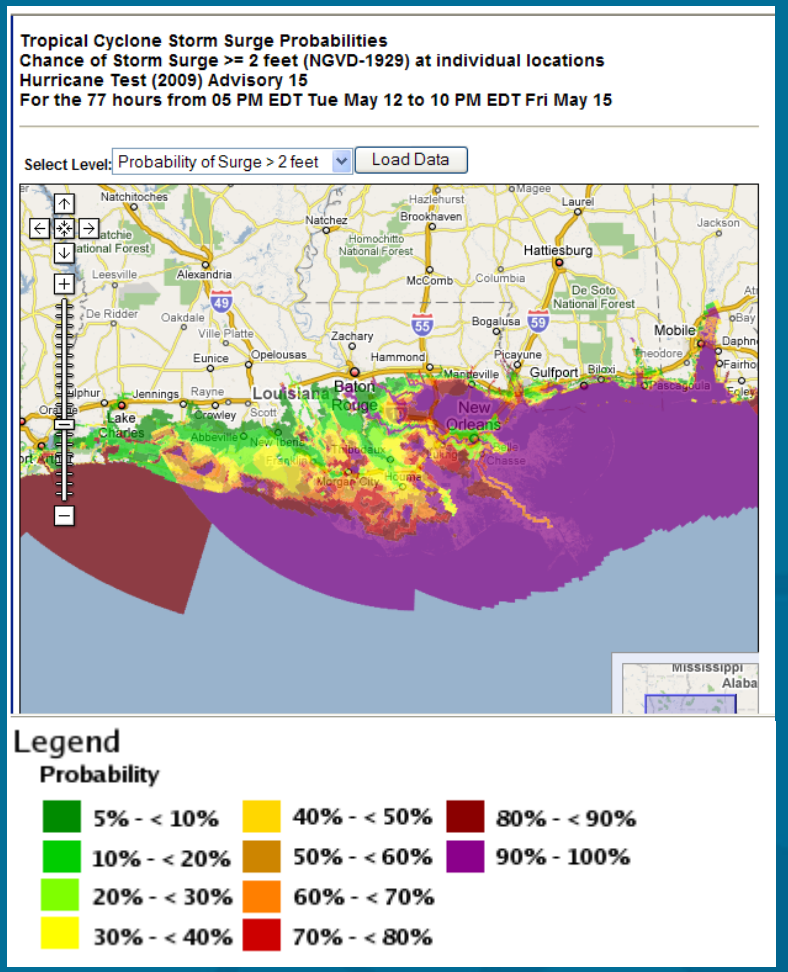
Size: Small (30%), Medium (40%), Large (30%)

Forward Speed: Fast (30%), Medium (40%), Slow (30%)

Intensity: Strong (30%), Medium (40%), Weak (30%)

When is it Available?

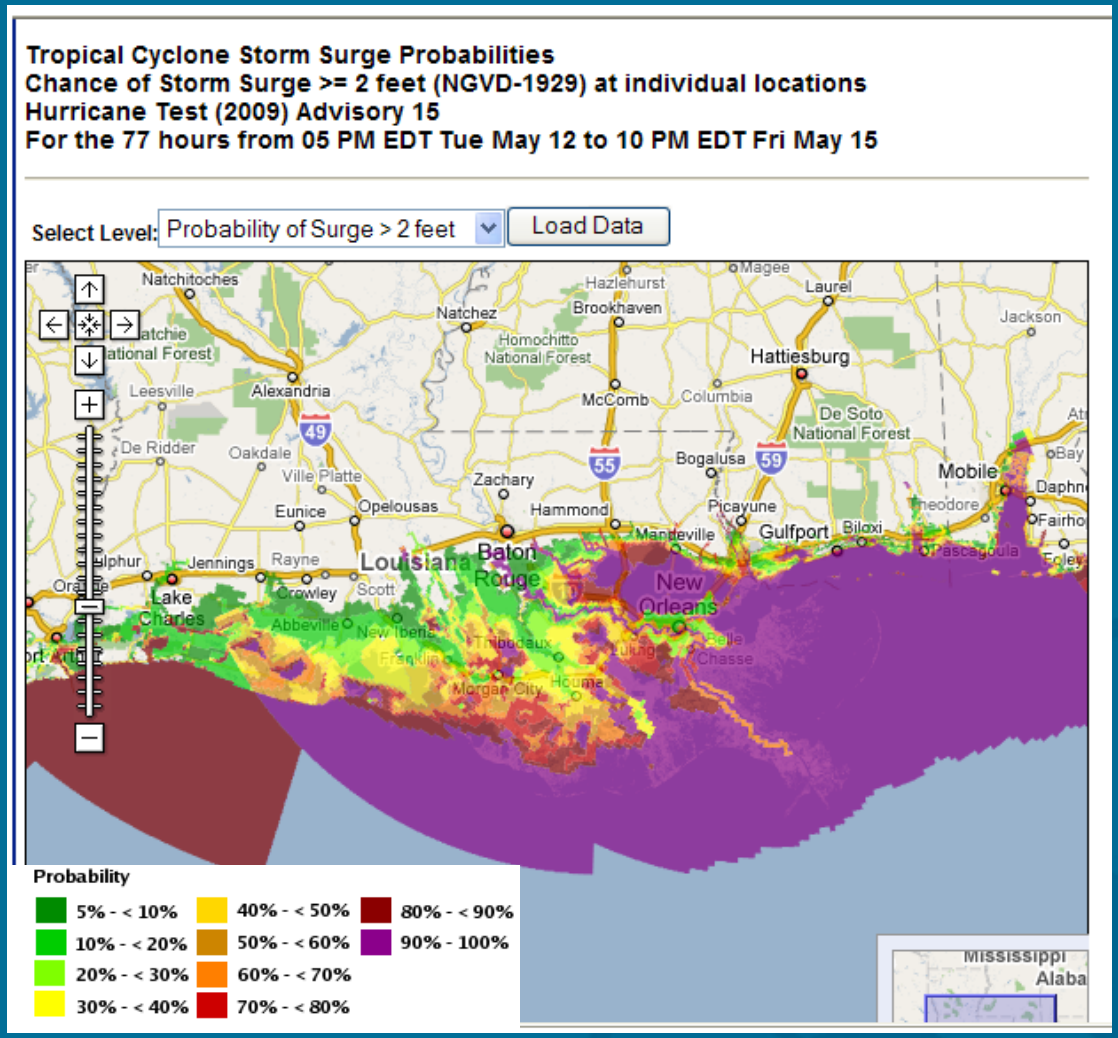
- Whenever a hurricane watch or warning is in effect
- Available about 30 minutes after the advisory release time

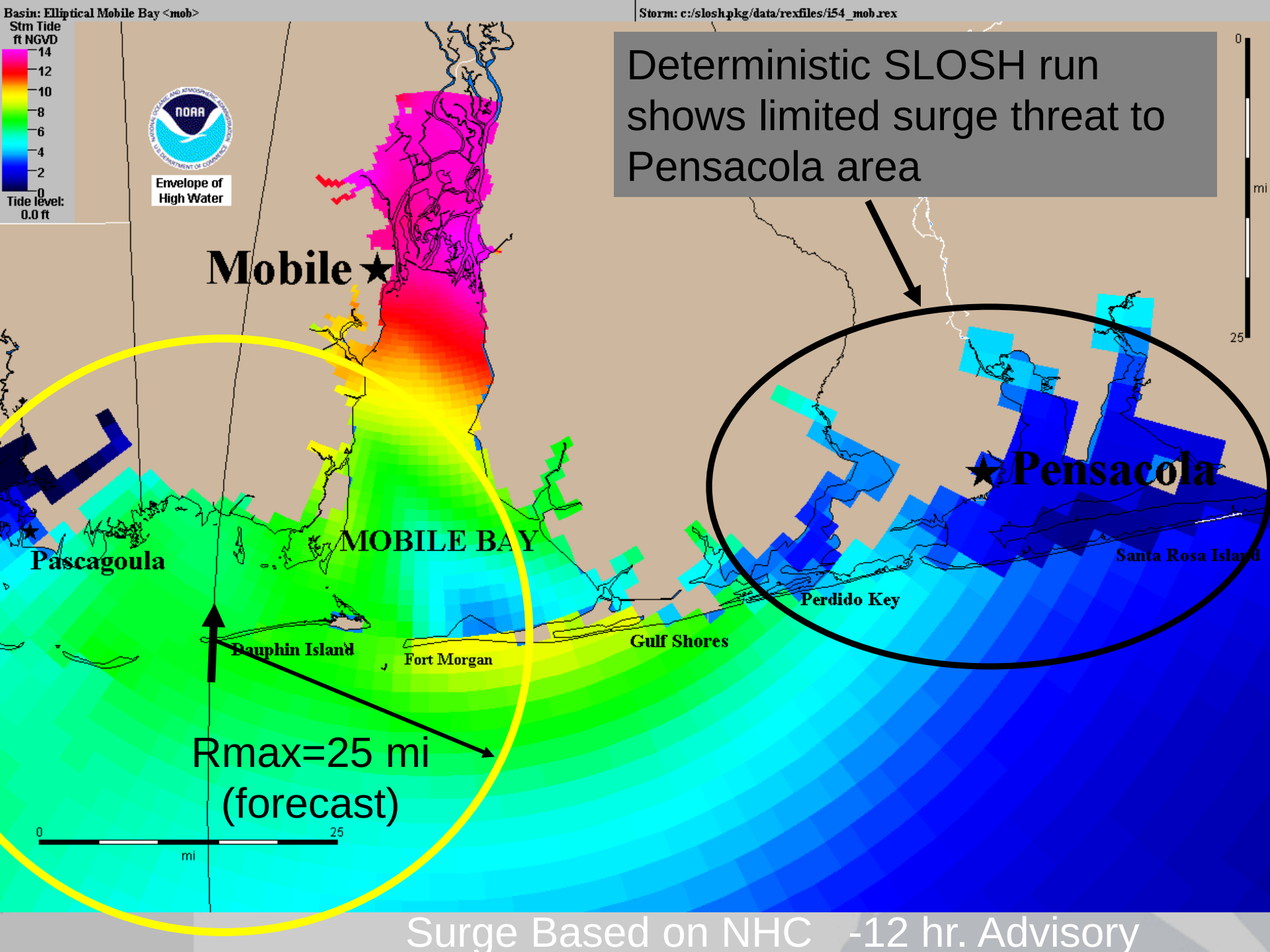


Understanding/Using Probability

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?

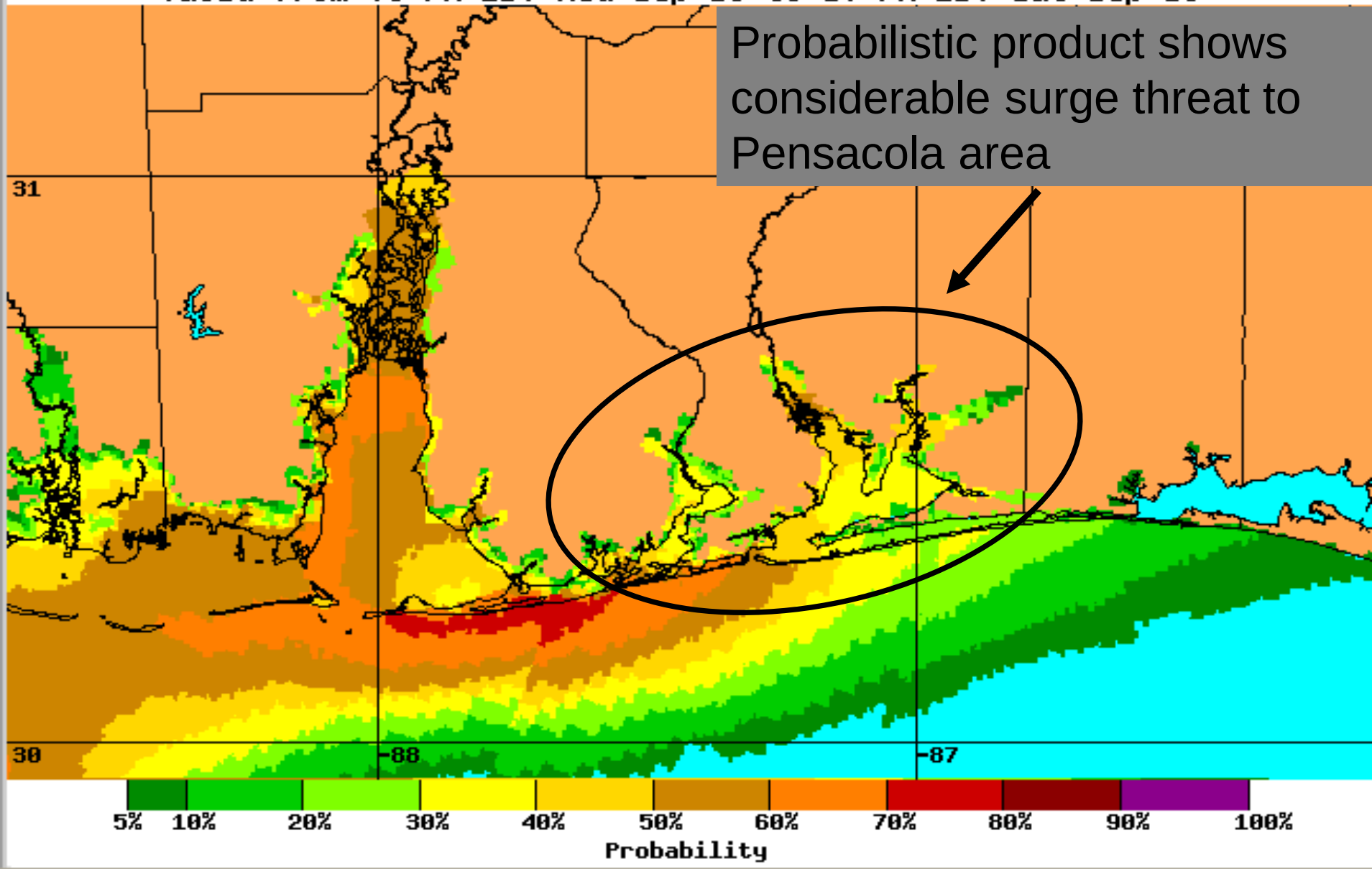


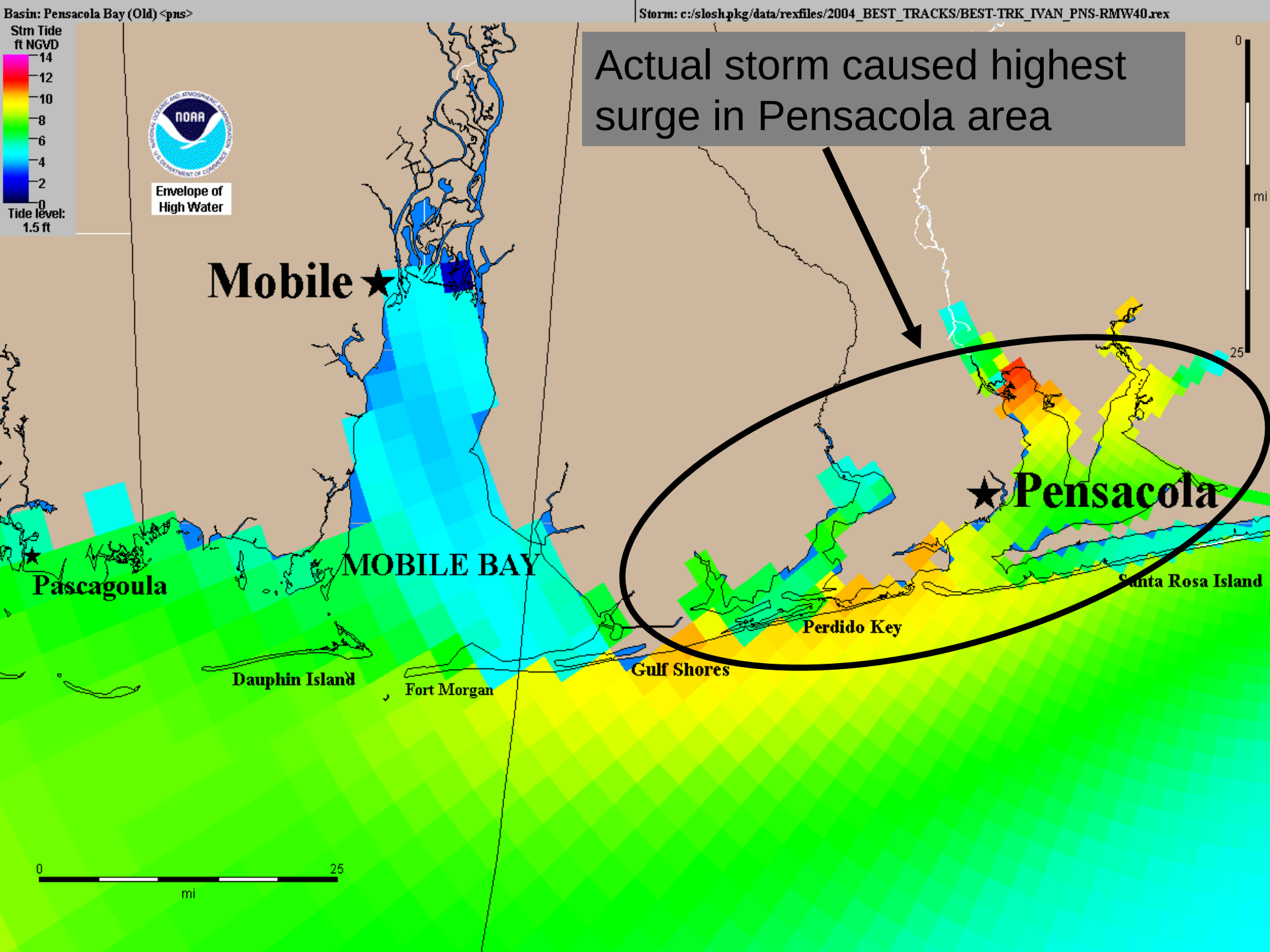


Surge Based on NHC -12 hr. Advisory

Storm: Ivan2004 Adv54 Type: Prob. of surge > 8 feet Zoom Level: Full

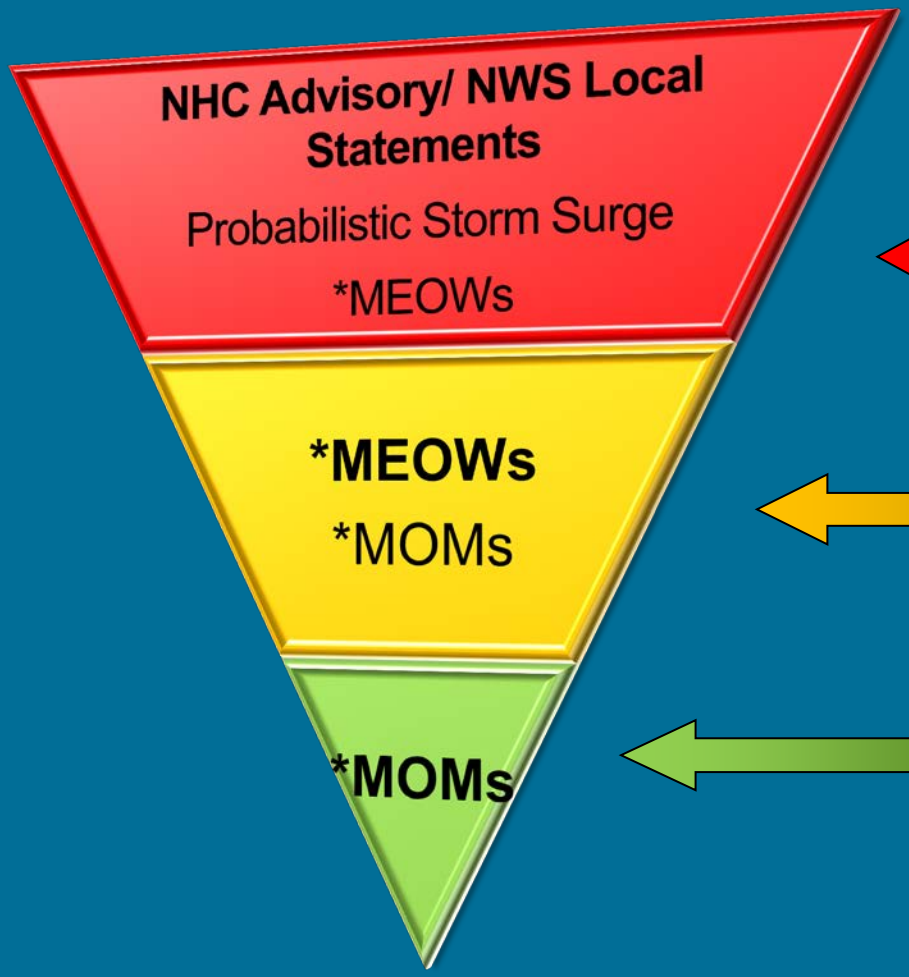
Experimental Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge >= 8 feet at Individual Locations
Hurricane Ivan (2004) Advisory 54
Valid from 05 PM EDT Wed Sep 15 to 10 PM EDT Sat Sep 18




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
Pascagoula
MOBILE BAY
Dauphin Island
Fort Morgan
Gulf Shores
Perdido Key
Santa Rosa Island
0
25
mi
0
25
mi

Surge Guidance Timeframe

NHC Storm Surge Product Decision Support Wedge



Tier 1

Response

< 48 h of landfall

Tier 2

Readiness

48 h – 120 h of landfall

Tier 3

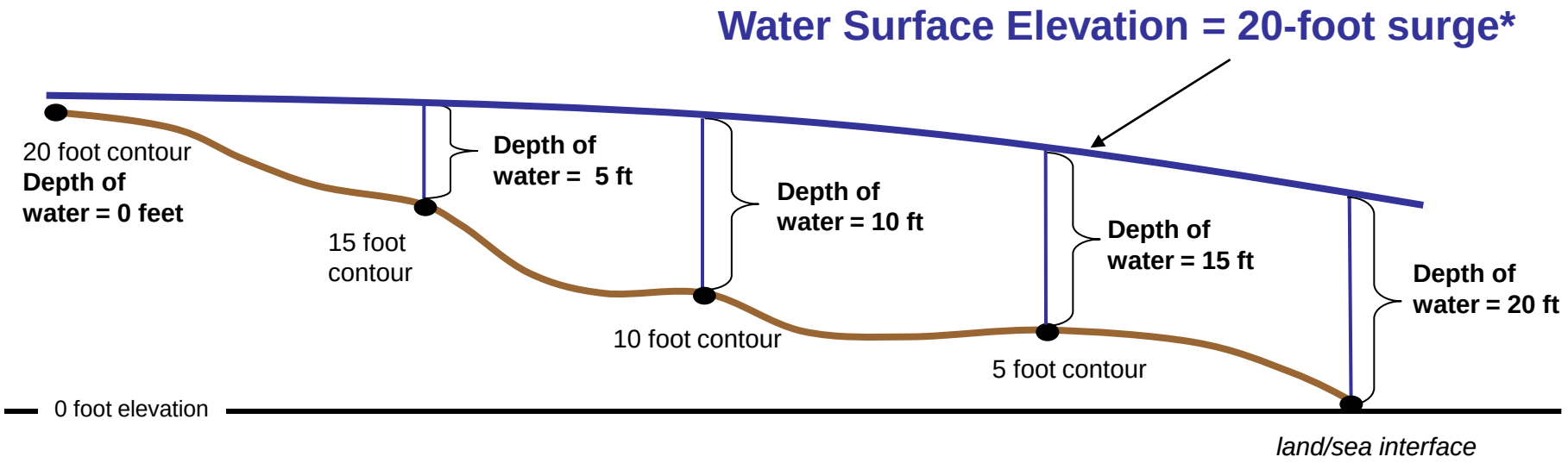
Planning/Mitigation

> 120 h of landfall

Storm Surge Inundation

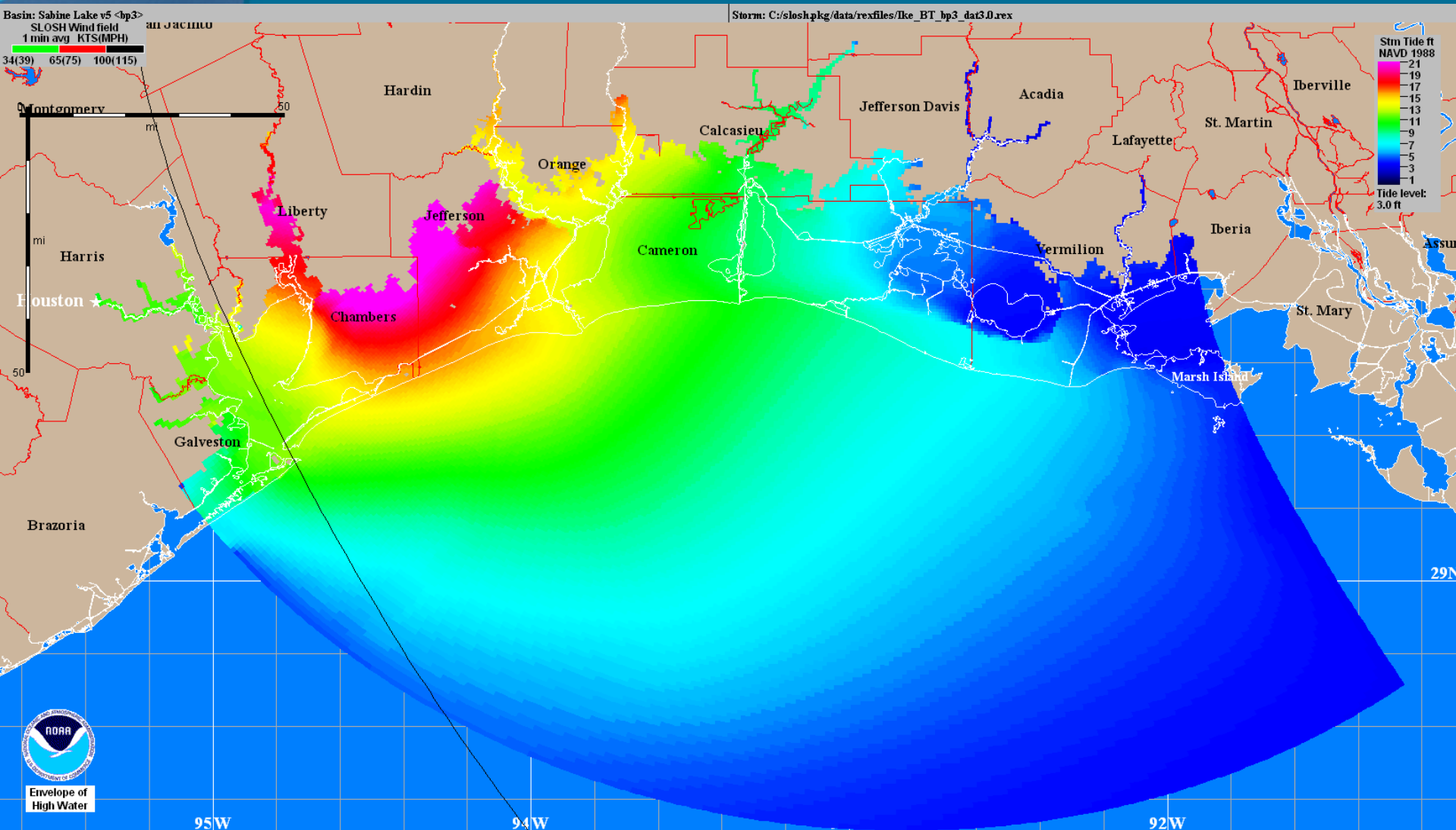
What does a 20-foot storm surge really mean to your location?

Storm surge models output water surface elevations for a specific area (grid cell)



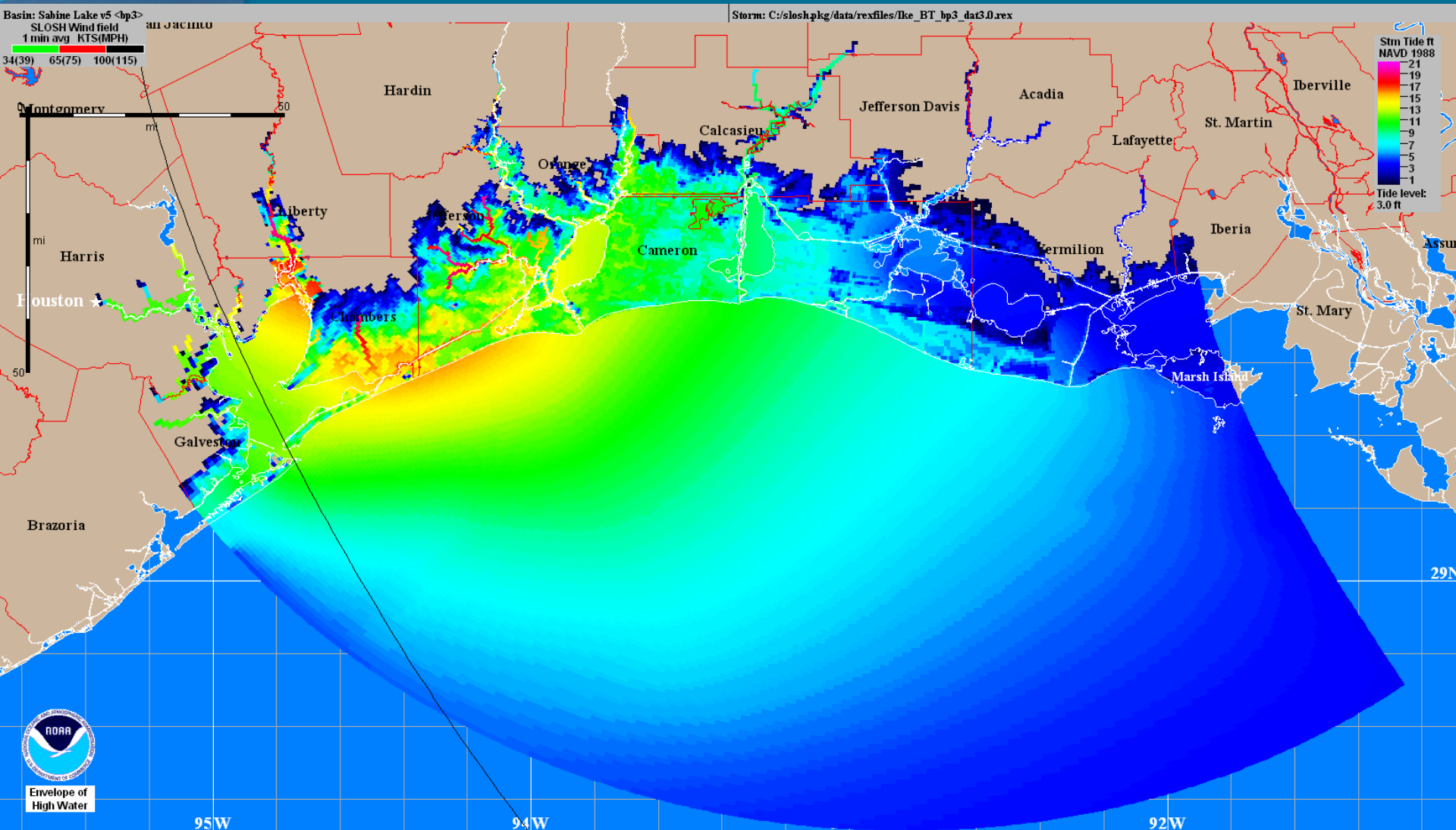
***This only represents surge. There may be waves on top of the surge.**

Height Above Reference Level



Height Above Ground Level

(Inundation)



New Surge Statement

Storm surge flooding of 2 to 4 feet above normal tide levels ... Can be expected along the west coast of Florida in areas of onshore flow south of Venice and in Florida Bay. Storm surge should begin to decrease along the east coast of Florida.

STORM SURGE WILL RAISE WATER LEVELS BY AS MUCH AS 4 FEET ABOVE GROUND LEVEL ALONG THE WEST COAST OF FLORIDA IN AREAS OF ONSHORE FLOW SOUTH OF VENICE AND IN FLORIDA BAY ... WITH LARGE AND DANGEROUS BATTERING WAVES ... THE SURGE COULD PENETRATE AS FAR INLAND AS ABOUT 30 MILES FROM THE SHORE WITH DEPTH GENERALLY DECREASING AS THE WATER MOVES INLAND. STORM SURGE SHOULD BEGIN TO DECREASE ALONG THE EAST COAST OF FLORIDA.

SLOSH Basin Updates

- Size/shape of basins
  - Size sometimes increased to better model surge
    - Additional hypothetical tracks to cover larger area
  - Grid shape typically unchanged
- NGVD29 → NAVD88
- Update topography/bathymetry information
  - More accurate representation of barriers, gaps, passes, and other features
- Higher resolution especially near the coast and the center of the grid
- Hypothetical tracks now include “average” AND “large” size storms

Basin Status

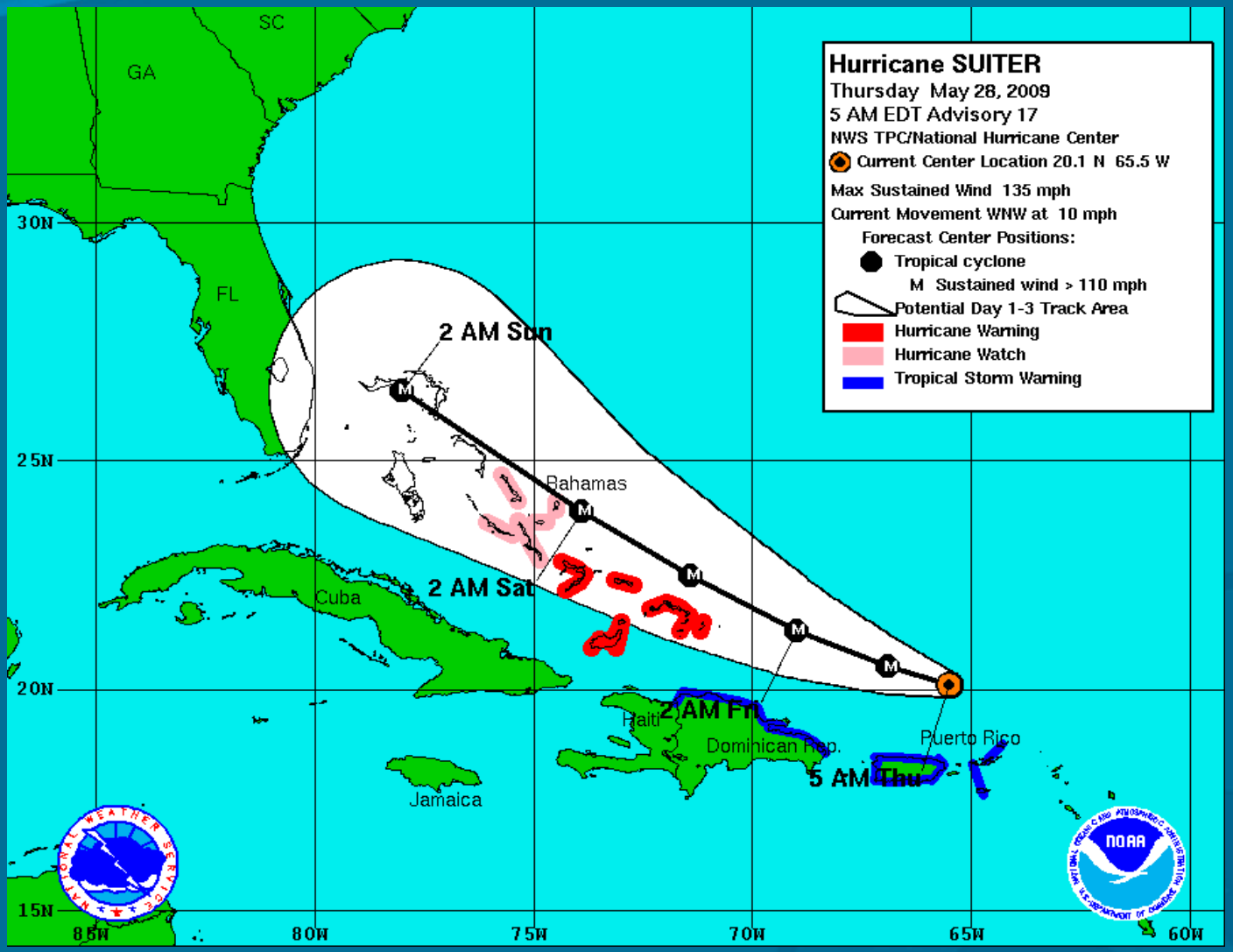
- Planned basin updates for 2011
  - Wilmington*
  - Laguna Madre*
  - New Orleans
  - Jacksonville
  - Vermillion
  - Charleston
  - Galveston
- Recently updated basins:
  - All Florida basins except Jacksonville
  - Other: New York, New Orleans

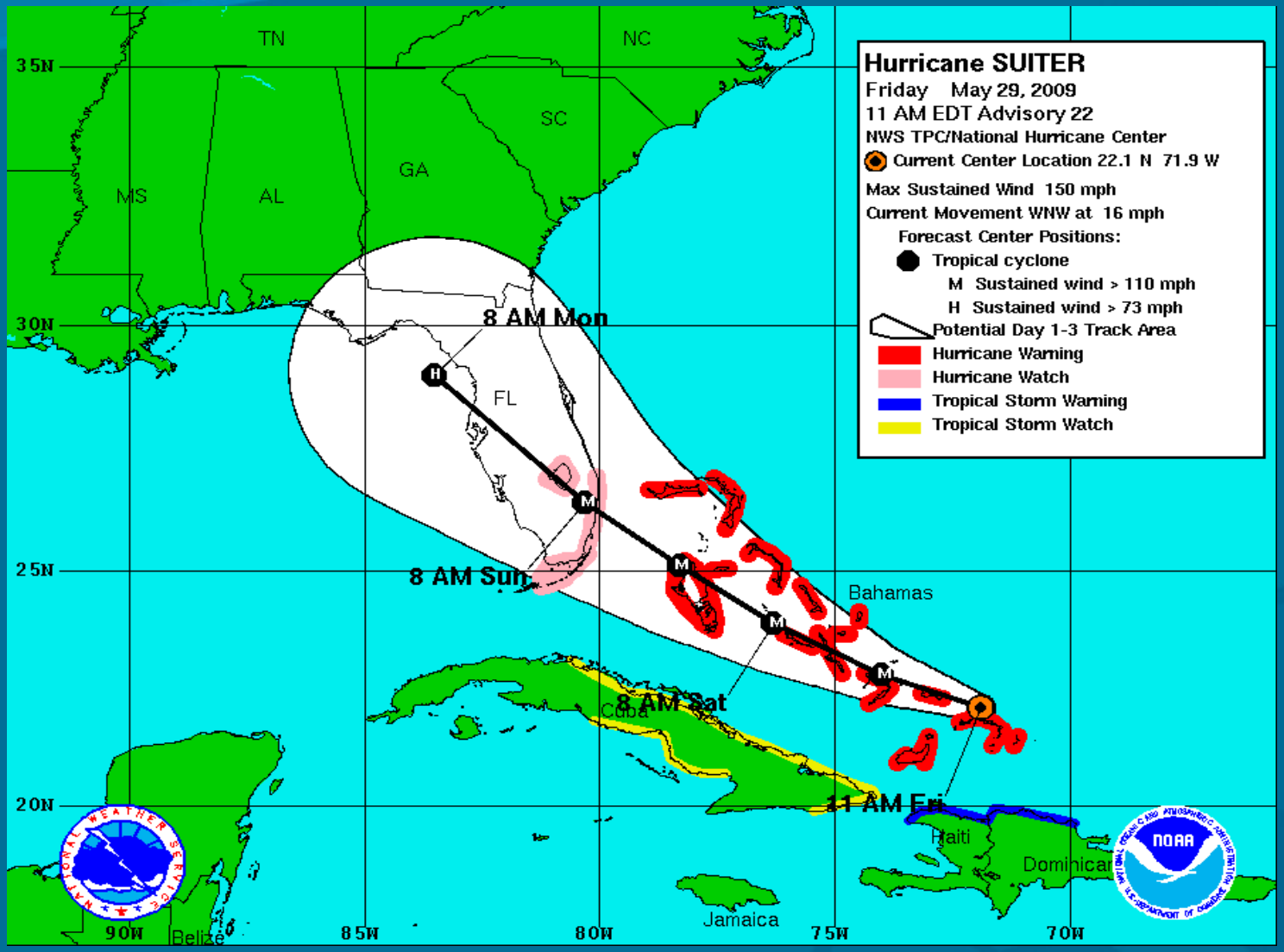
Storm Surge Unit

Jamie Rhome – Team Lead
Dr. Cristina Forbes
Michael Lowry
Tarah Sharon
Jeff Pereira

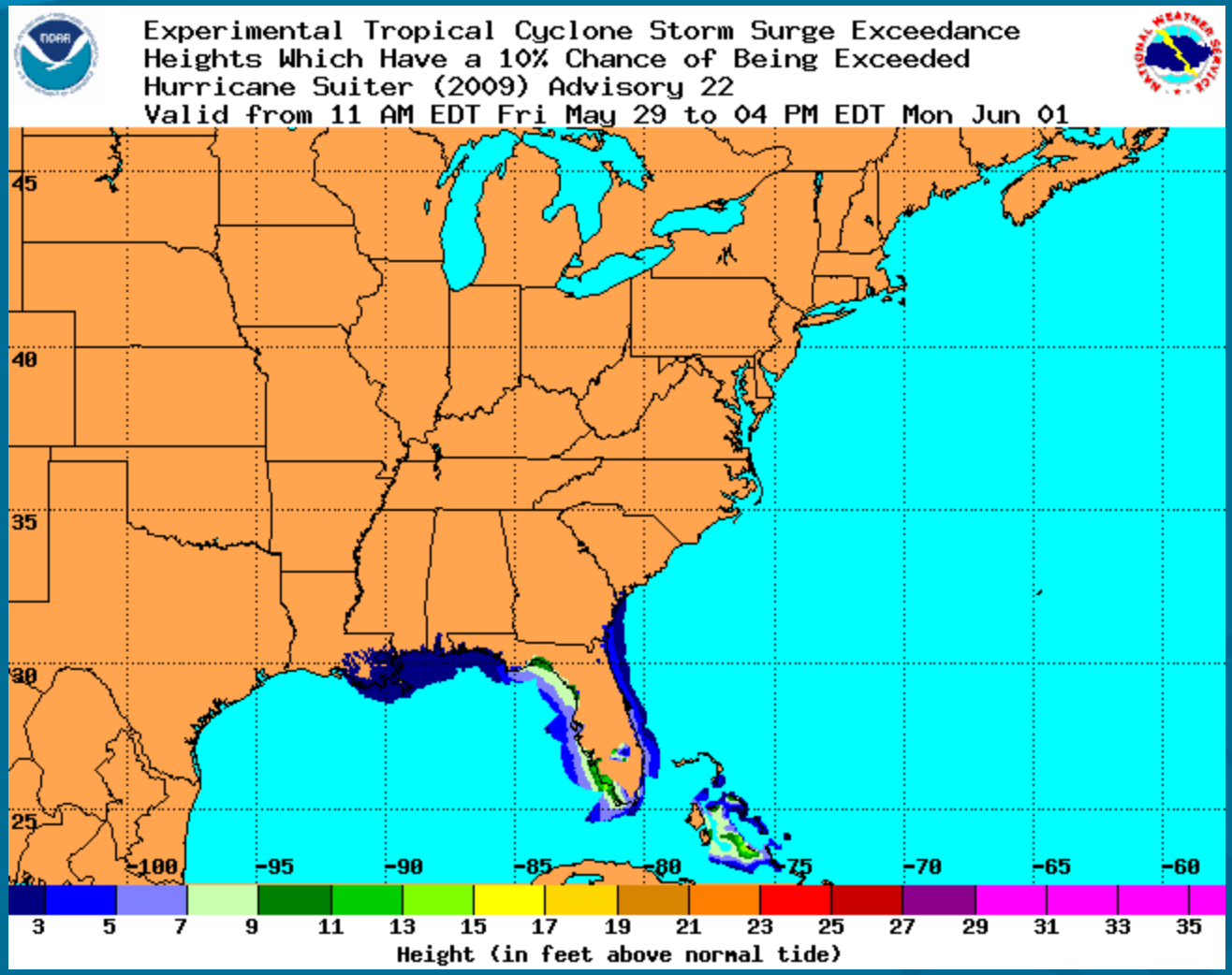
New Website:
http://www.nhc.noaa.gov/ssurge

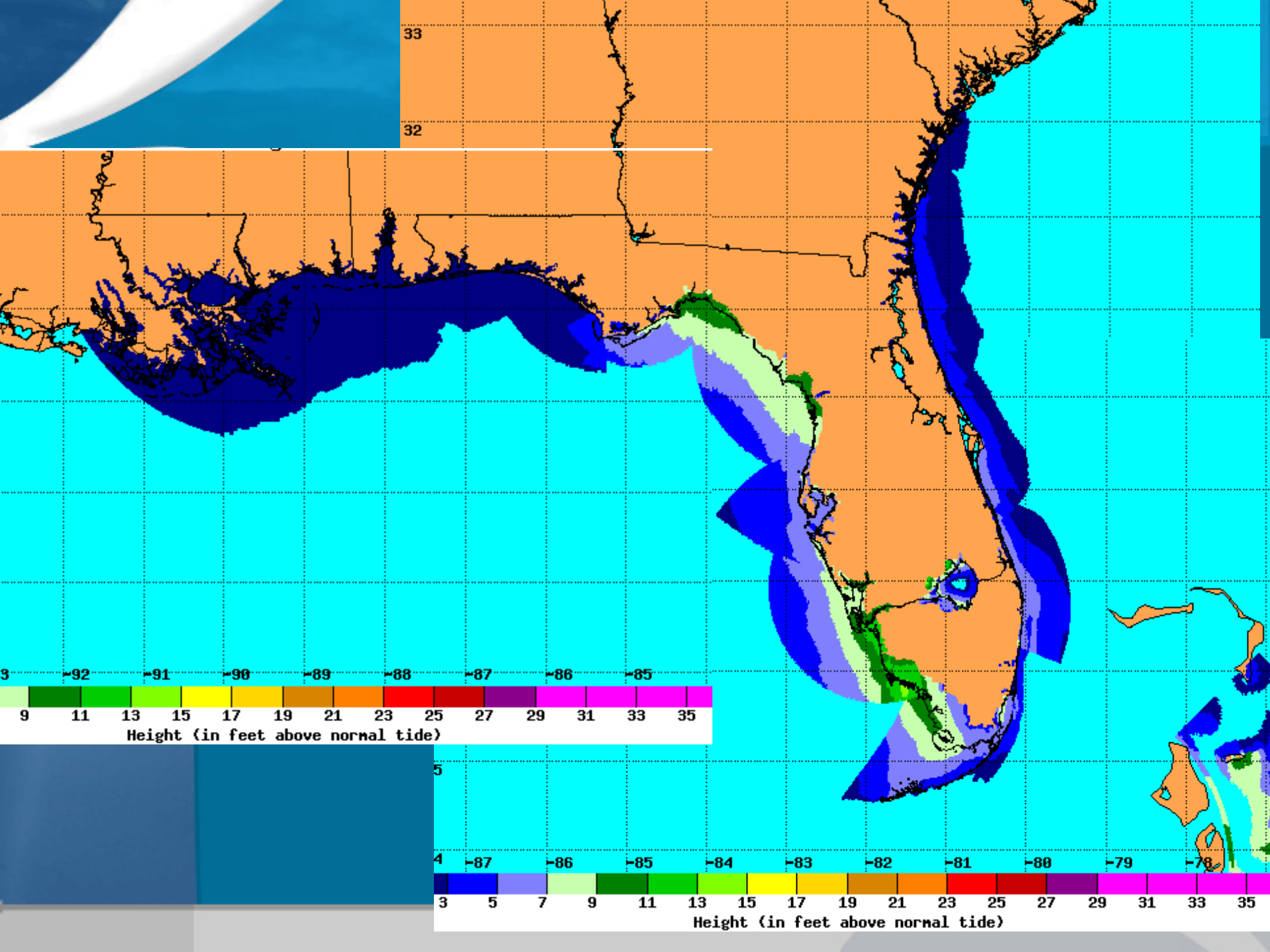
Exercise

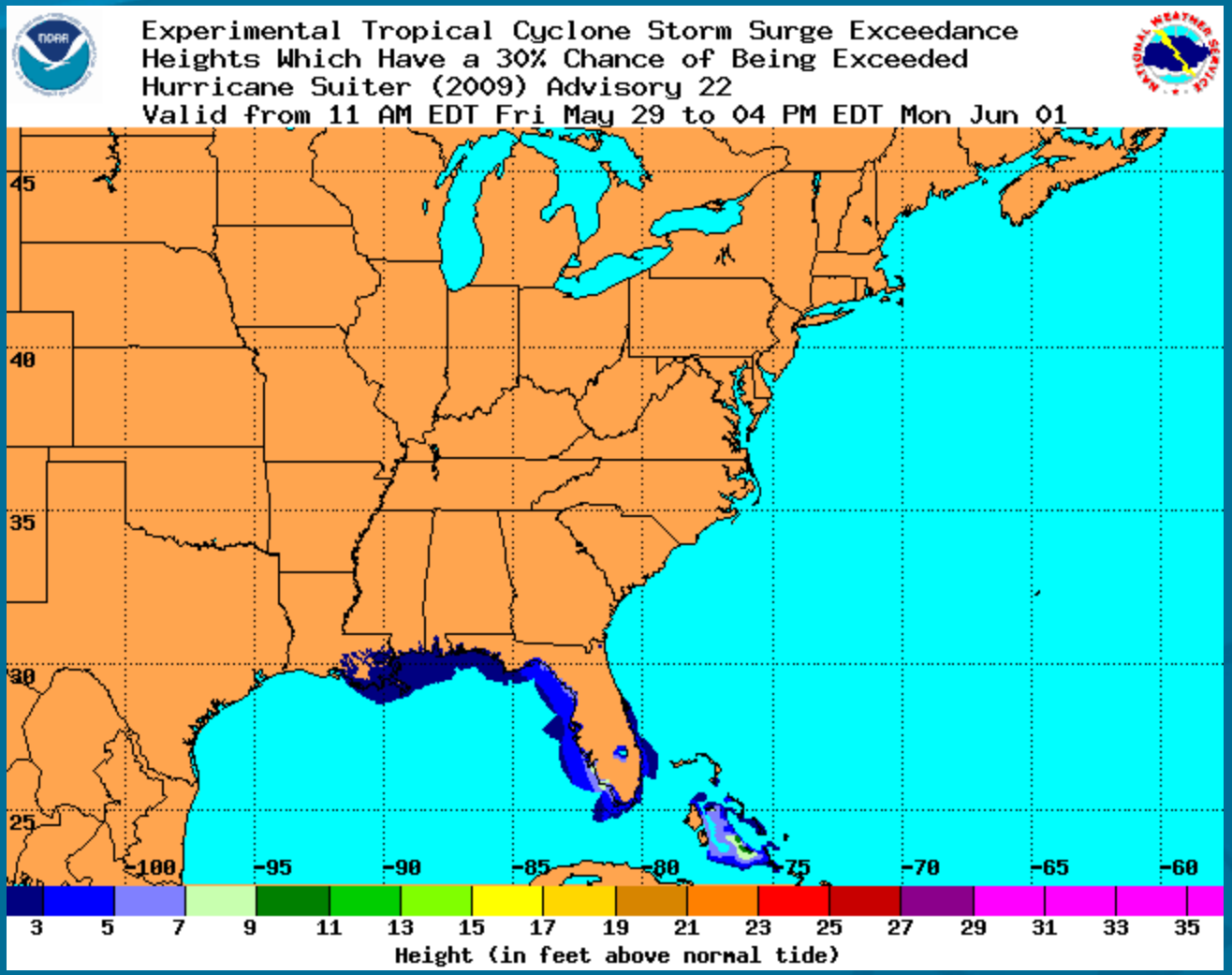

Hurricane SUITER
Thursday May 28, 2009
5 AM EDT Advisory 17
NWS TPC/National Hurricane Center
Current Center Location 20.1 N 65.5 W
Max Sustained Wind 135 mph
Current Movement WNW at 10 mph
Forecast Center Positions:
Tropical cyclone
M Sustained wind > 110 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
SC
GA
FL
30N
25N
20N
15N
85W
80W
75W
70W
65W
60W
2 AM Sun
2 AM Sat
2 AM Fri
5 AM Thu
Bahamas
Cuba
Haiti
Dominican Rep.
Puerto Rico
Jamaica
NOAA

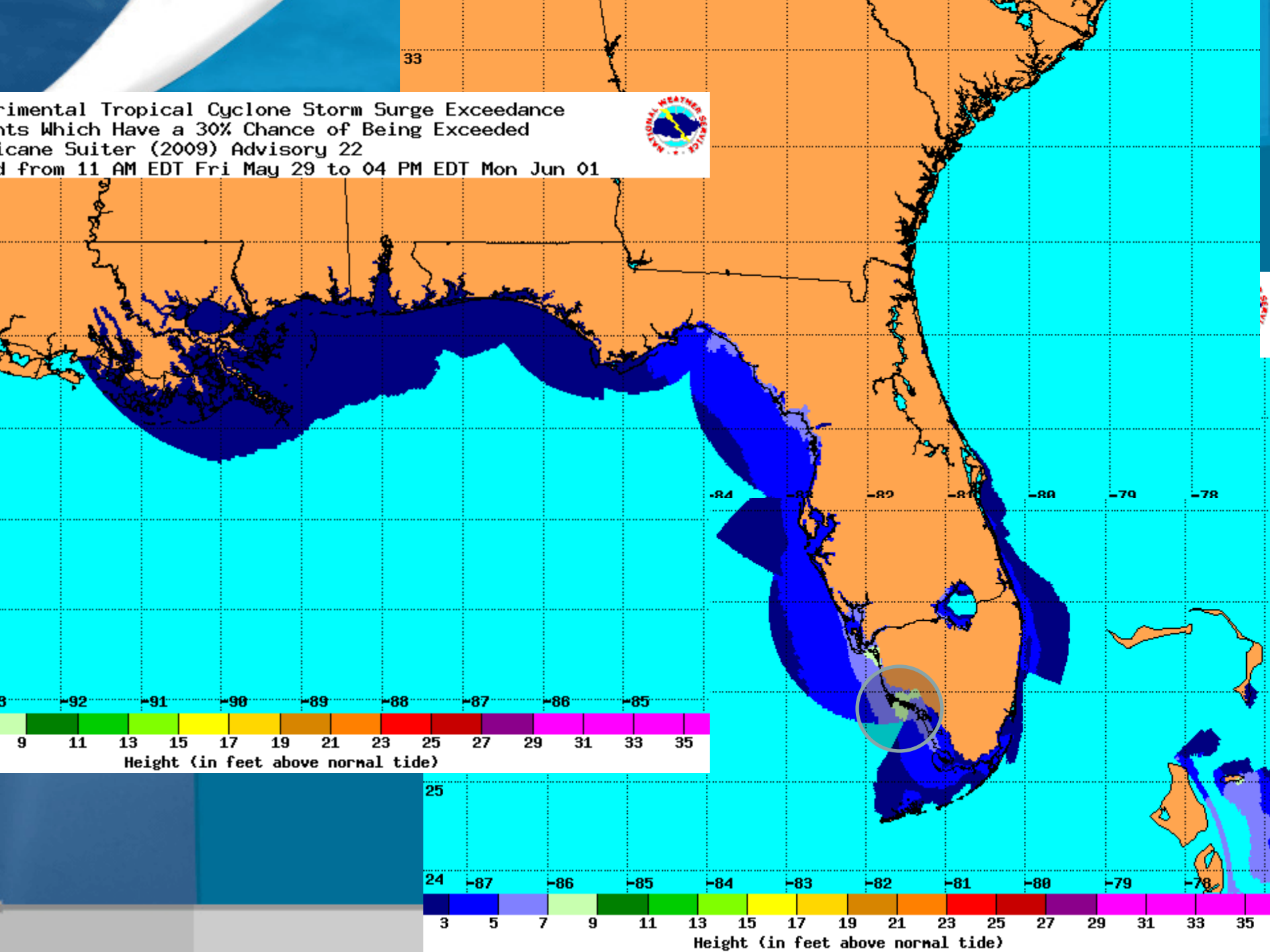

Hurricane SUITER
Friday May 29, 2009
11 AM EDT Advisory 22
NWS TPC/National Hurricane Center
Current Center Location 22.1 N 71.9 W
Max Sustained Wind 150 mph
Current Movement WNW at 16 mph
Forecast Center Positions:
Tropical cyclone
M Sustained wind > 110 mph
H Sustained wind > 73 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
Tropical Storm Watch
8 AM Mon
8 AM Sun
8 AM Sat
11 AM Fri
TN
NC
SC
GA
MS
AL
FL
Bahamas
Cuba
Haiti
Jamaica
Belize
35N
30N
25N
20N
90W
85W
80W
75W
70W

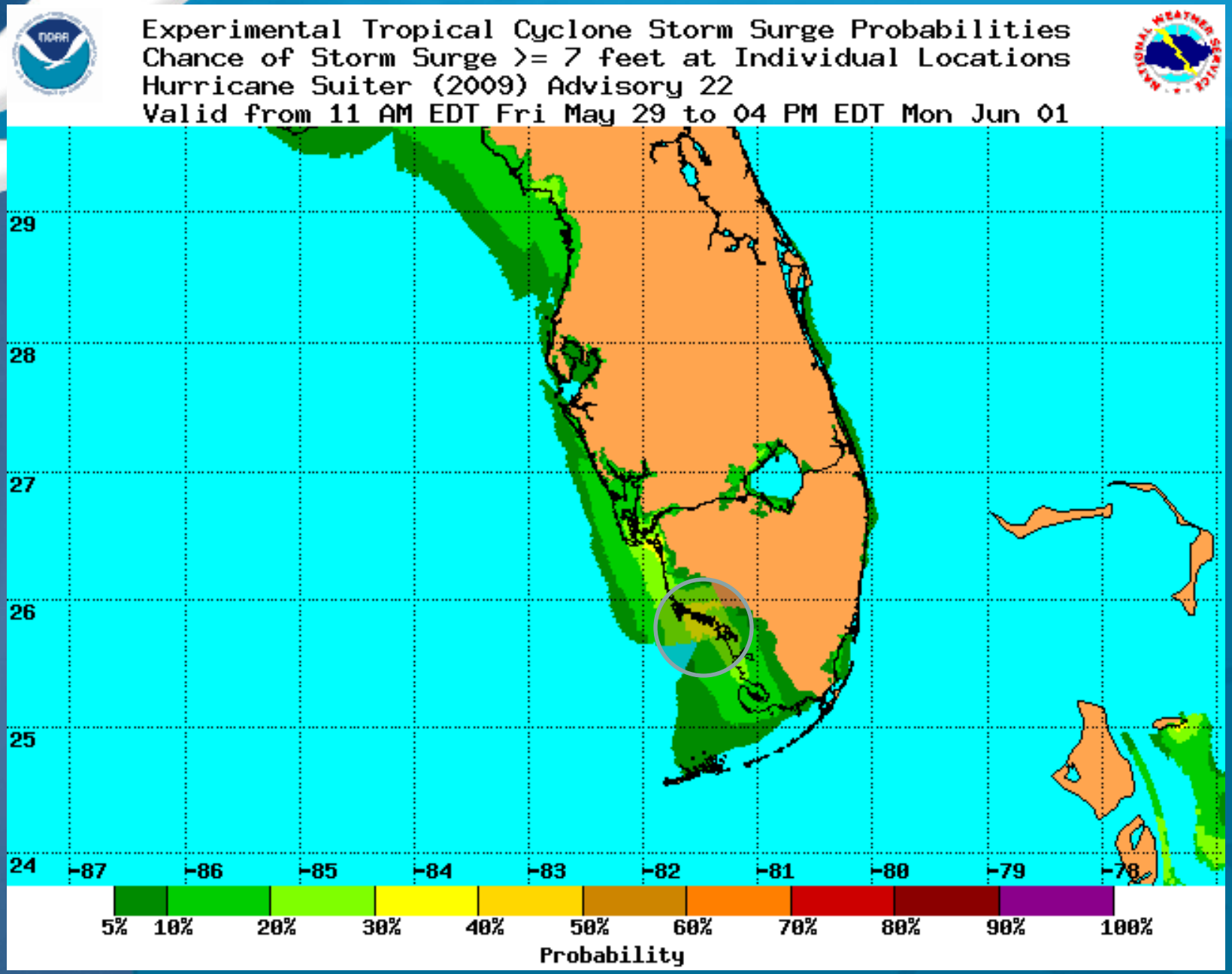
http://slosh.nws.noaa.gov/forArthur/2011natHurCon/psurge



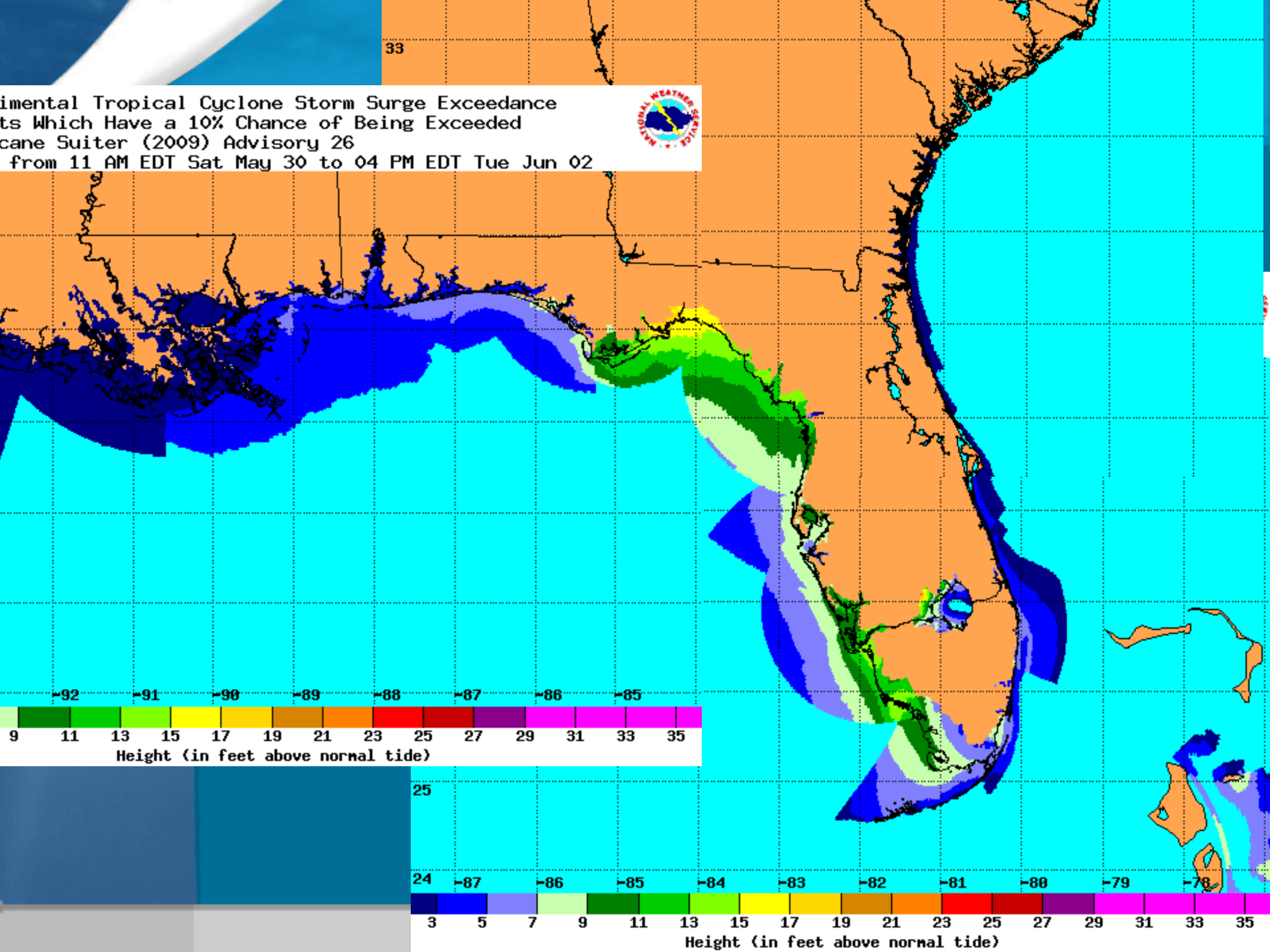

33
32
-92
-91
-90
-89
-88
-87
-86
-85
9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)
-87
-86
-85
-84
-83
-82
-81
-80
-79
-78
3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)


Experimental Tropical Cyclone Storm Surge Exceedance
Heights Which Have a 30% Chance of Being Exceeded
Hurricane Suiter (2009) Advisory 22
Valid from 11 AM EDT Fri May 29 to 04 PM EDT Mon Jun 01
45
40
35
30
25
-100
-95
-90
-85
-80
-75
-70
-65
-60
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
Height (in feet above normal tide)


rimental Tropical Cyclone Storm Surge Exceedance
nts Which Have a 30% Chance of Being Exceeded
icane Suiter (2009) Advisory 22
d from 11 AM EDT Fri May 29 to 04 PM EDT Mon Jun 01
NATIONAL WEATHER SERVICE
33
-84
-82
-80
-79
-78
-92
-91
-90
-89
-88
-87
-86
-85
9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)
25
24
-87
-86
-85
-84
-83
-82
-81
-80
-79
-78
3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)


Experimental Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge >= 7 feet at Individual Locations
Hurricane Suiter (2009) Advisory 22
Valid from 11 AM EDT Fri May 29 to 04 PM EDT Mon Jun 01
29
28
27
26
25
24
-87
-86
-85
-84
-83
-82
-81
-80
-79
-78
5%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Probability

Hurricane SUITER
Saturday May 30, 2009
11 AM EDT Advisory 26
NWS TPC/National Hurricane Center
Current Center Location 24.4 N 77.5 W
Max Sustained Wind 125 mph
Current Movement WNW at 15 mph
Forecast Center Positions:
Tropical cyclone
M Sustained wind > 110 mph
H Sustained wind > 73 mph
Potential Day 1-3 Track Area
Hurricane Warning
Hurricane Watch
Tropical Storm Warning
Tropical Storm Watch
8 AM Tue
8 AM Mon
8 AM Sun
11 AM Sat
TN
AR
MS
AL
GA
SC
LA
FL
Bahamas
Cuba
35N
30N
25N
20N
90W
85W
80W
75W
NOAA


imental Tropical Cyclone Storm Surge Exceedance
ts Which Have a 10% Chance of Being Exceeded
cane Suiter (2009) Advisory 26
from 11 AM EDT Sat May 30 to 04 PM EDT Tue Jun 02
33
92 91 90 89 88 87 86 85
9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)
25
24
87 86 85 84 83 82 81 80 79 78
3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
Height (in feet above normal tide)