

Storm Surge Overview



HURRICANE
EVACUATION
ROUTE

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National Hurricane Center
2010 National Hurricane Conference





Storm Surge



Storm Surge



Picture by Don McCrosky, Entergy's Michoud Power Plant Manager

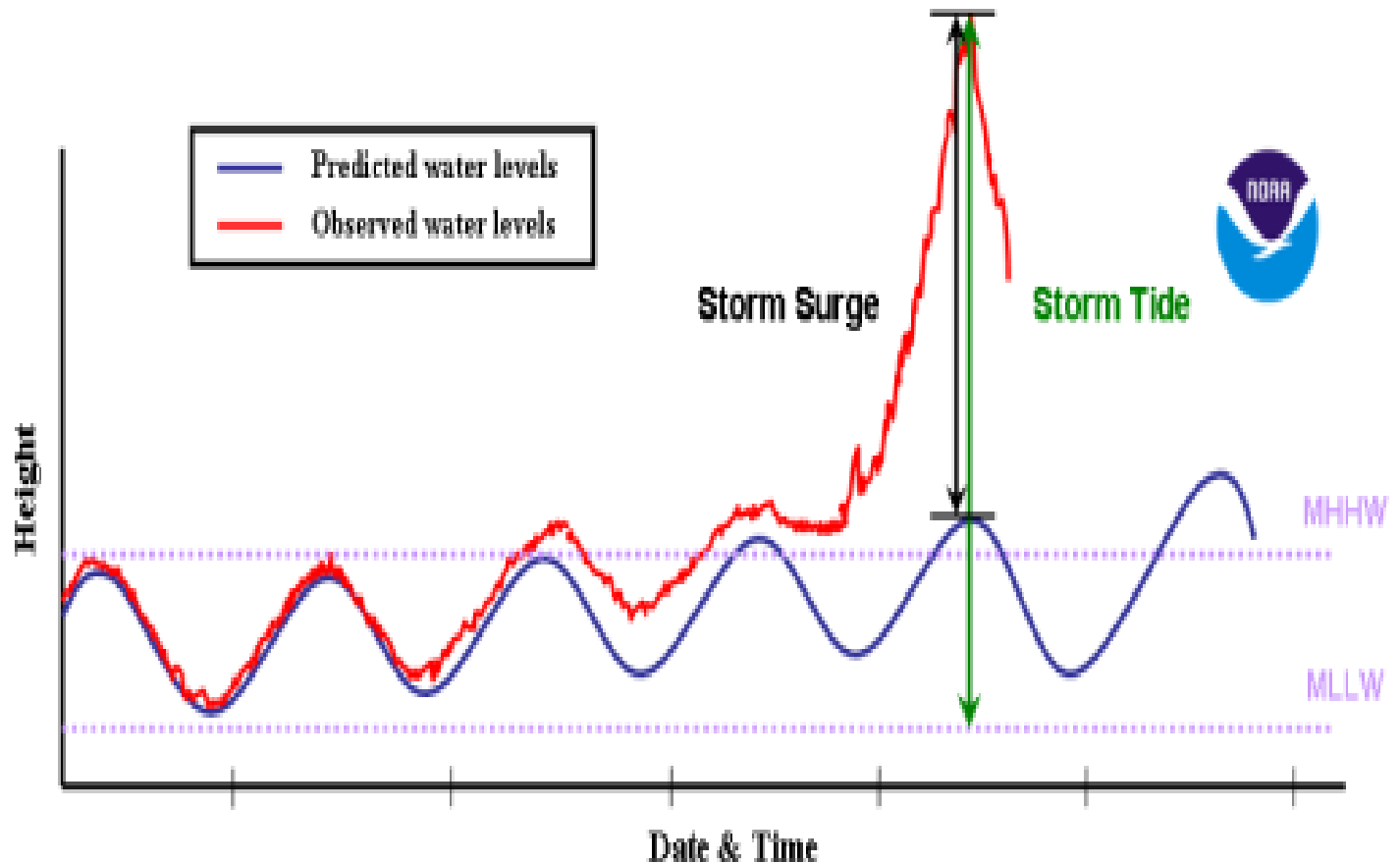
Storm Surge Defined

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

STORM TIDE is the total water level during a storm (i.e astronomical tide + storm surge)



Storm Surge/Storm Tide



Debunking the Myth



Category	Central Pressure		Winds (mph)	Surge	Damage
	Millibars	Inches			
5	< 920	< 27.17	>155	>18'	Catastrophic
4	944-920	27.88-27.17	131-155	13'-18'	Extreme
3	964-945	28.47-27.91	111-130	9'-12'	Extensive
2	979-965	27.91-28.50	96-110	6'-8'	Moderate
1	≤ 980	≤ 28.94	74-95	4'-5'	Minimal

Cat . 3
Katrina: 26 ft

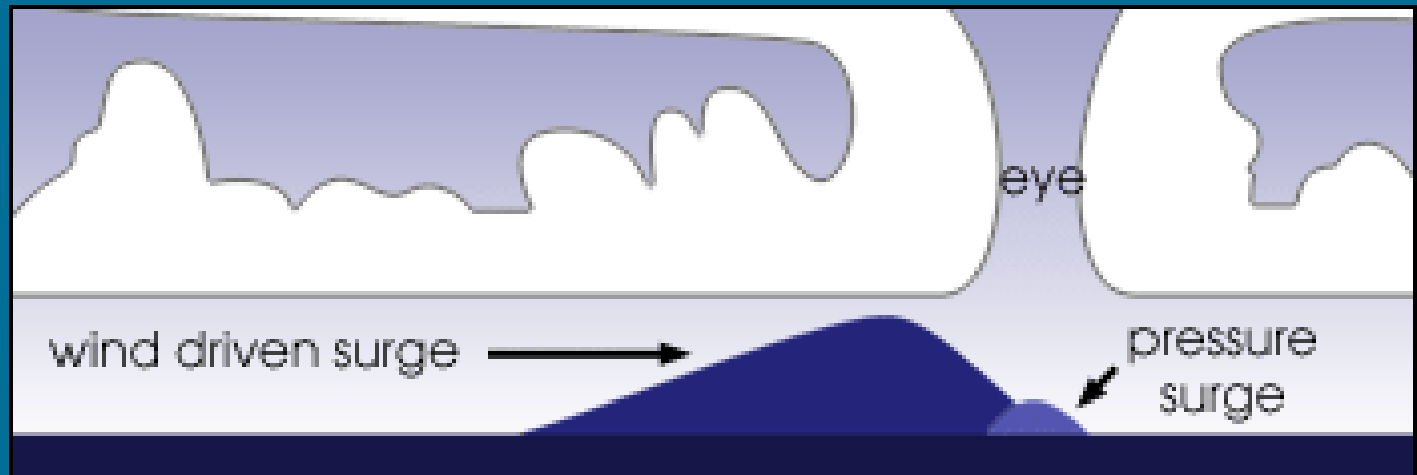


Cat . 4
Charley: 7 ft



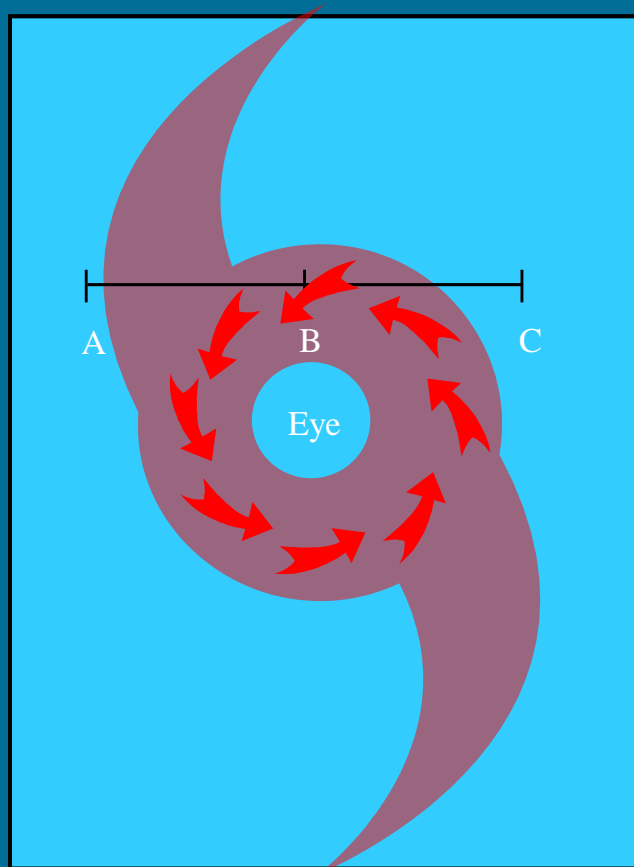
The Effects of Low Pressure

- Lower central pressure associated with the storm causes the ocean to rise/bulge up
- However, the contribution of pressure to total storm surge is small compared to wind

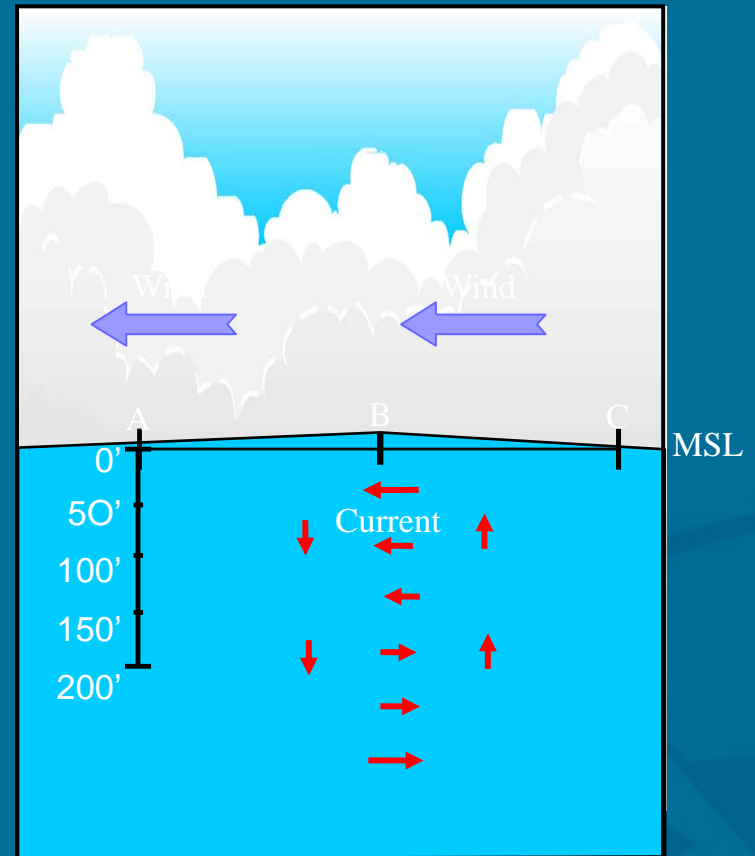


DEEP WATER

a. Top view of Sea Surface



b. Side view of Cross Section "ABC"



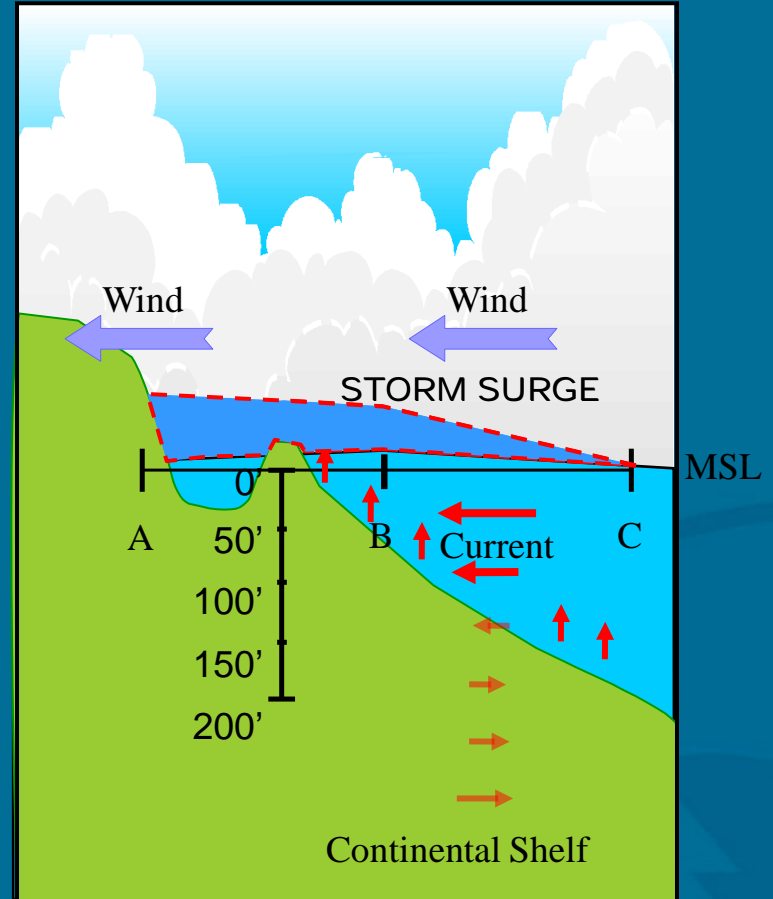


LANDFALL

Figure 1 consists of three panels. The top panel is a map of the Gulf of Mexico showing the intensity of hurricanes during the 2005 season. A color scale on the left indicates intensity levels from 1 (blue) to 5 (red). The map shows the paths of several hurricanes, including Charley, Frances, Ivan, and Wilma, with labels for their landfalls. The middle panel is an aerial photograph of a flooded area, showing a large blue barge and a white container. The bottom panel is an aerial photograph of a flooded area, showing a large blue barge and a white container.



The diagram illustrates a storm surge on a continental shelf. On the left, a green landmass slopes down to a blue ocean. A black line represents Mean Sea Level (MSL). A red dashed line shows the water level during a storm surge, which is higher than MSL. Two purple arrows labeled 'Wind' point from the right towards the land. A vertical scale on the left indicates depths of 0, 50', 100', 150', and 200'. Three points are marked: A is on the land at the shoreline; B is on the shelf at a depth of 50'; and C is further out on the shelf. Red arrows indicate the direction of water movement: a large red arrow points from the right towards the land near the surface, and several smaller red arrows point from the right towards the land at various depths, showing the surge moving inland. The label 'Continental Shelf' is at the bottom.



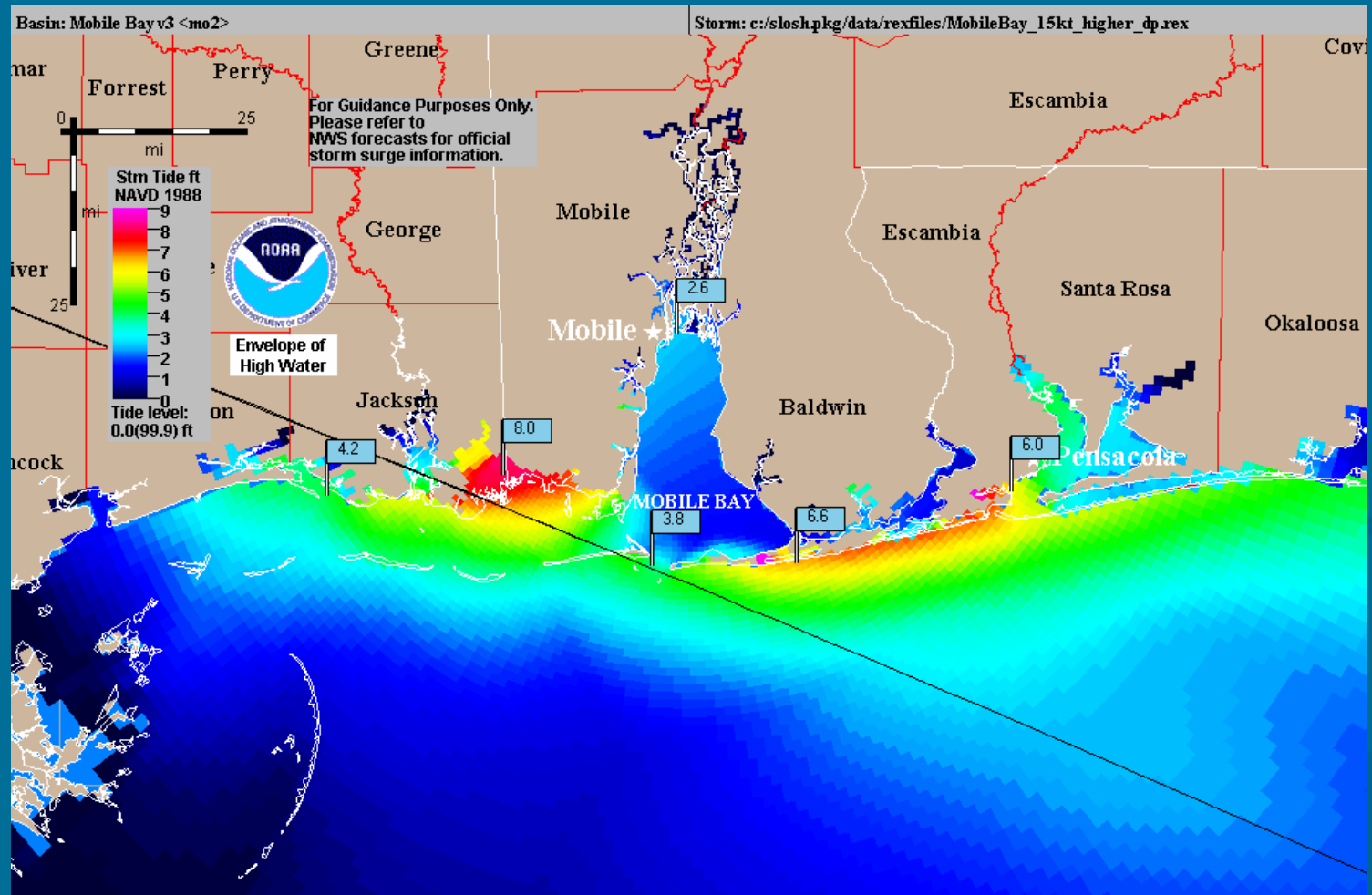
Factors Affecting Storm Surge



- **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

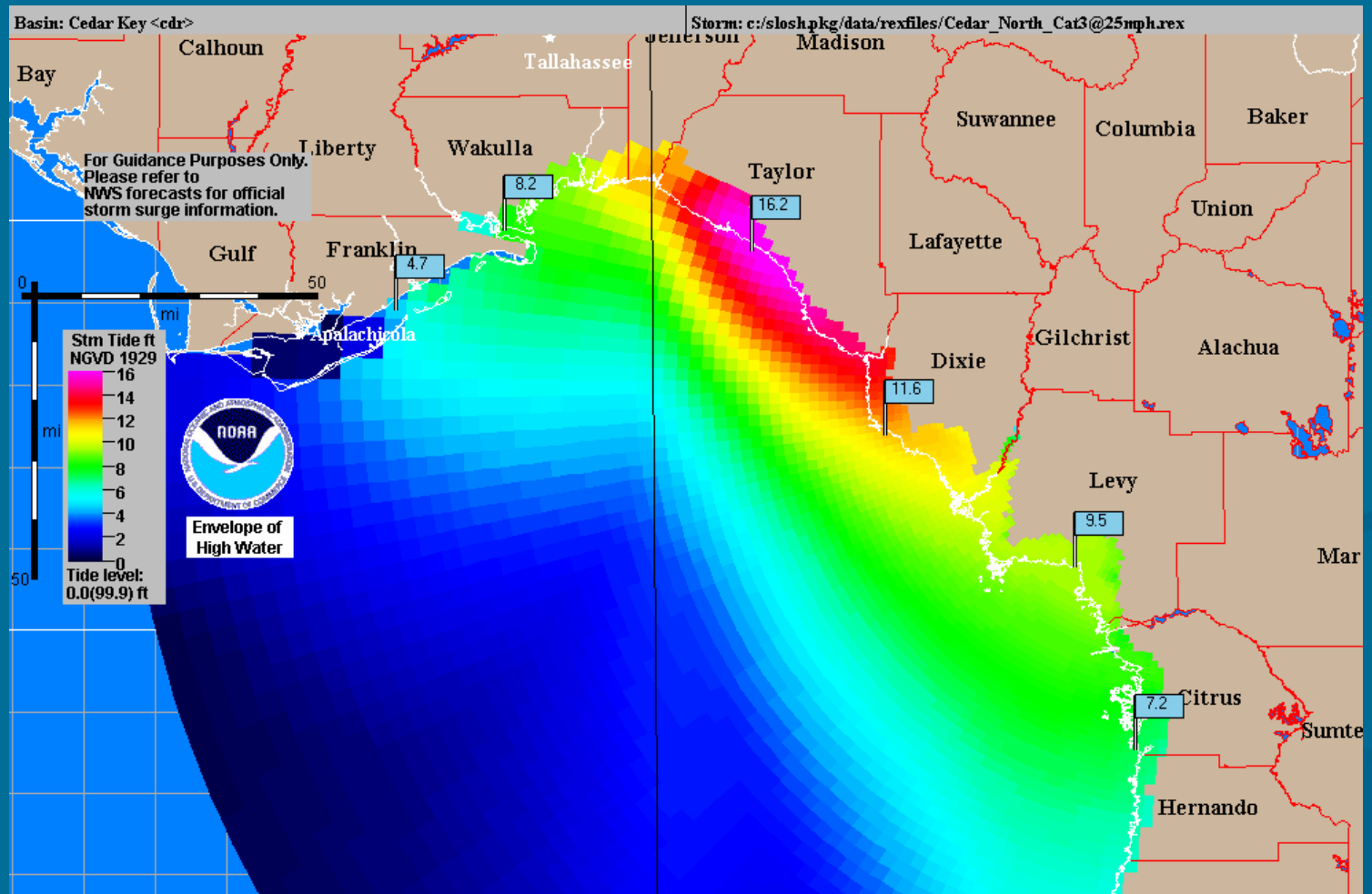
Intensity (Wind Speed)

15 mph stronger

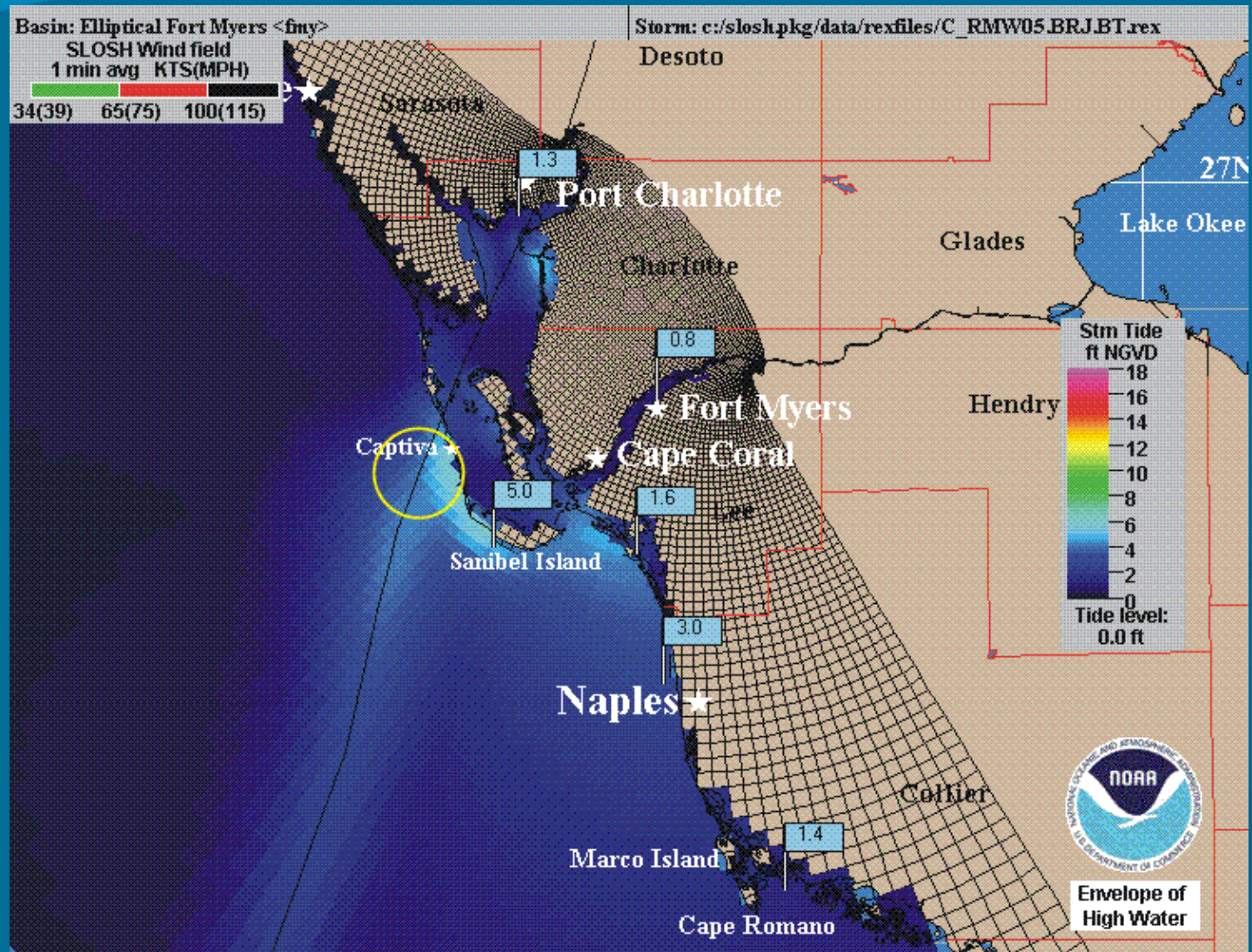


Forward Speed

25 mph

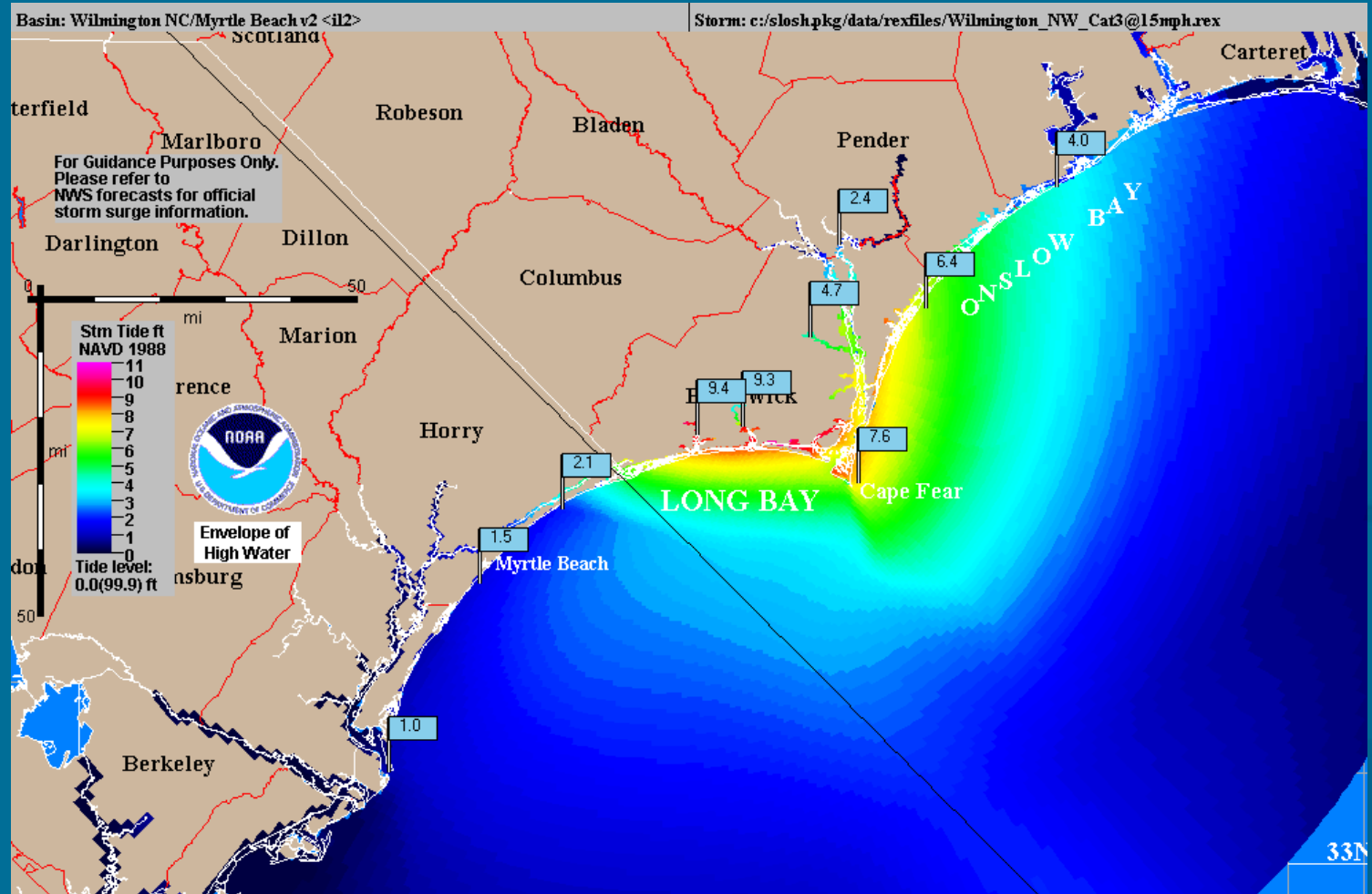


Size (Radius of Max Winds)



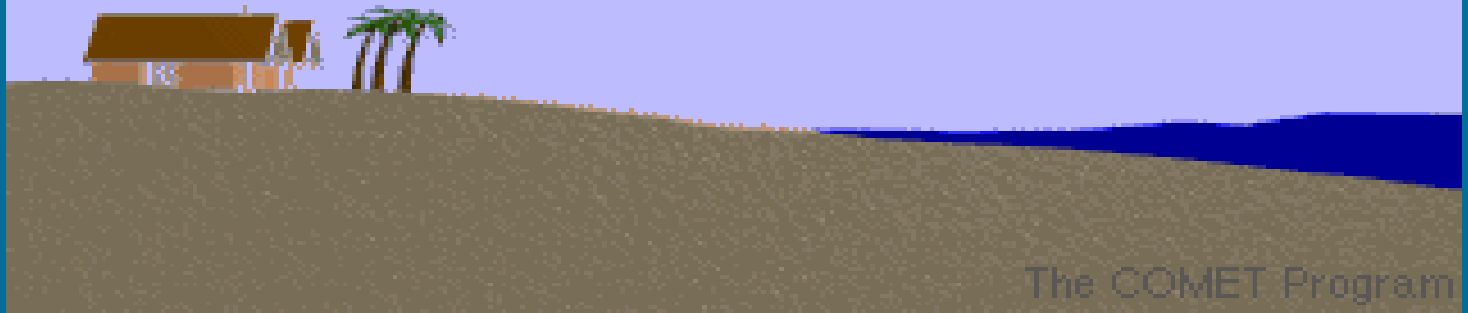
Angle of Approach

NNW Motion

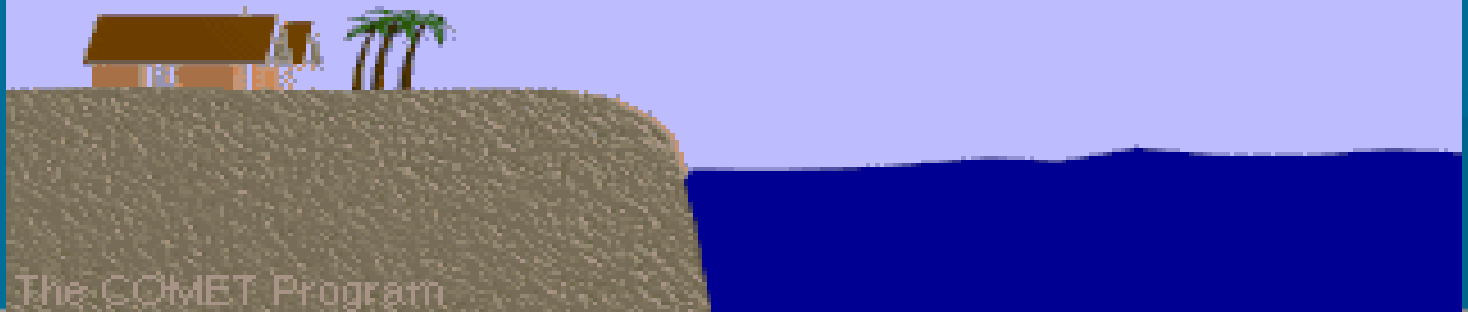


Width and Slope of Shelf

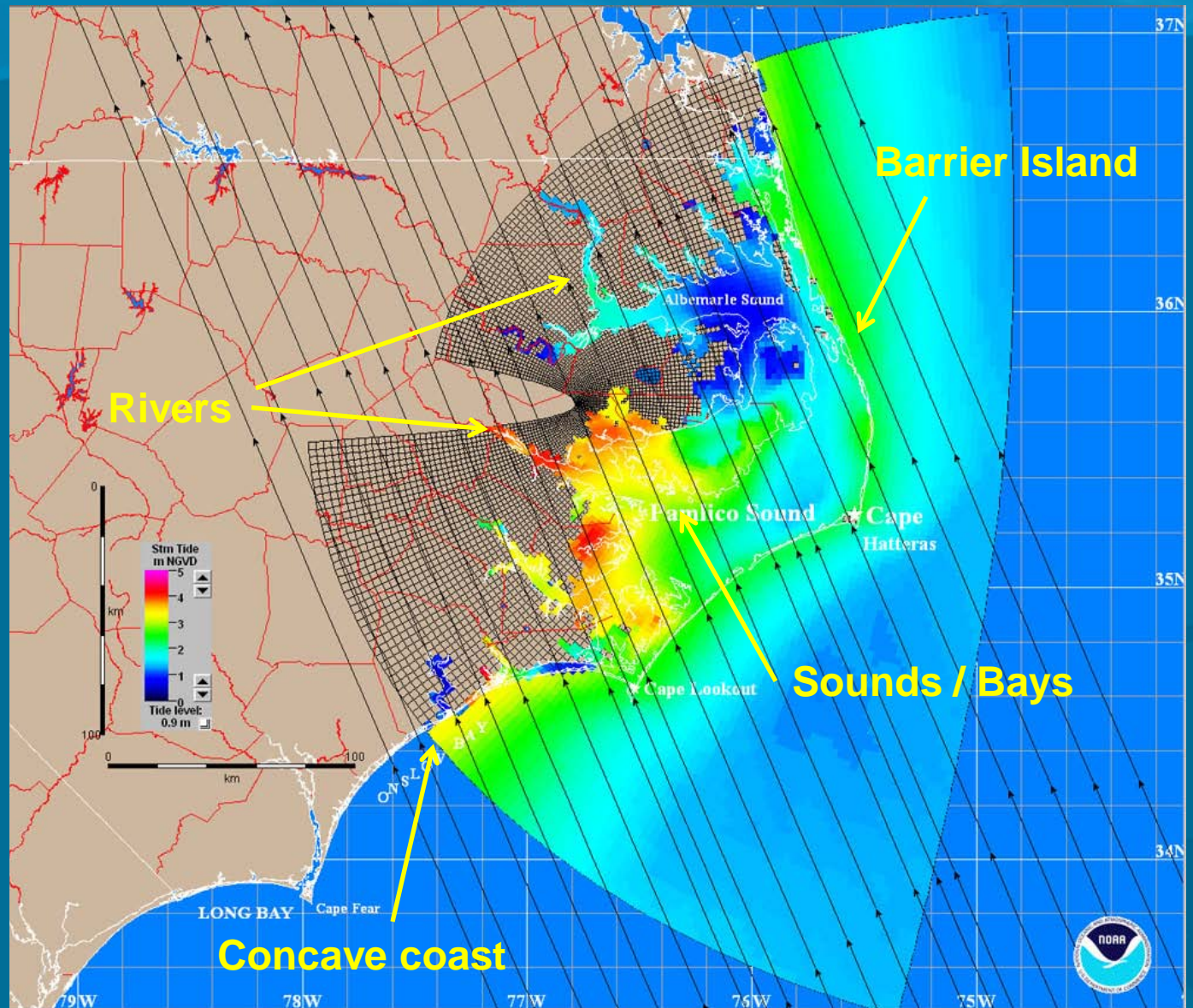
Wide shelf/
gentle slope



Narrow shelf/
sharp slope

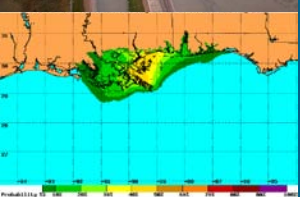
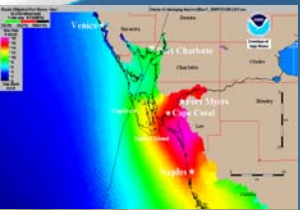


Local Features



Measuring Storm Surge

- Tide stations (NOAA)
 - Still water
 - Traditionally most reliable
 - Limited stations
 - Stations often fail at height of event
- High water marks (FEMA/USGS)
 - Perishable
 - Traditionally best method for capturing highest surge
 - Subjective and often include impacts of wave runup/setup
- Pressure Sensors (USGS)
 - Relatively new method
 - Deployed in advance of storm at expected location of highest surge
 - Can contain effects of waves



Surge Data Issues

- Instrument failures during event
 - Incomplete data or data does not capture height of event
- Different reference levels
 - Complicated conversion methods
- Different or even unknown error characteristics
 - Incompatible data sources
- Data measuring different things
 - Stillwater versus wave runup



Forecasting Surge: SLOSH

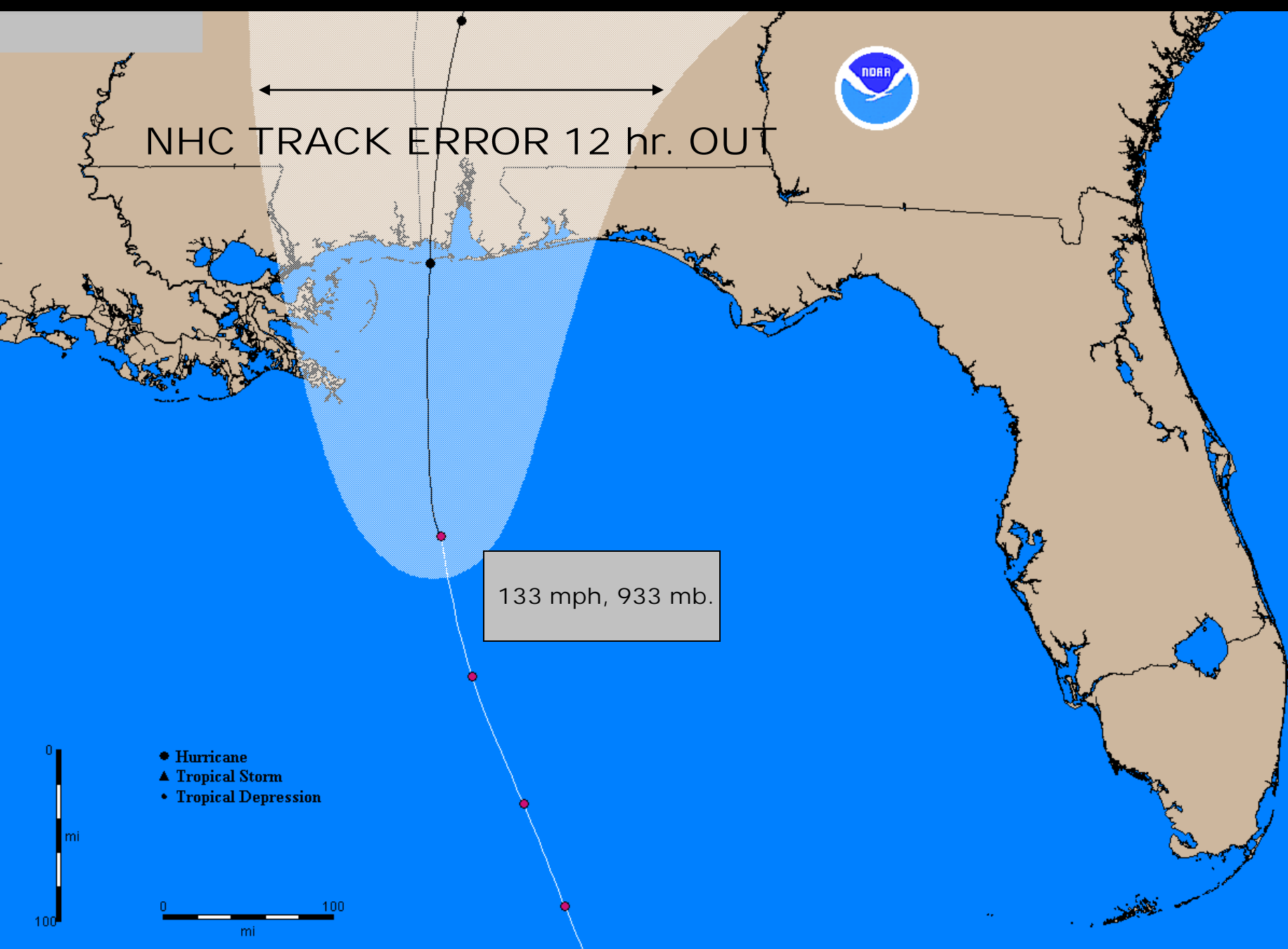
- Sea, Lake, and Overland Surges from Hurricanes
- A computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights (and winds) resulting from historical, hypothetical, or predicted hurricanes.
- Basis for “hazard analysis” portion of coastal hurricane evacuation plans



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





Hurricane Advisory – Approximately 12 hr. before landfall

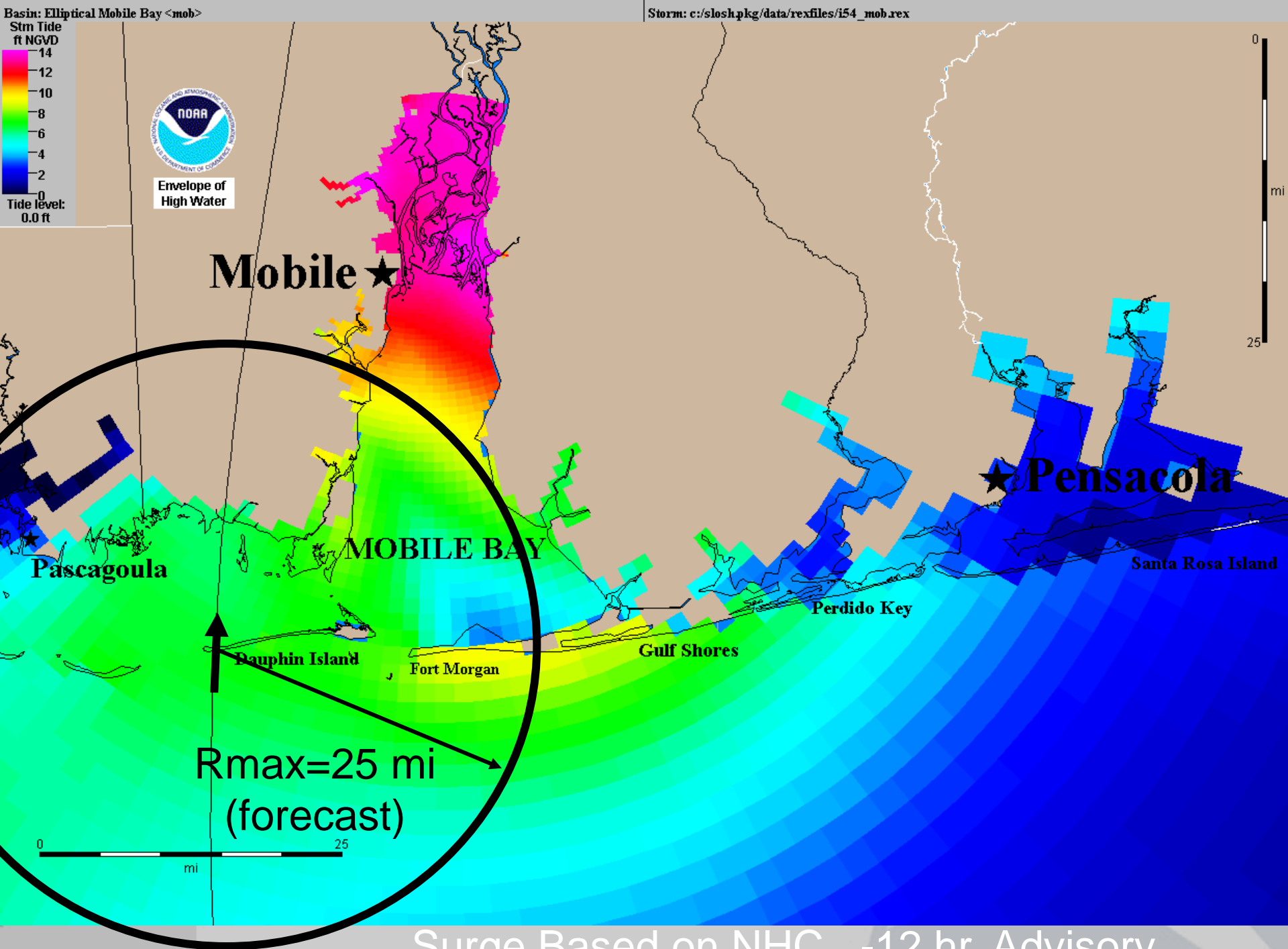
Basin: Elliptical Mobile Bay <mob>

Storm: c:/slosh/pkg/data/rexfiles/i54_mob.rex

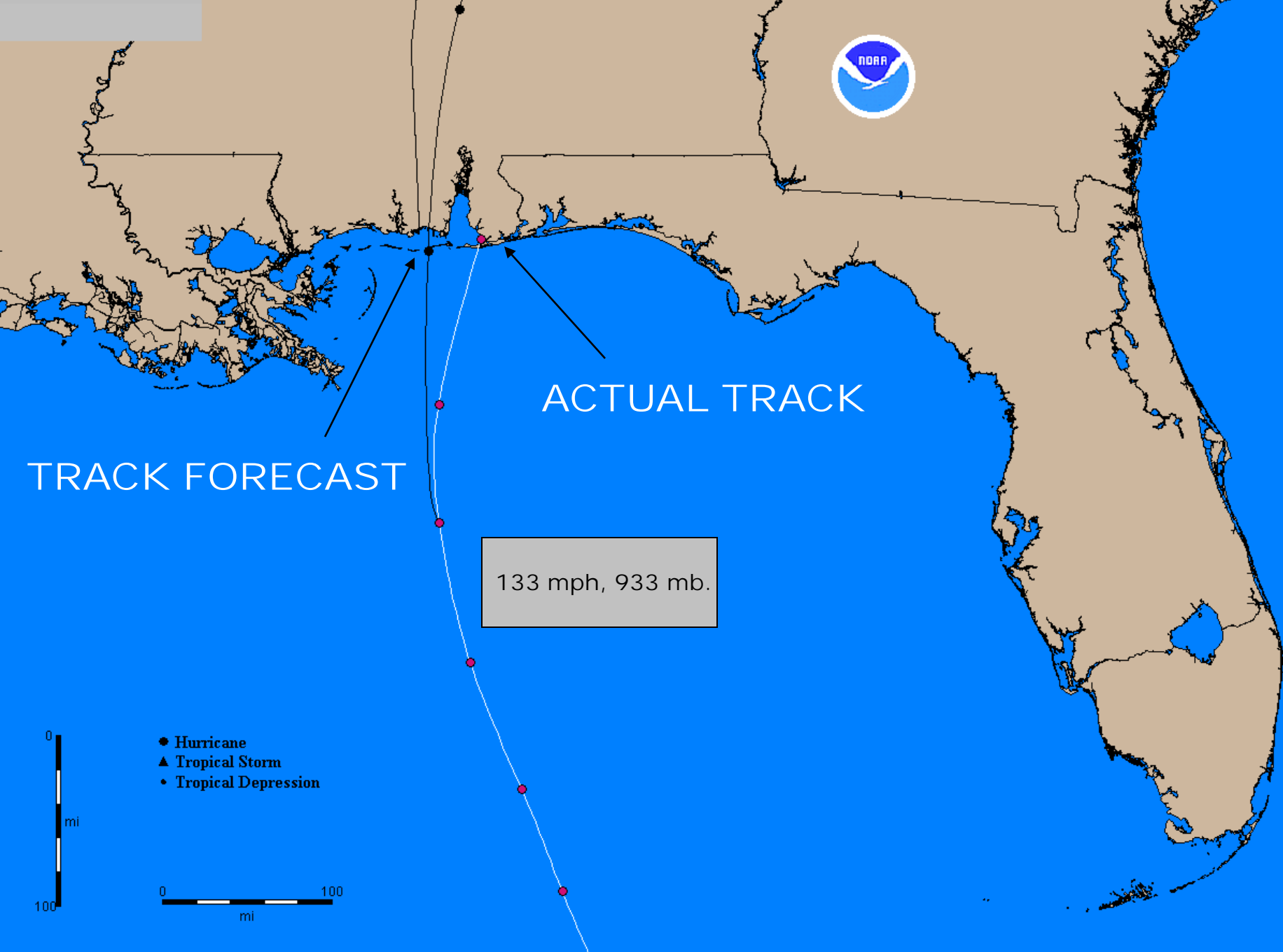
Stm Tide
ft NGVD
14
12
10
8
6
4
2
0
Tide level:
0.0 ft



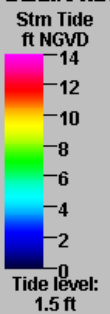
Envelope of
High Water



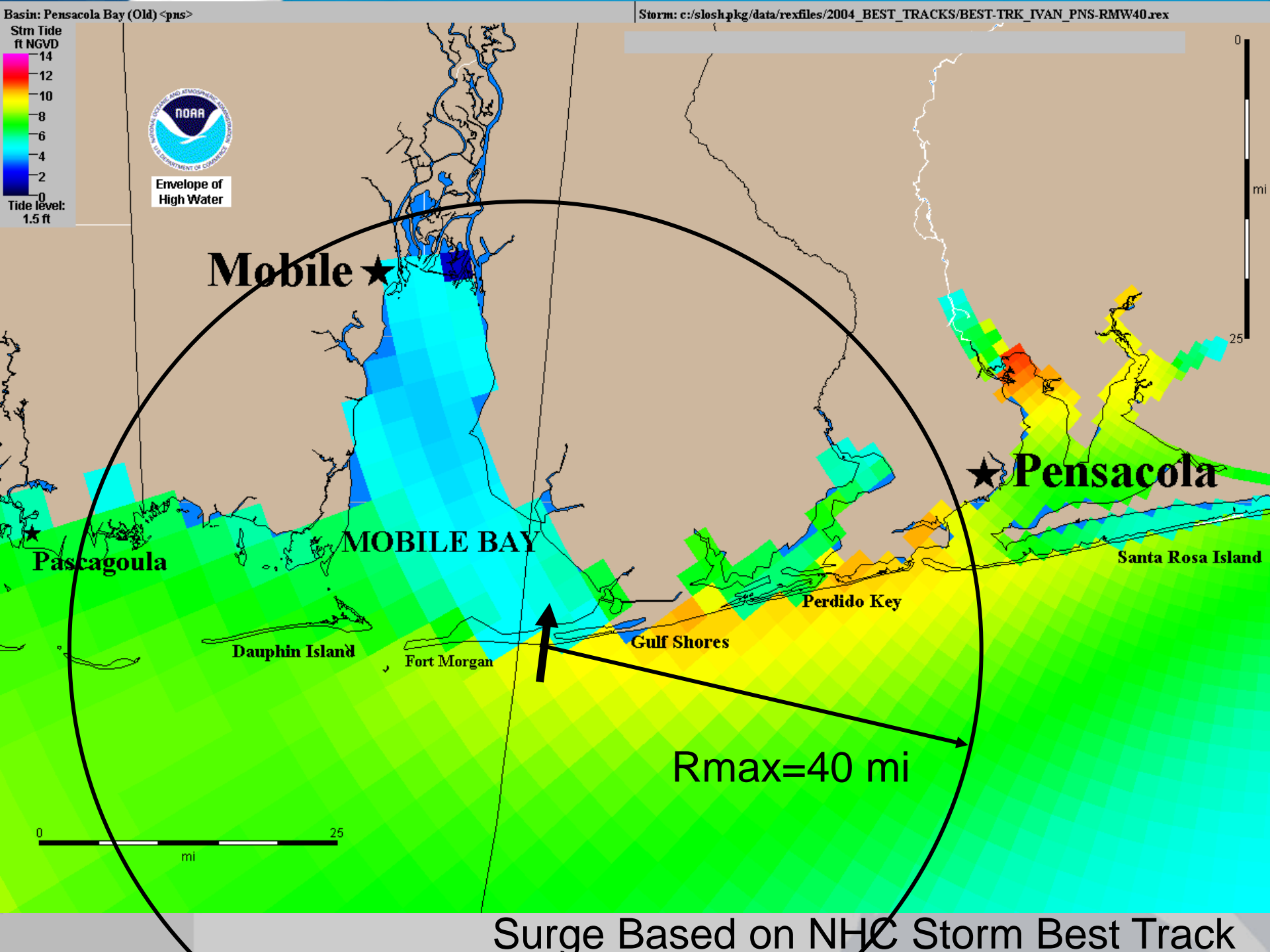
Surge Based on NHC -12 hr. Advisory



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



Envelope of
High Water



Mobile ★

MOBILE BAY

Pascagoula ★

Dauphin Island

Fort Morgan

Gulf Shores

Perdido Key

Santa Rosa Island

★ **Pensacola**

Rmax=40 mi

Surge Based on NHC Storm Best Track

Basin: Elliptical Fort Myers <fny>

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

Storm: d:/slosh/pkg/data/rexfiles/C_RMW25.BRJ.BT.rex



Envelope of
High Water

Venice★

Sarasota

Desoto

★ Port Charlotte

Charlotte

Glades

Hendry

★ Fort Myers

★ Cape Coral

Lee

Sanibel Island

Naples★

Collier

0
25
mi

0 25
mi

RMW = 25 mi., "Average" Size

Basin: Elliptical Fort Myers <fny>

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

Storm: d:/slosh/pkg/data/rexfiles/C_RMWO6.BRJ.BT.rex



Envelope of
High Water

Venice

Sarasota

Desoto

Port Charlotte

Charlotte

Glades

Fort Myers

Cape Coral

Hendry

Lee

Sanibel Island

Naples

Collier

0
25
mi

0 25
mi

RMW = 6 mi.

Alternatives to Single Track Runs

- MEOWs
- MOMs
- Probabilistic



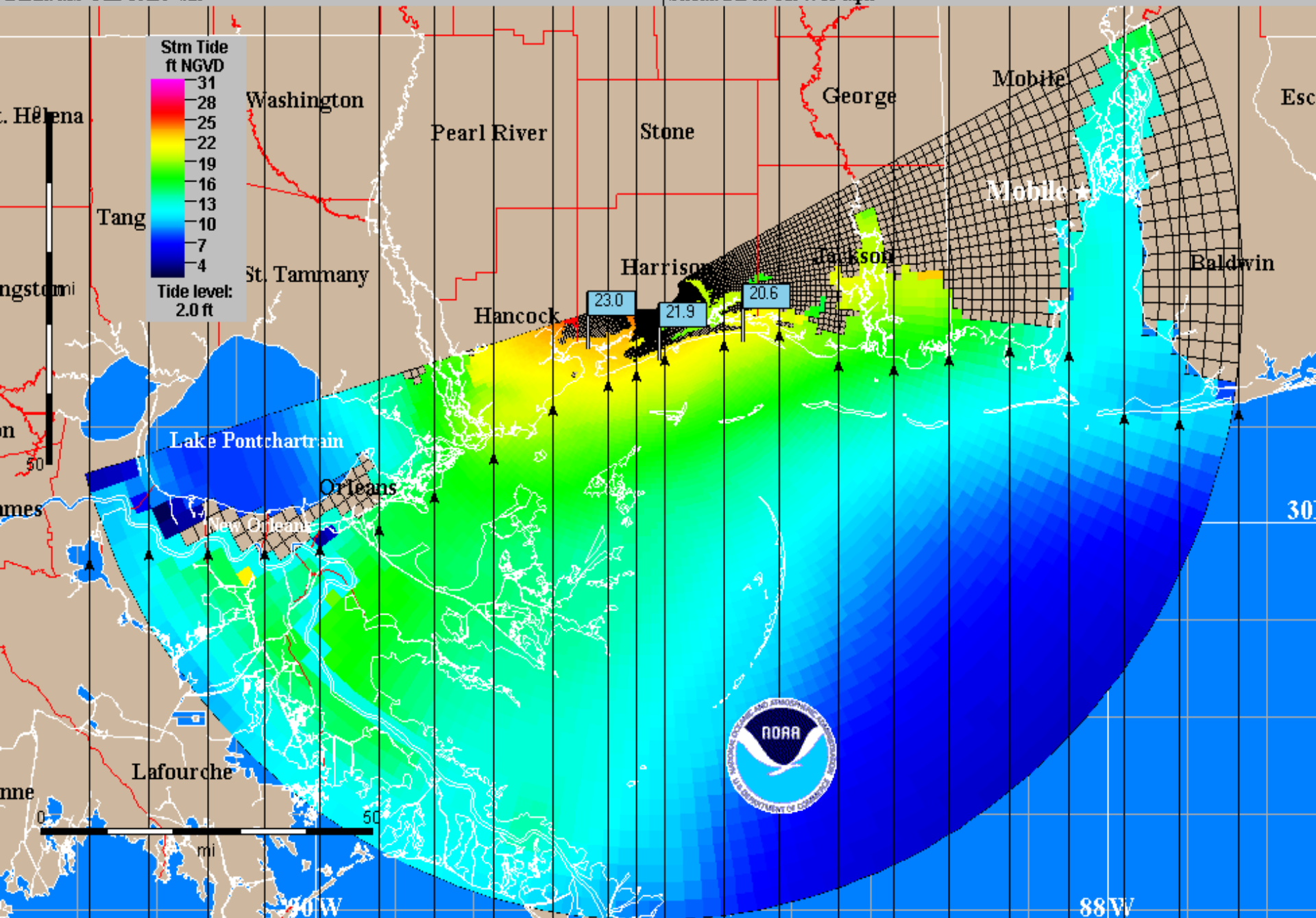
MEOW

- Maximum Envelope of Water
- Composite of maximum storm surge heights at each grid cell using hypothetical hurricanes run with the same:
 - Category (Intensity)
 - Forward Speed
 - Landfall Direction
 - Initial Tide Levels
- Composite achieved by reviewing parallel tracks that make landfall at different locations
- Over 80 MEOWs have been generated for some basins



Basin: MS-Gulf Coast <hix>

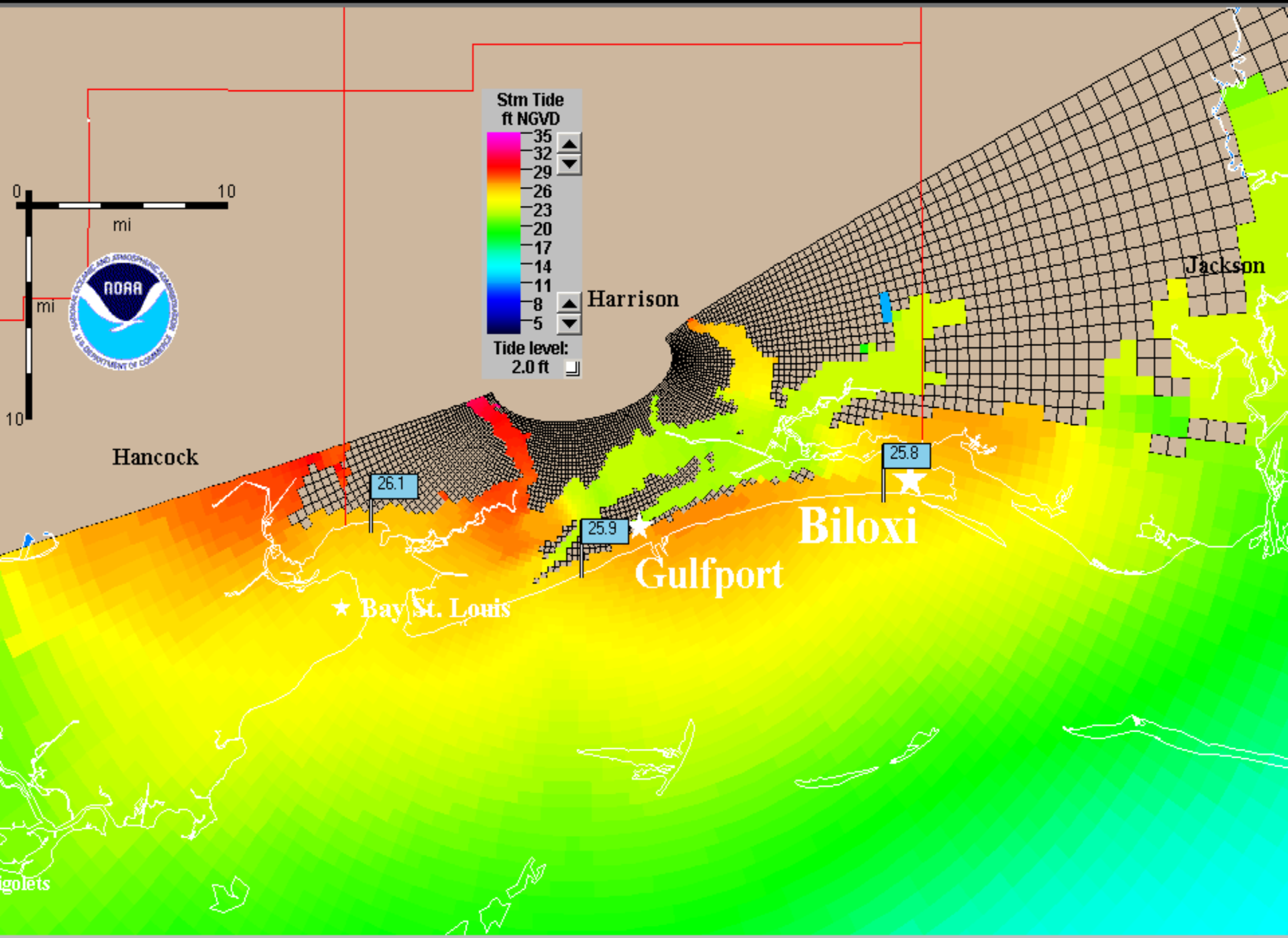
Storm: Dir n: Cat 4: 15 mph



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 5 MOMs per basin, i.e. one per storm category





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
- P-surge uses a representative storm for each portion of the error distribution space rather than a random sampling



Errors Used by P-surge

The ensemble is based on distributions of the following:

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



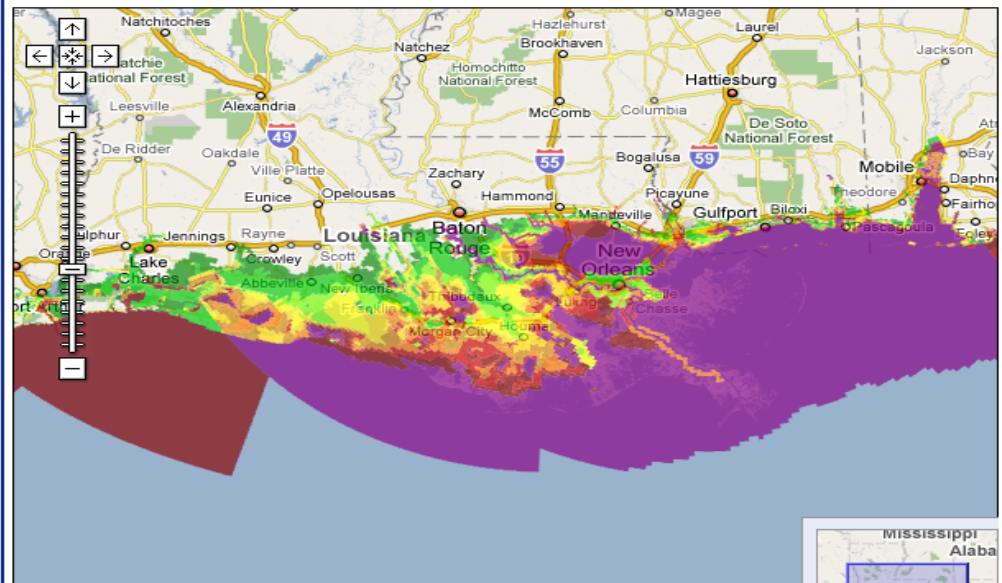
When is it Available?

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



Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge ≥ 2 feet (NGVD-1929) at individual locations
Hurricane Test (2009) Advisory 15
For the 77 hours from 05 PM EDT Tue May 12 to 10 PM EDT Fri May 15

Select Level: Probability of Surge > 2 feet



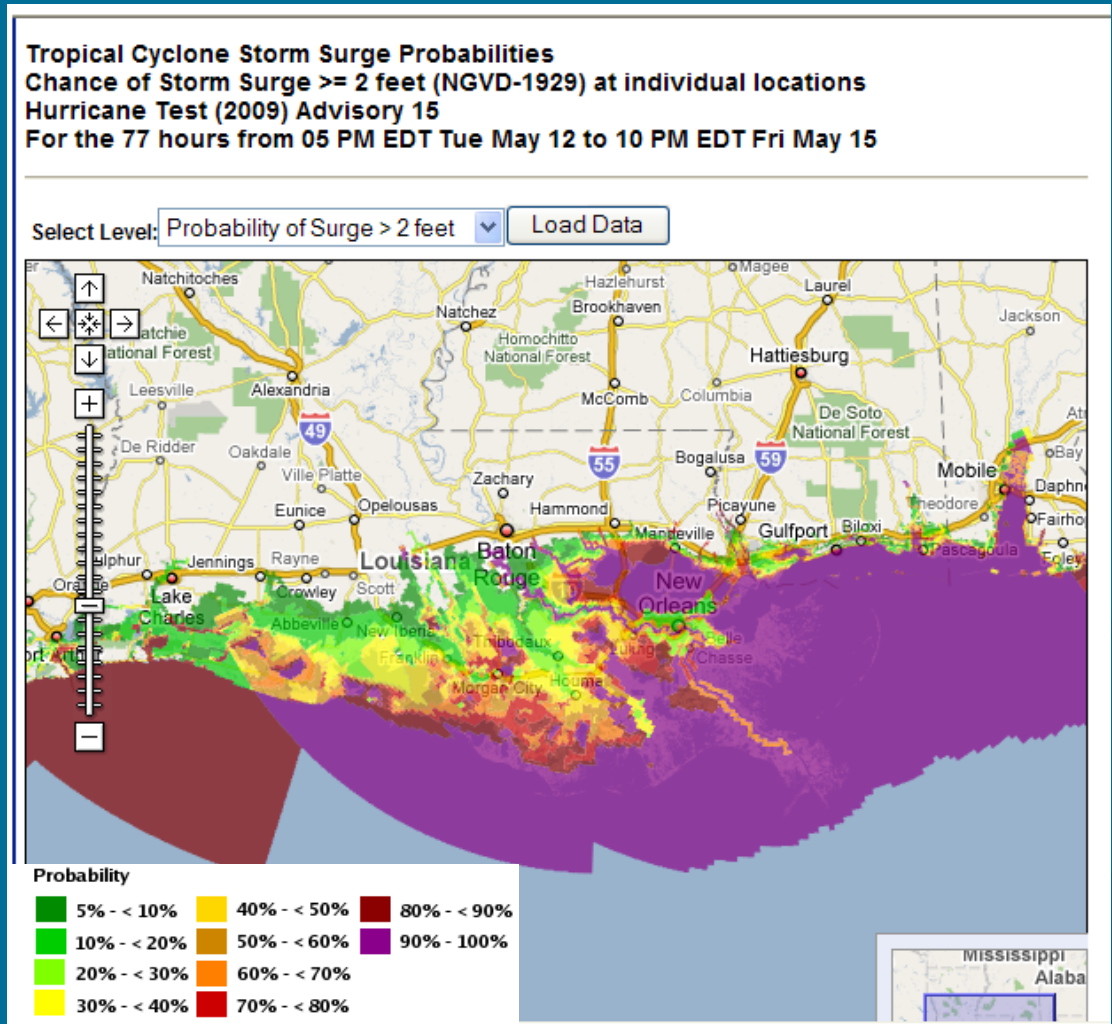
Legend

Probability

5% - < 10%	40% - < 50%	80% - < 90%
10% - < 20%	50% - < 60%	90% - 100%
20% - < 30%	60% - < 70%	
30% - < 40%	70% - < 80%	

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
- The odds of winning the Mega Millions lottery are 1 in 135,145,920, yet ~1/2 of Americans play the lottery (AP)



Basin: Elliptical Mobile Bay <mob>

Storm: c:/slosh/pkg/data/rexfiles/i54_mob.rex

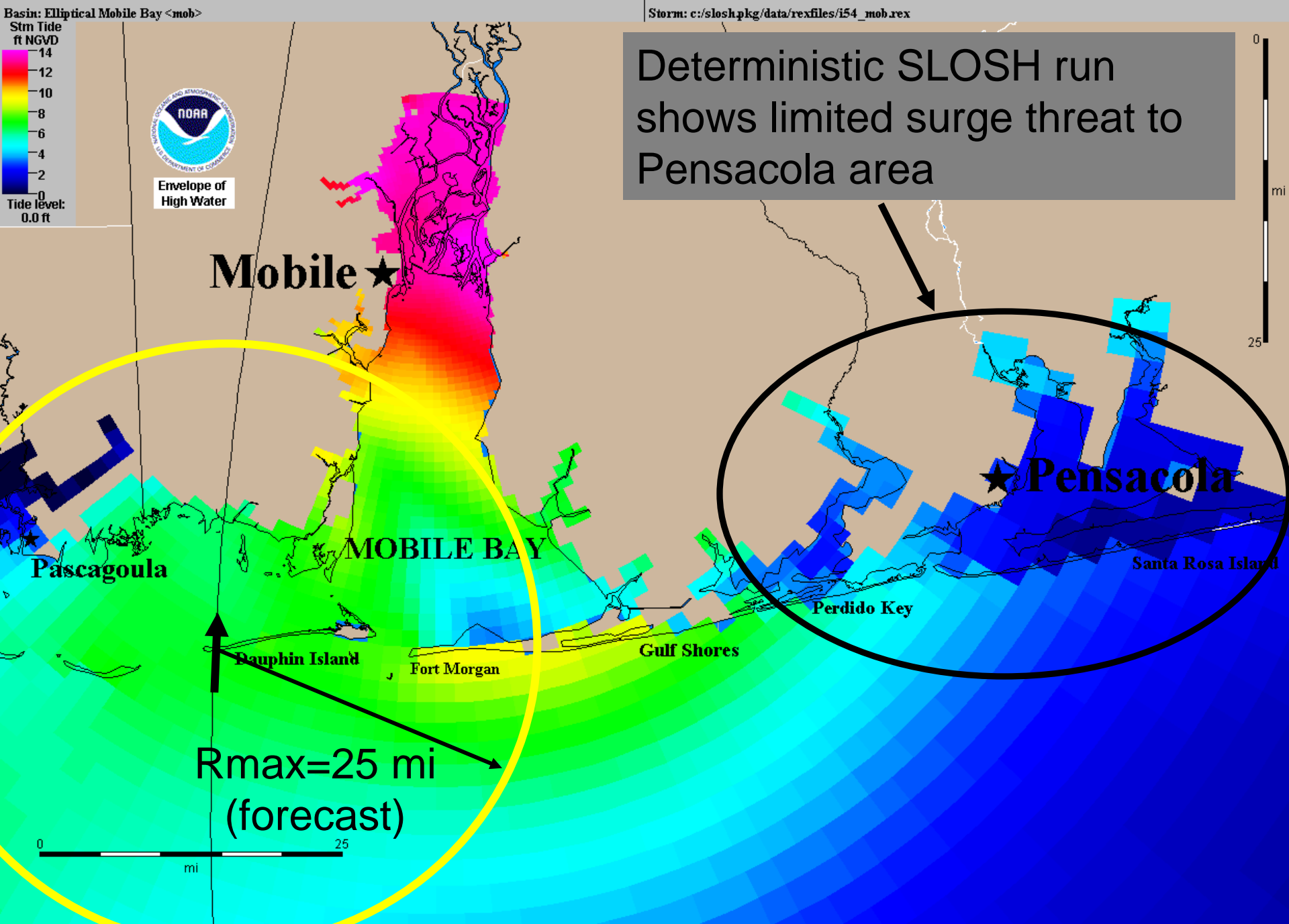
Stm Tide
ft NGVD

14
12
10
8
6
4
2
0

Tide level:
0.0 ft



Envelope of
High Water



Probabilistic Storm Surge 2008

Surge Based on NHC

-12 hr. Advisory

Storm: Ivan2004 Adv54

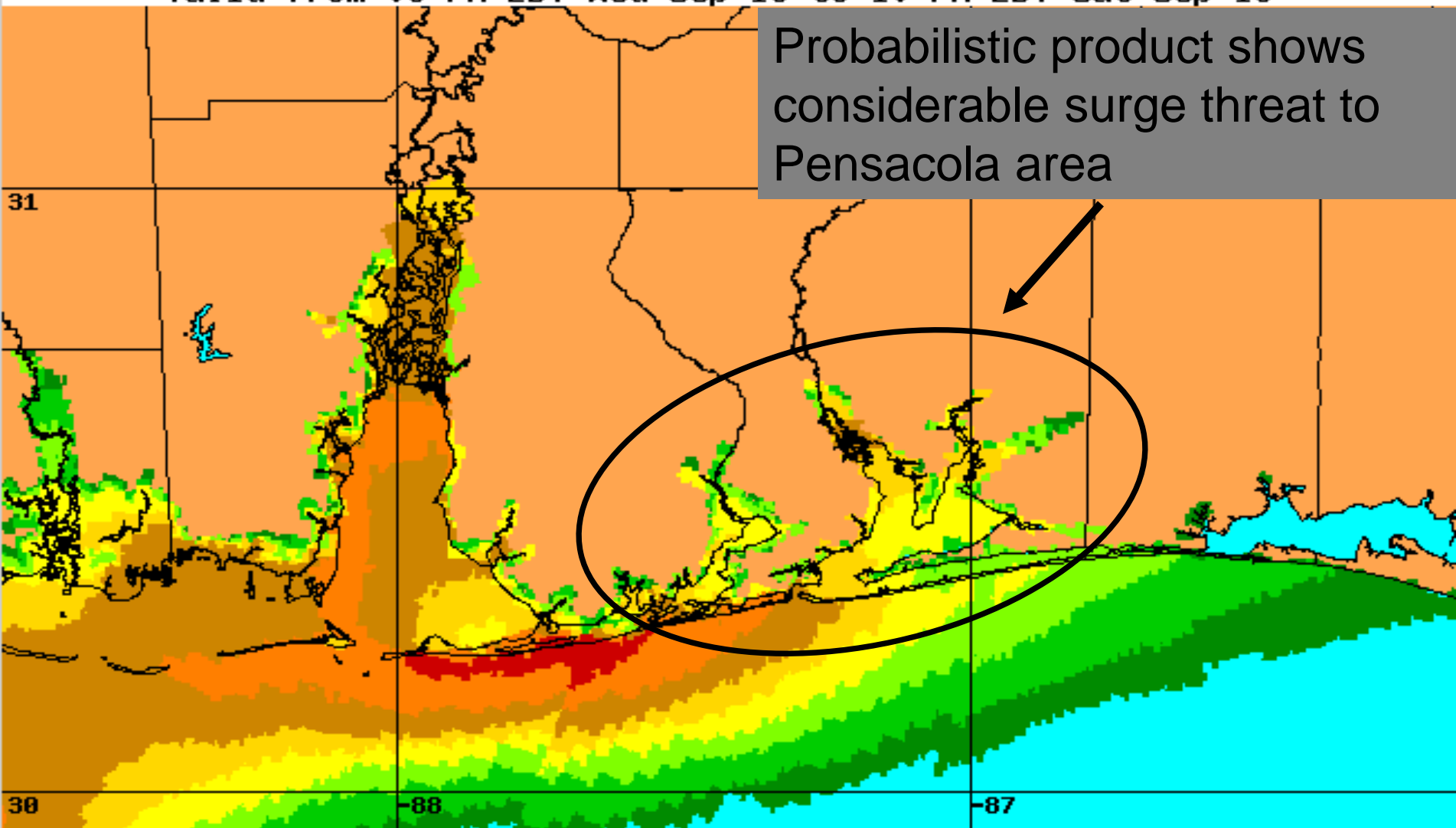
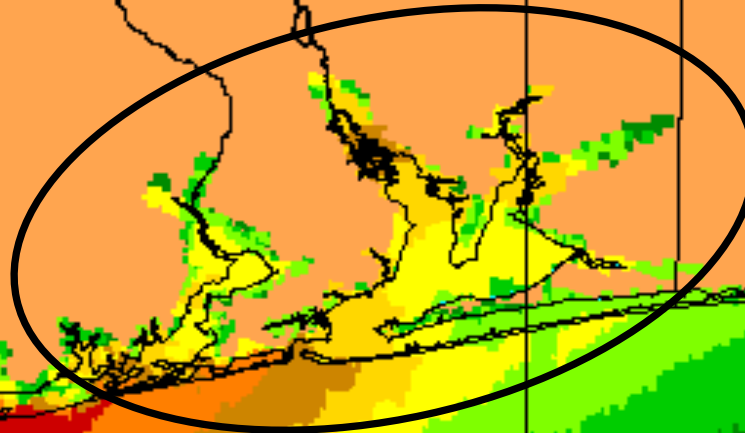
Type: Prob. of surge > 8 feet

Zoom Level: Full



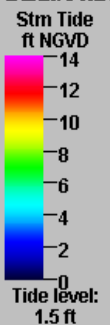
Experimental Tropical Cyclone Storm Surge Probabilities
Chance of Storm Surge \geq 8 feet at Individual Locations
Hurricane Ivan (2004) Advisory 54
Valid from 05 PM EDT Wed Sep 15 to 10 PM EDT Sat Sep 18

Probabilistic product shows
considerable surge threat to
Pensacola area



5% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Probability



Envelope of
High Water

Mobile ★

MOBILE BAY

Pascagoula ★

Dauphin Island

Fort Morgan

Gulf Shores

Perdido Key

★ **Pensacola**

Santa Rosa Island

Actual storm caused highest
surge in Pensacola area



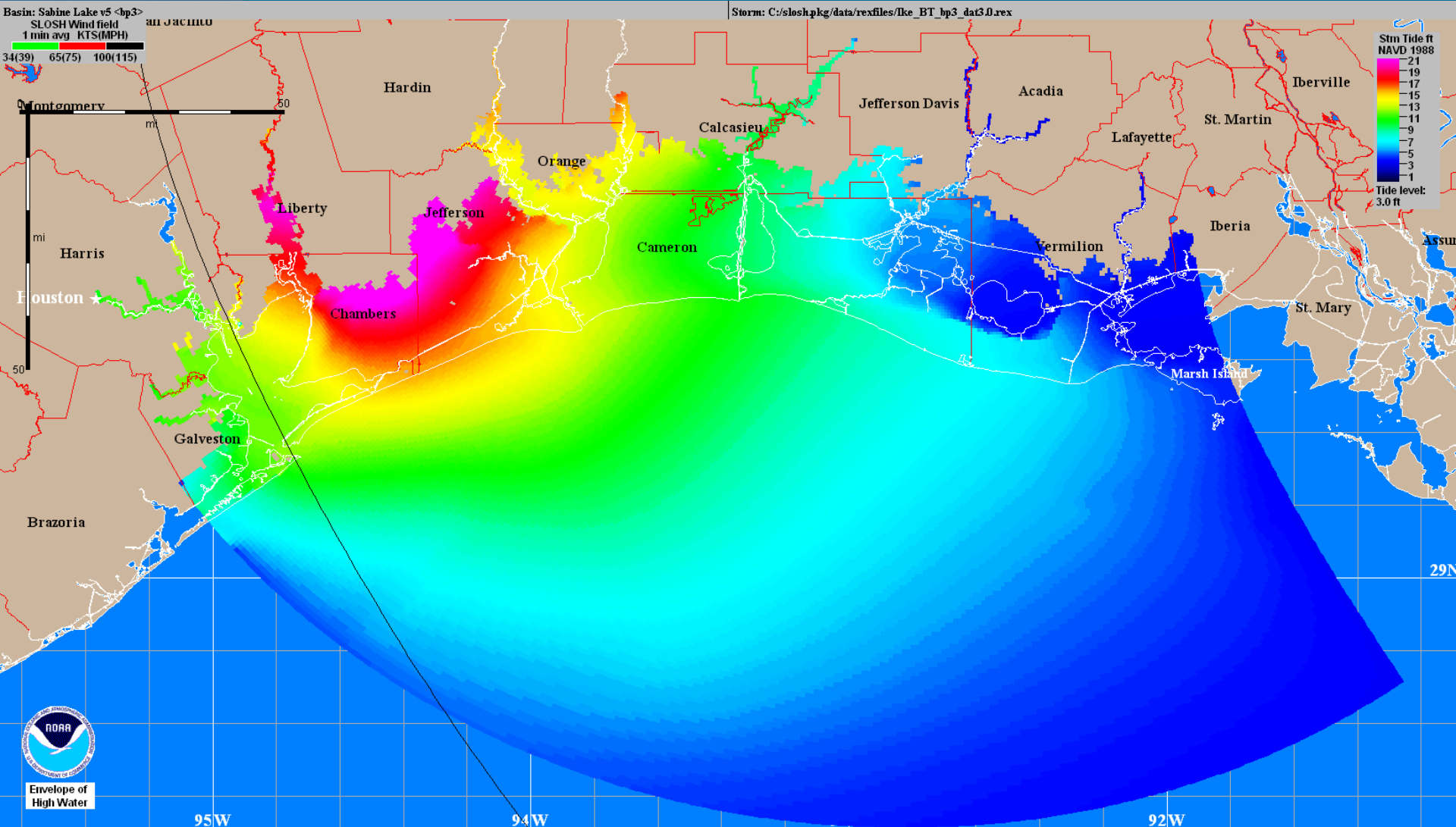
Surge Guidance Timeframe

- Day 5: MOMs
- Day 4: MEOWs/MOMs
- Day 3: MEOWs/MOMs
- Day 2: MEOWs/P-Surge/Operational Runs
- Day 1: MEOWs/P-Surge/Operational Runs

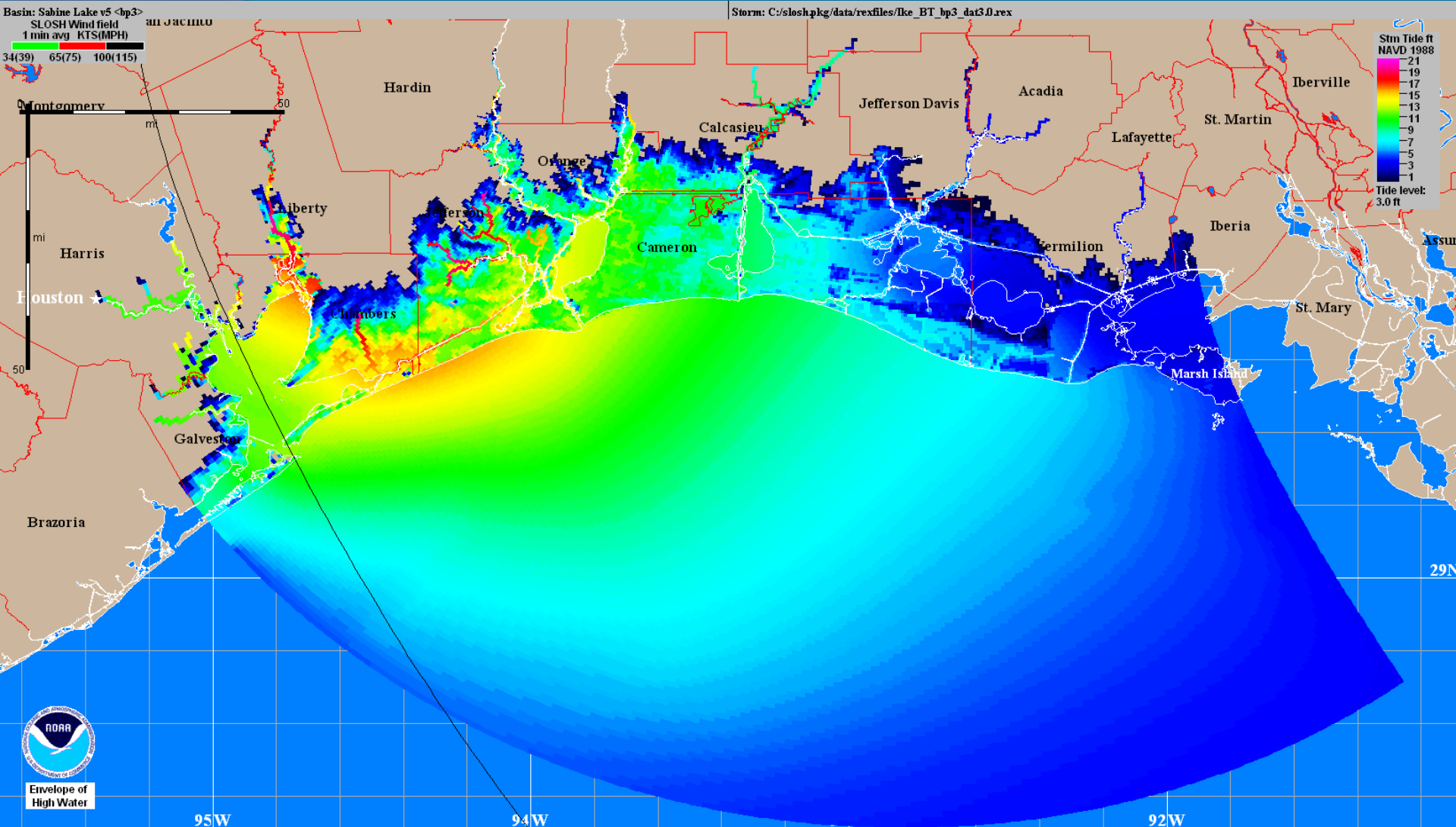
Given current NHC intensity errors, always allow for one category higher on the Saffir-Simpson scale



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 10 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.