

**STOP**

- risk identification
- risk measurement
- risk management

# Definitions:

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

Jelesnanski, Chen & Shaffer; SLOSH; NOAA T.R. NWS48

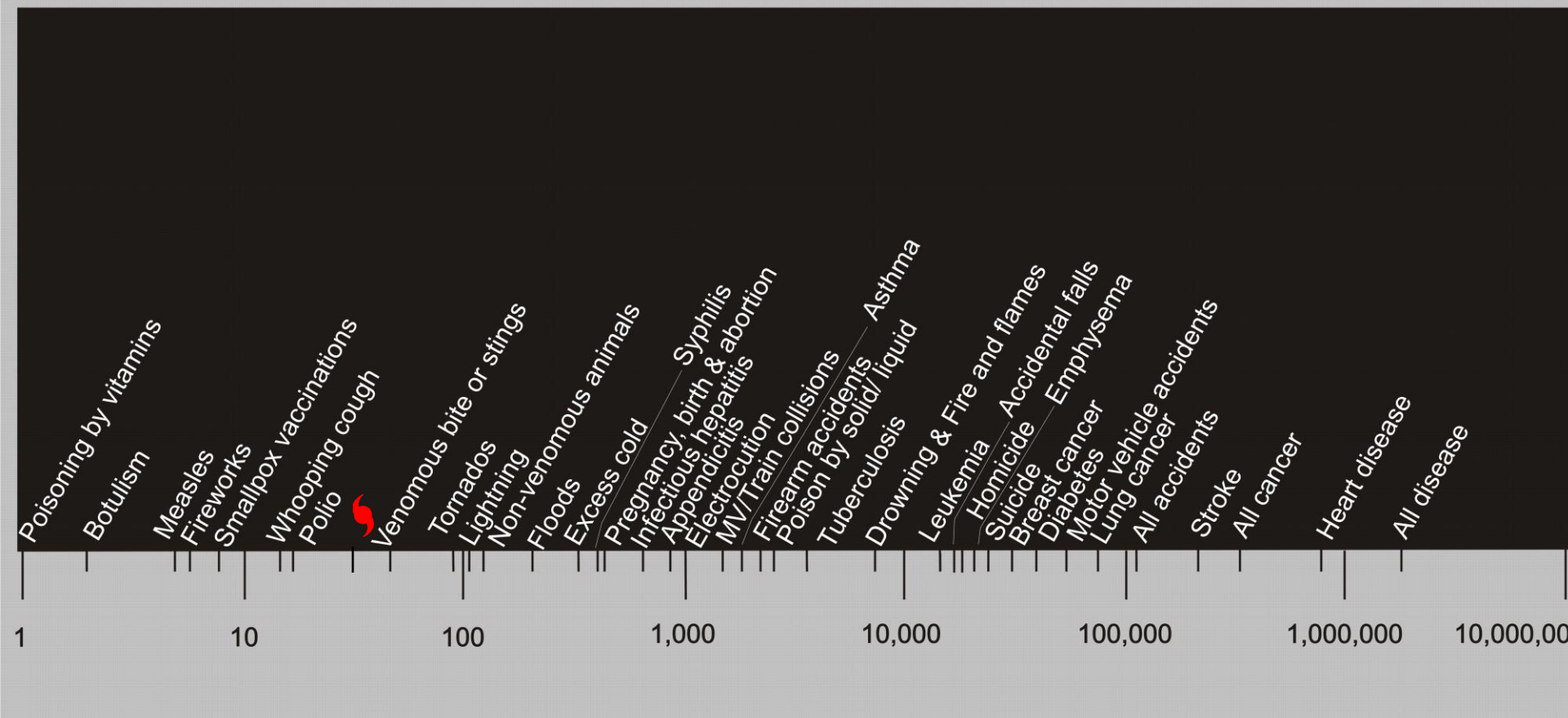
**STORM TIDE** is the total water level ---above a datum-- generated by a storm

= Astro Tide + STORM SURGE + anomaly + ....

## A HUMAN DEFINITION:

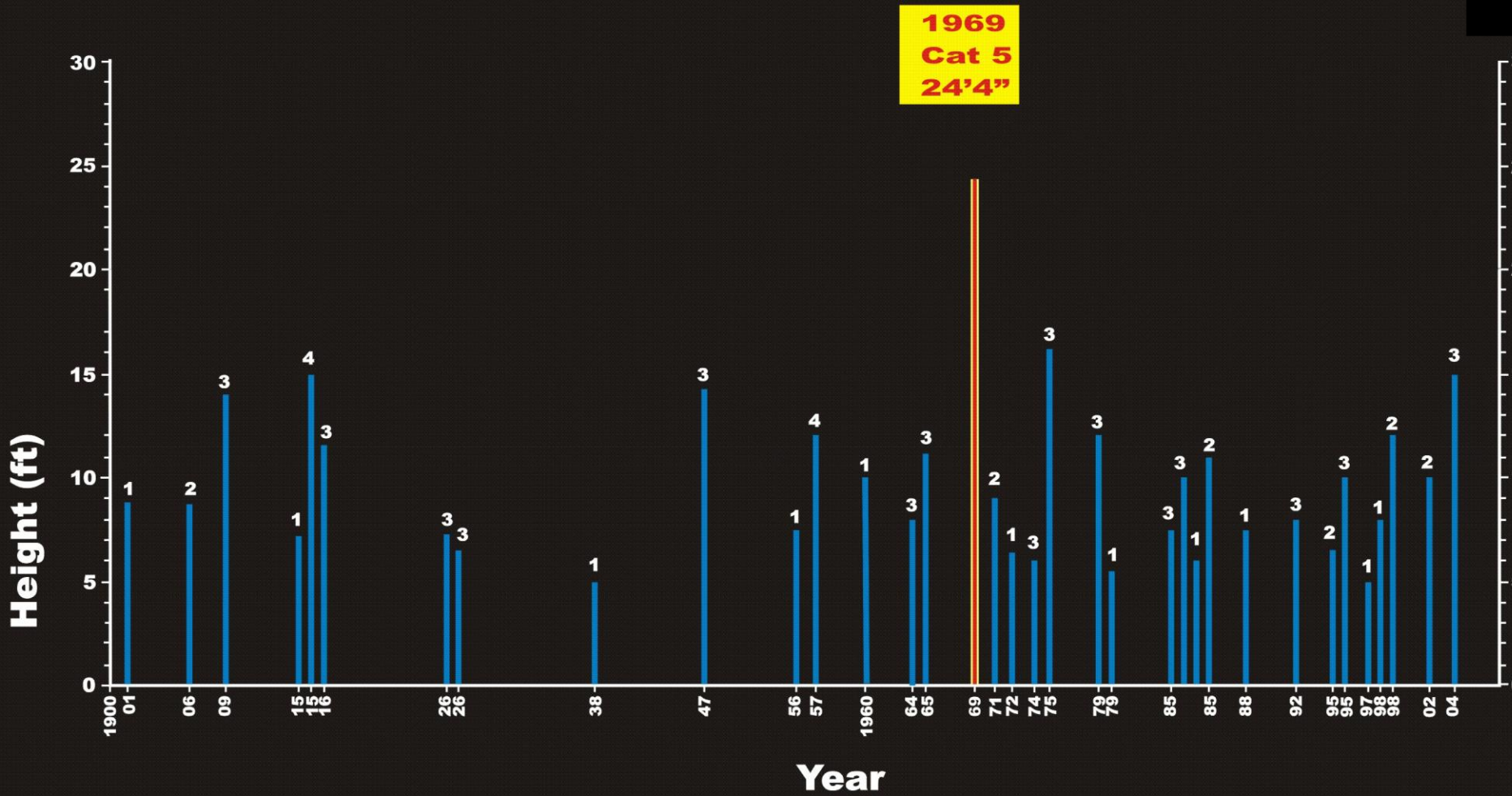
**STORM SURGE** is a temporary rise in sea level. It thrusts the coastline inland. It normally does not destroy structures but... it does drown people.

# Annual Number Of Deaths In the United States by Cause



“Sound engineering judgment”  
is superior to statistics only  
as long as the adequate  
statistical method is  
unknown.

# Storm Surge for the Gulf Coast From Apalachicola, FL to Louisiana/ Texas Border

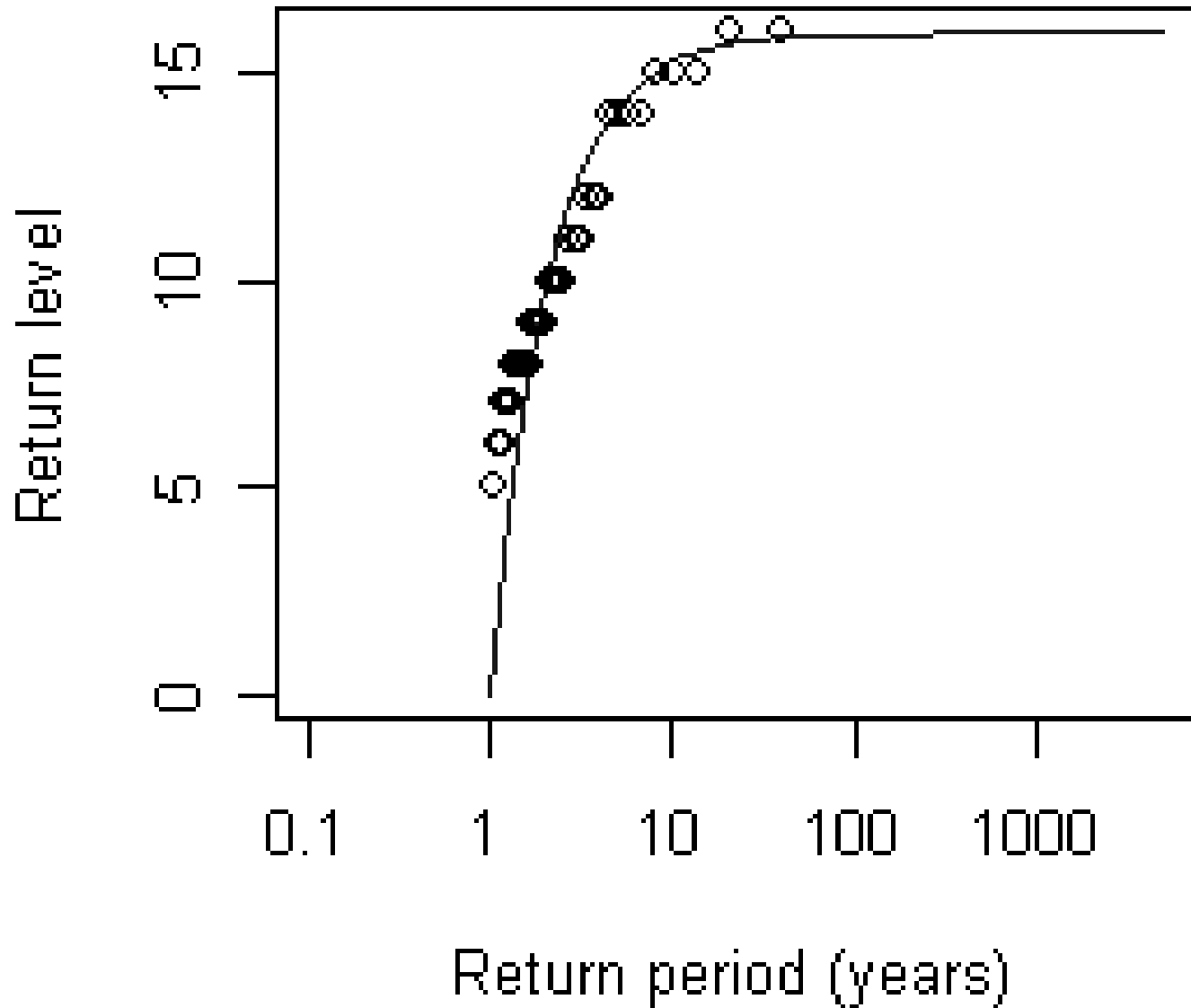


Gumbel, “Statistics of Extremes”

“Il est impossible que l'improbable n'arrive jamais.”

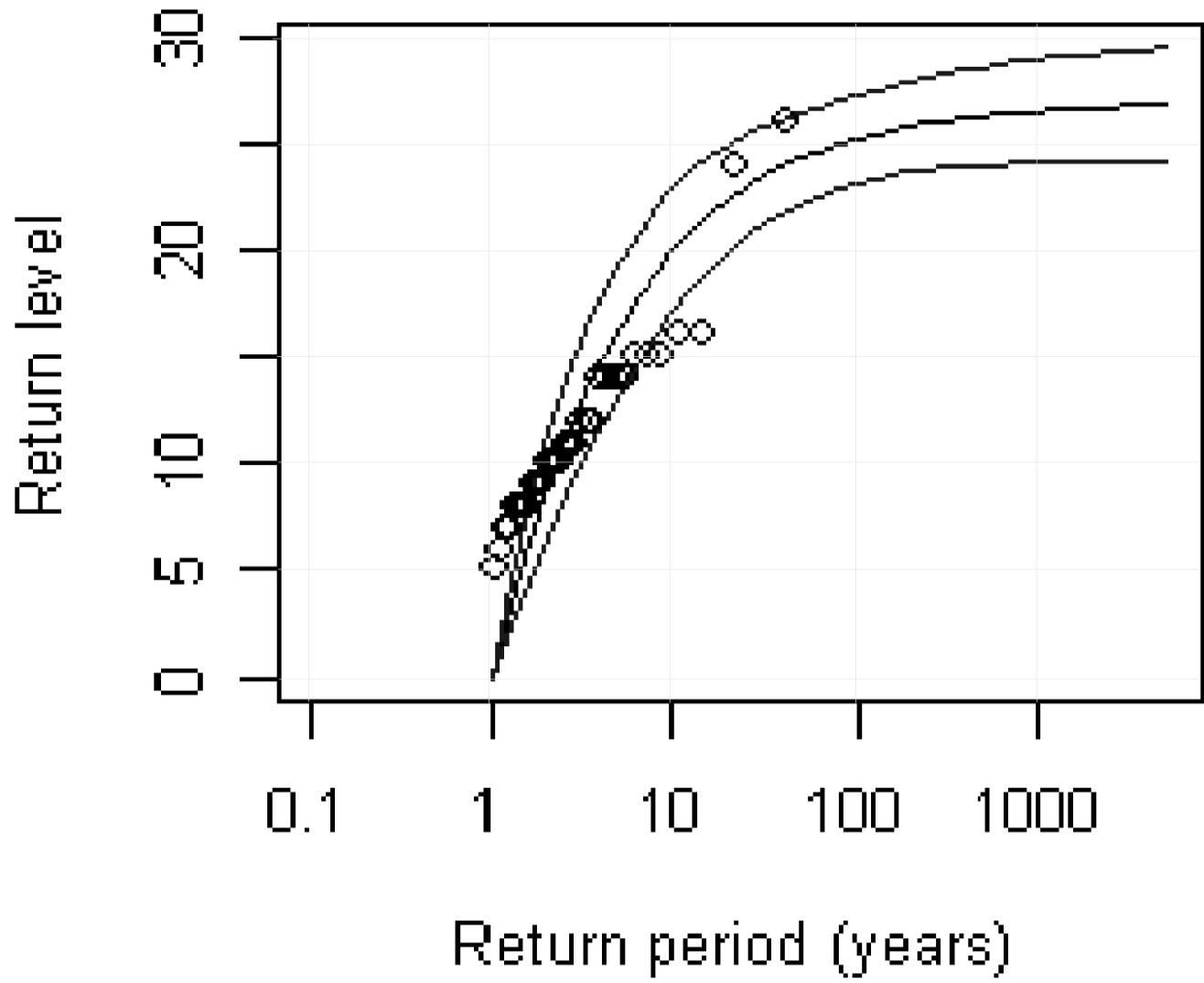
**The improbable is  
bound to happen  
one day**

# Return Level Plot





# Return Level Plot



**Hurricanes are far too  
unique, generally  
speaking, for any sort of  
statistical tabulation to  
have *any* value for  
storm surge guidance.**

**S** **EA**

**L** **AKE**

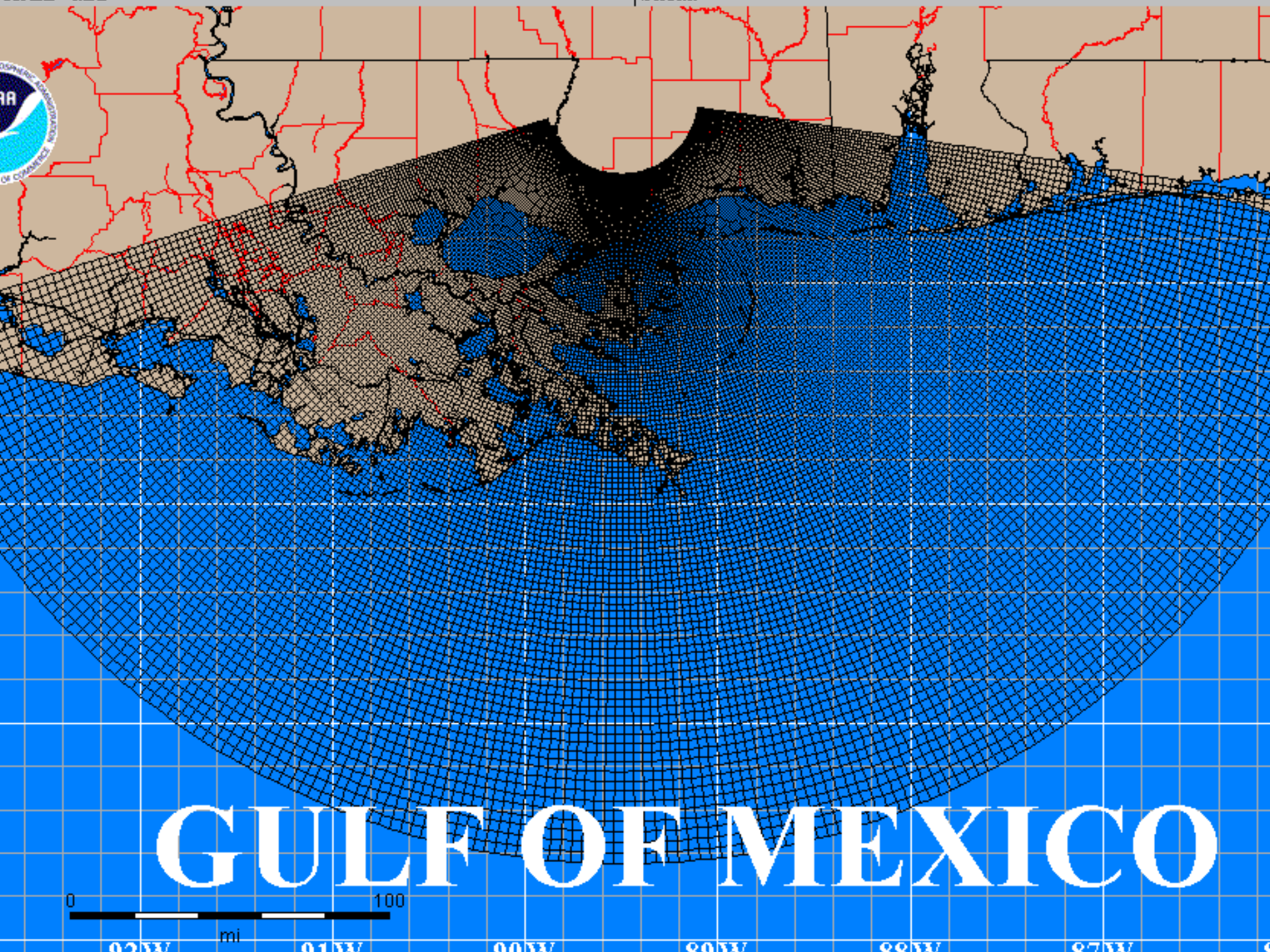
**O** **VERLAND**

**S** **URGE**

from

**H** **URRICANES**





# GULF OF MEXICO

0 100

mi

02°W

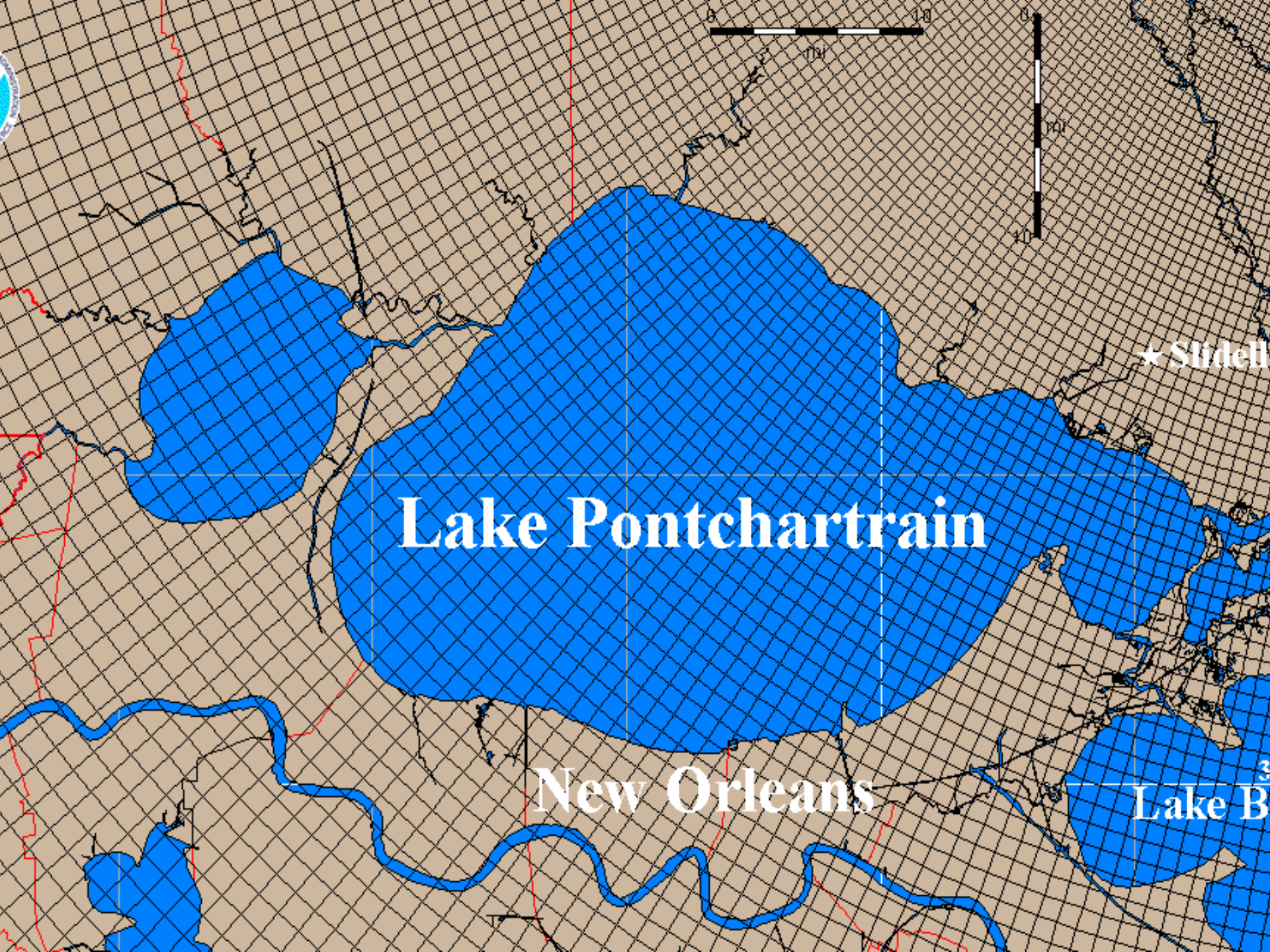
01°W

00°W

00°W

00°W

07°W



Lake Pontchartrain

New Orleans

Lake B

★ Slidell

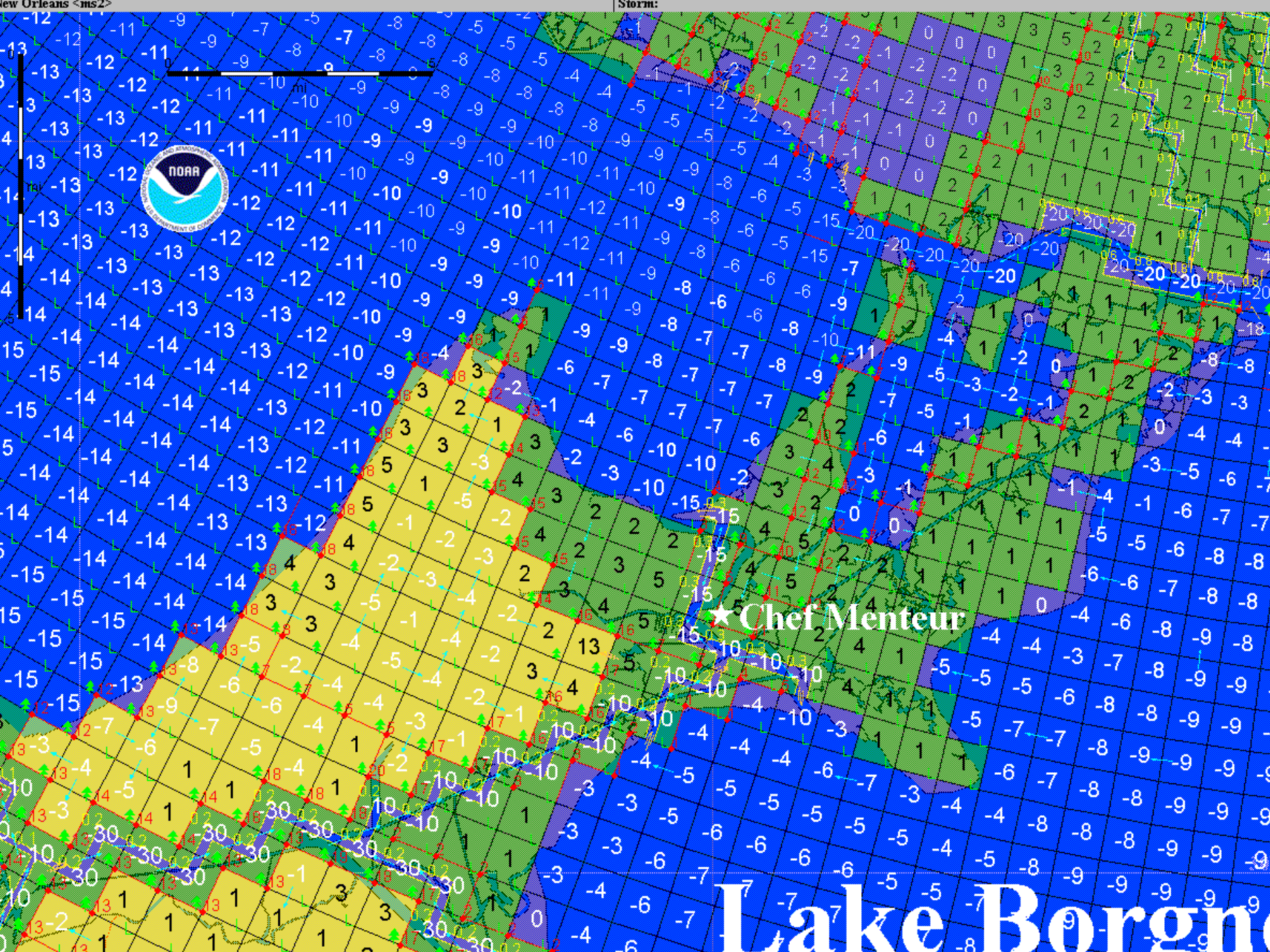










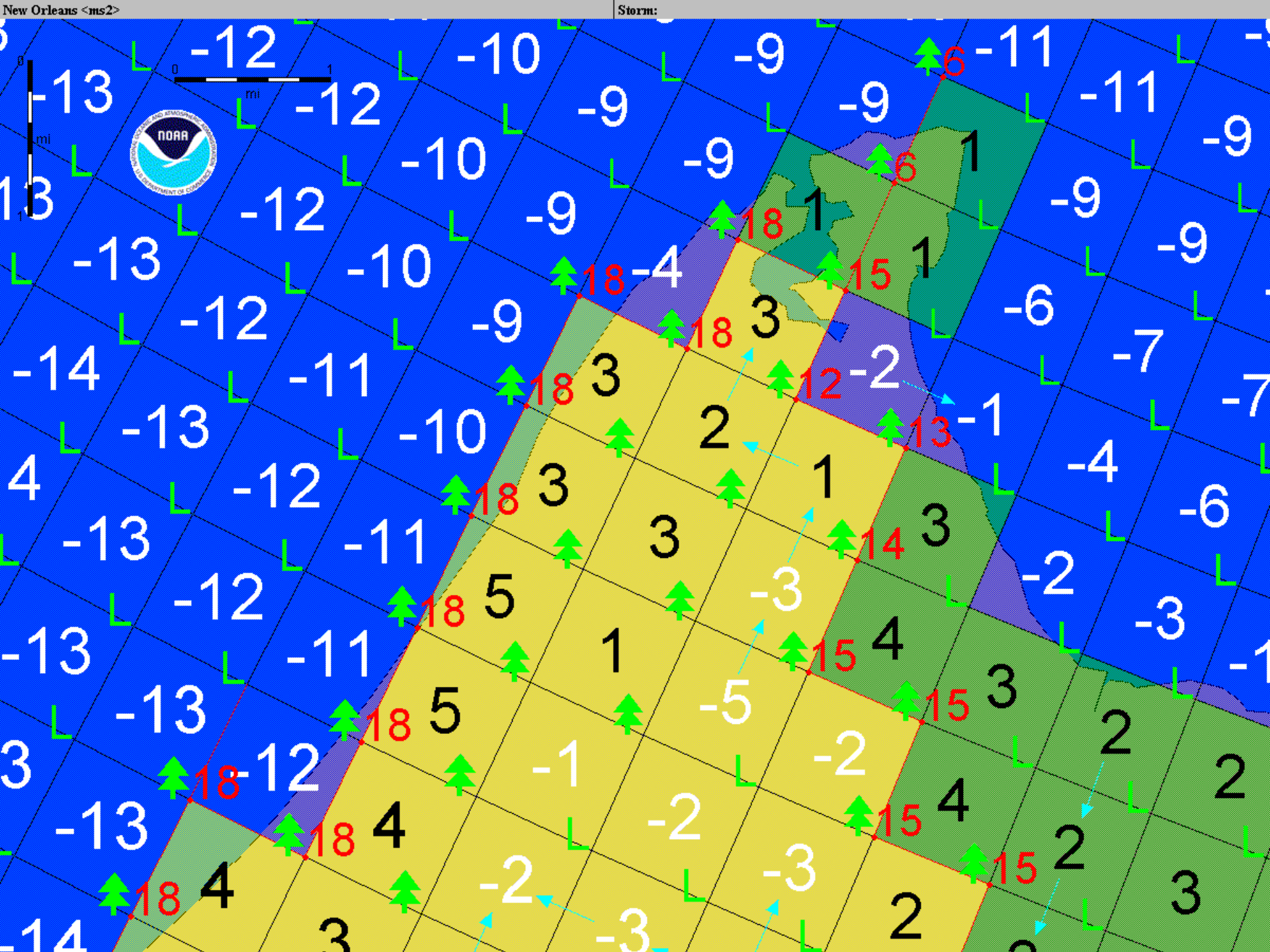


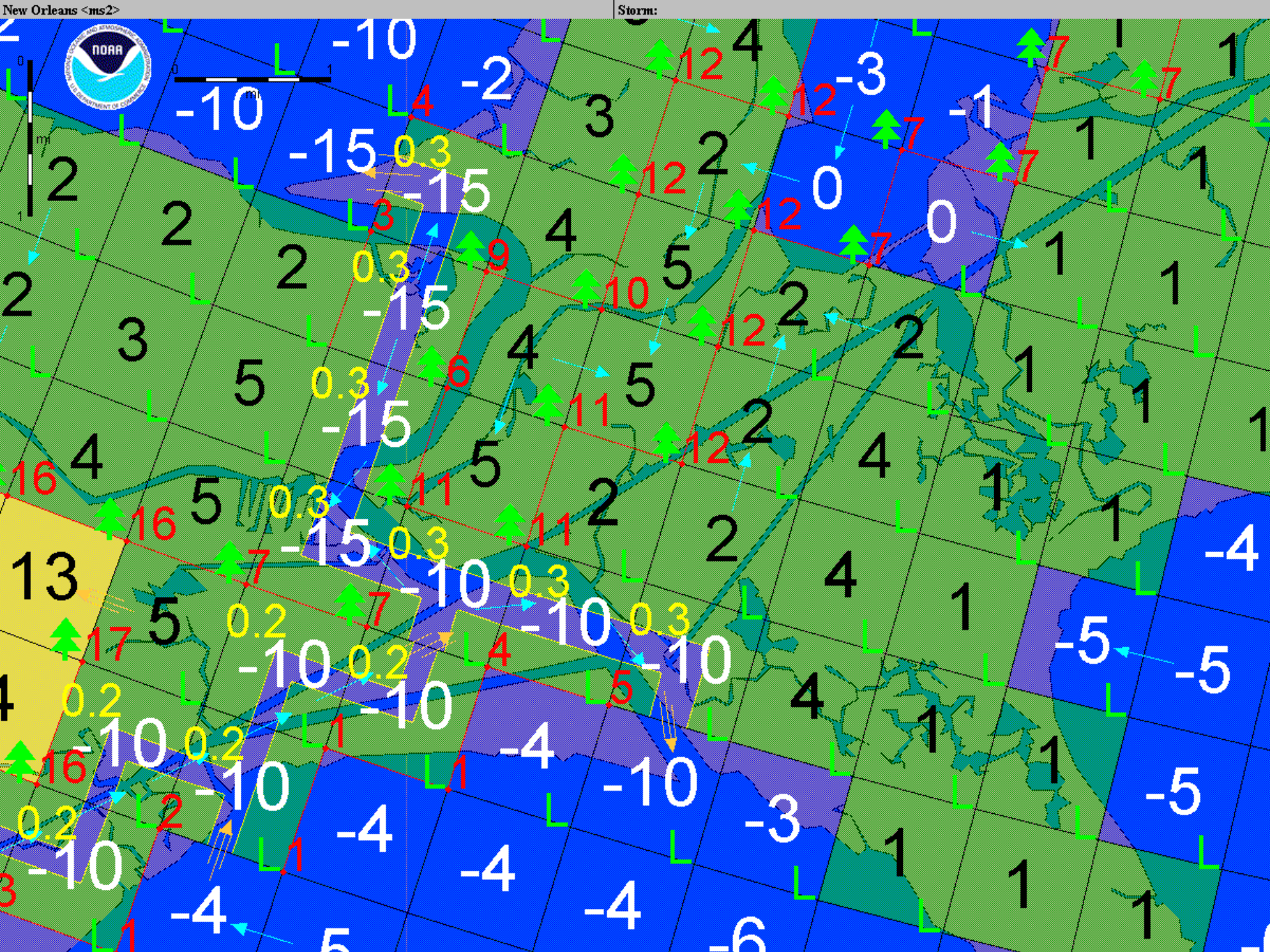
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

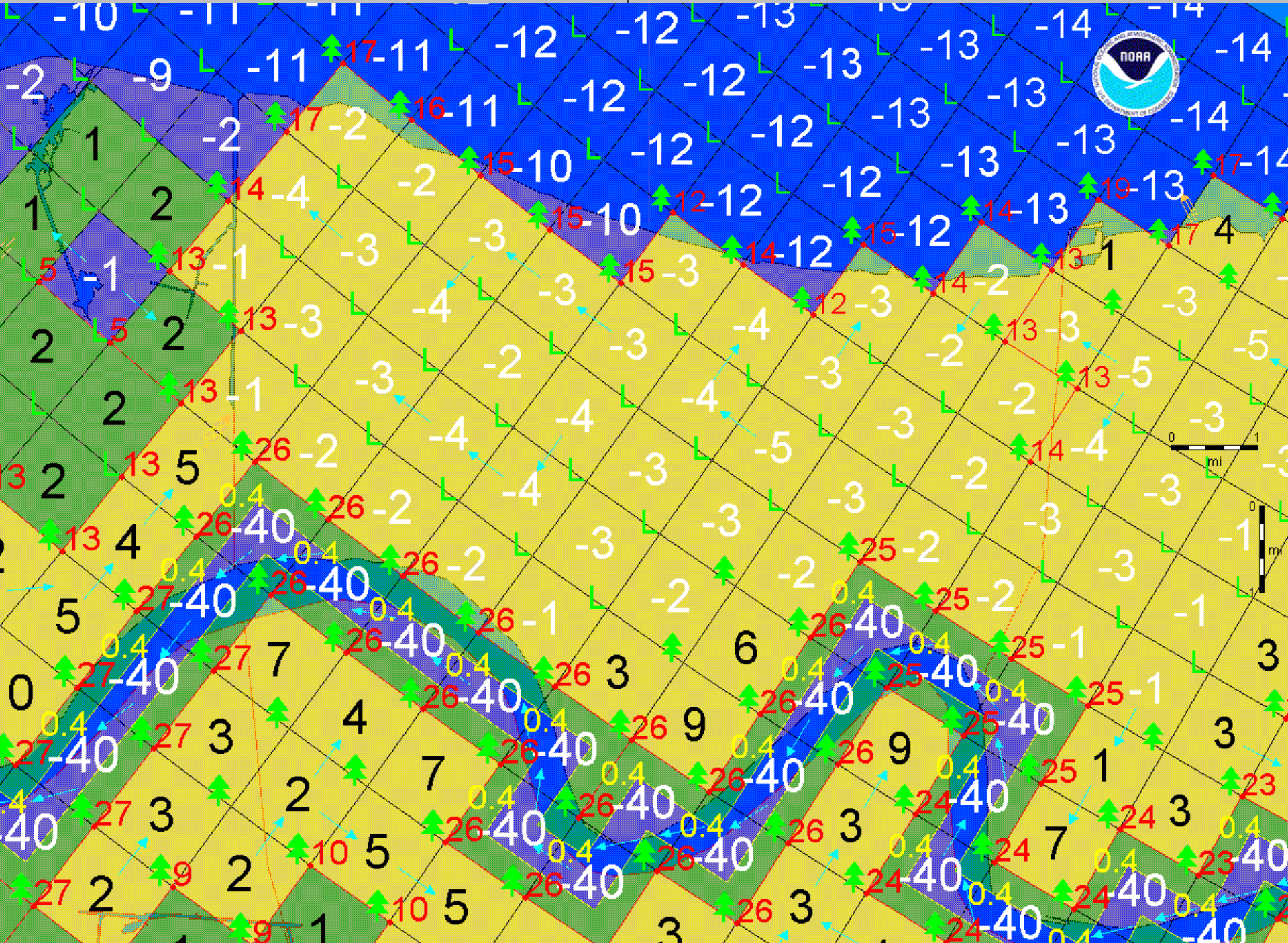
Storm:

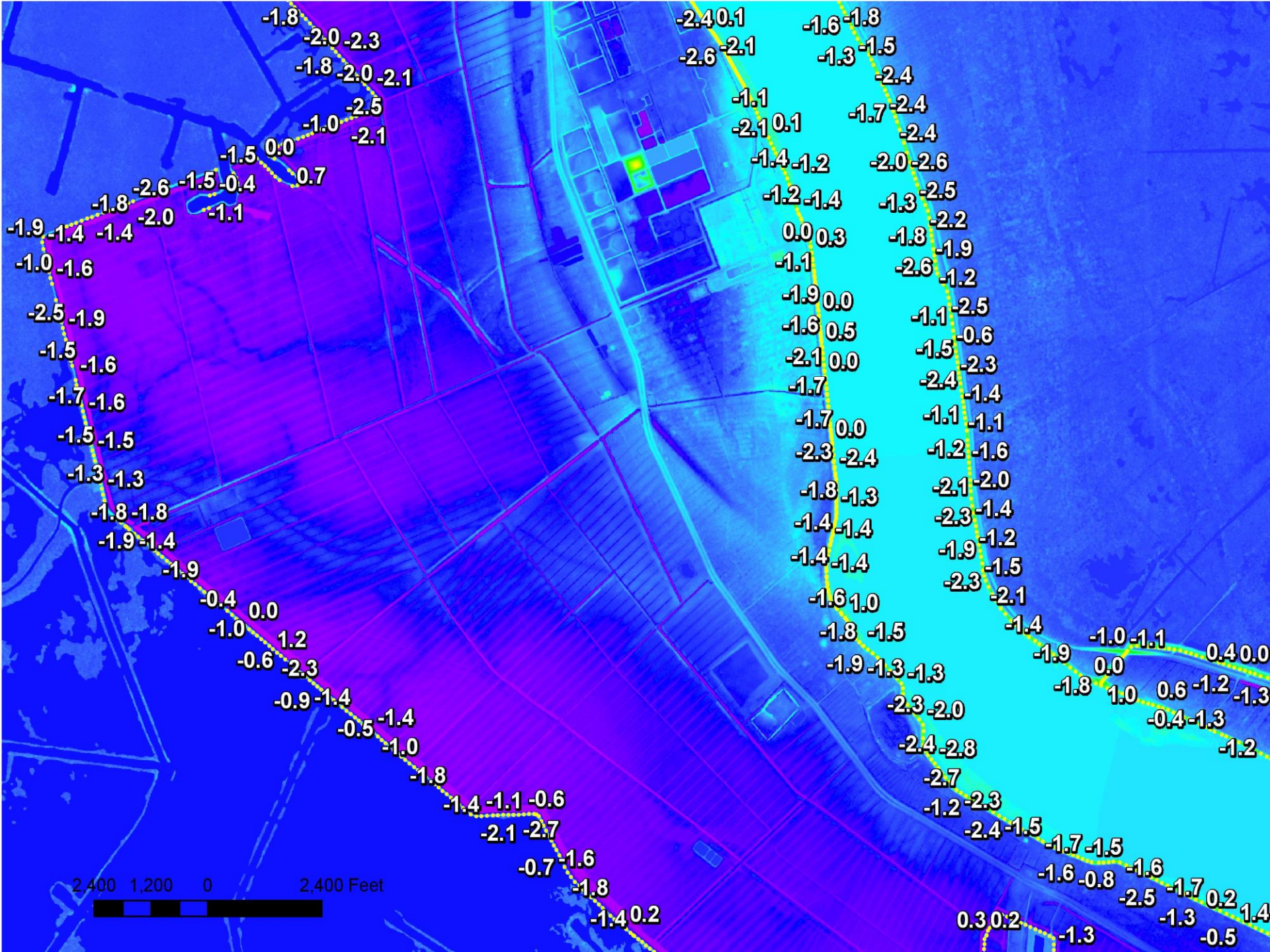
★ Chef Menteur

Lake Borgne









# SLOSH Data

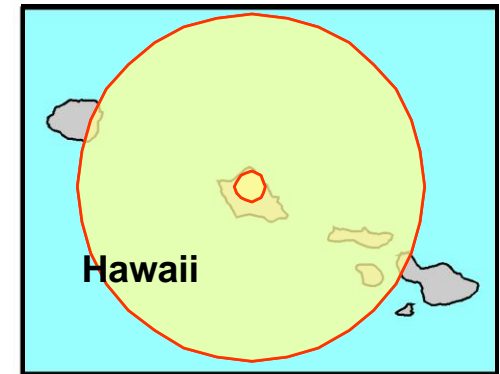
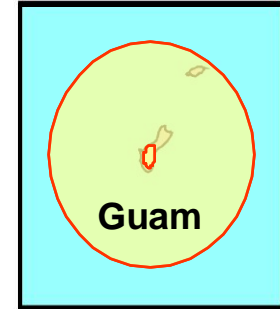
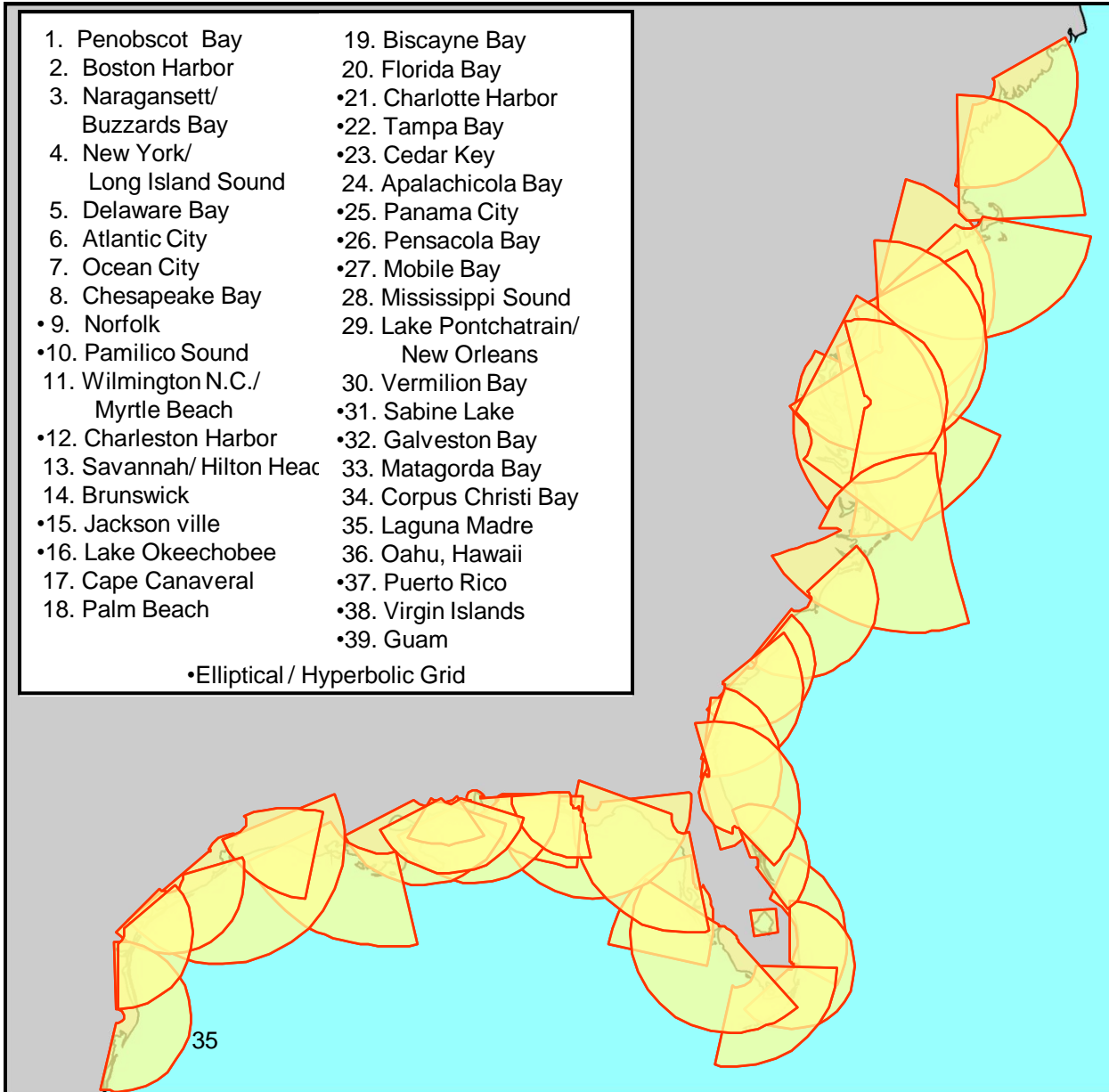
- **The National Weather Service has run several thousand hypothetical hurricanes for each basin with the SLOSH model**
- **Resulting flooding data from each run are saved**



# SLOSH BASINS

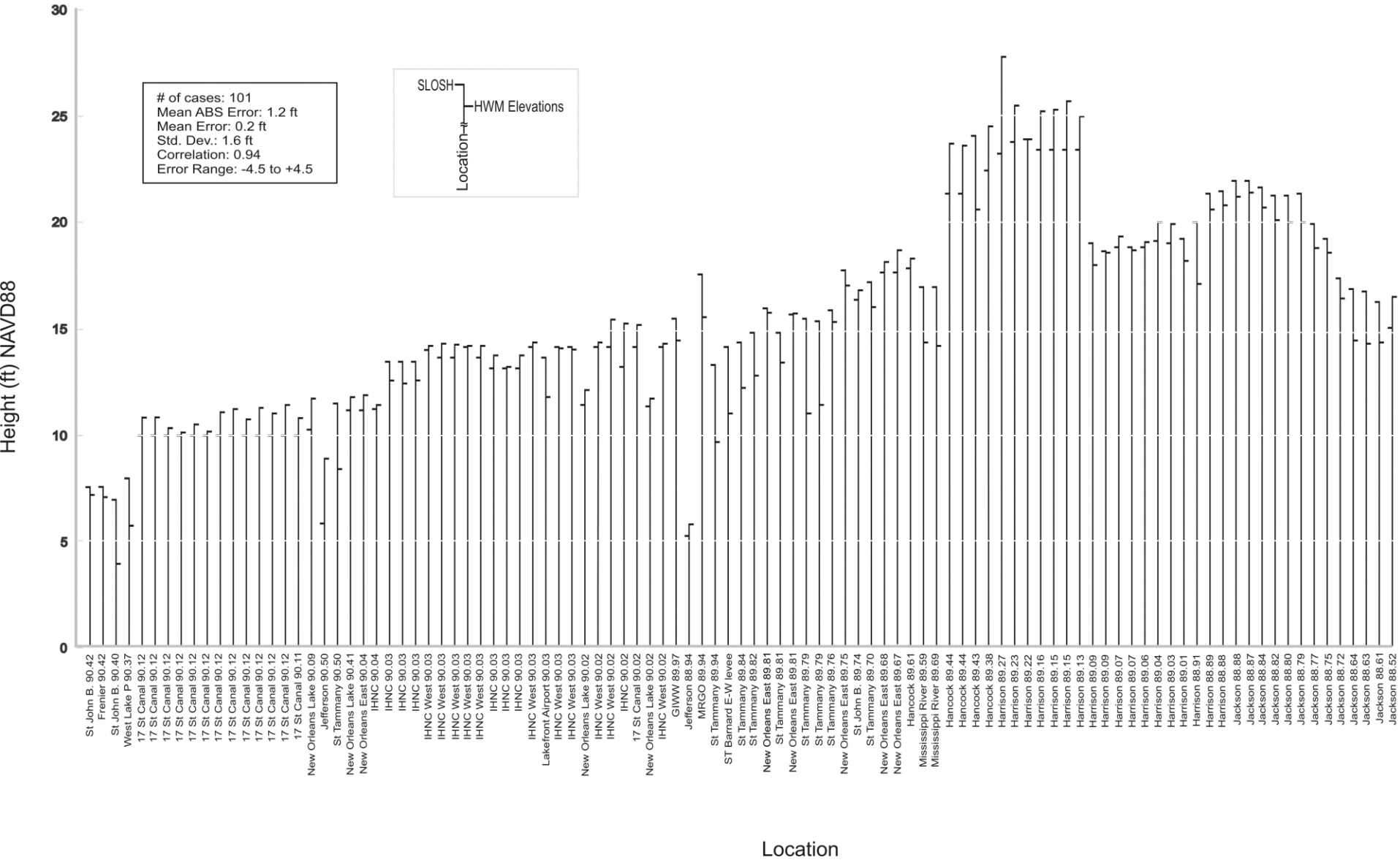
- |                                      |  |
|--------------------------------------|--|
| 1. Penobscot Bay                     | 19. Biscayne Bay                       |
| 2. Boston Harbor                     | 20. Florida Bay                        |
| 3. Naragansett/<br>Buzzards Bay      | •21. Charlotte Harbor                  |
| 4. New York/<br>Long Island Sound    | •22. Tampa Bay                         |
| 5. Delaware Bay                      | •23. Cedar Key                         |
| 6. Atlantic City                     | 24. Apalachicola Bay                   |
| 7. Ocean City                        | •25. Panama City                       |
| 8. Chesapeake Bay                    | •26. Pensacola Bay                     |
| •9. Norfolk                          | •27. Mobile Bay                        |
| •10. Pamlico Sound                   | 28. Mississippi Sound                  |
| 11. Wilmington N.C./<br>Myrtle Beach | 29. Lake Pontchartrain/<br>New Orleans |
| •12. Charleston Harbor               | 30. Vermilion Bay                      |
| 13. Savannah/ Hilton Heac            | •31. Sabine Lake                       |
| 14. Brunswick                        | •32. Galveston Bay                     |
| •15. Jackson ville                   | 33. Matagorda Bay                      |
| •16. Lake Okeechobee                 | 34. Corpus Christi Bay                 |
| 17. Cape Canaveral                   | 35. Laguna Madre                       |
| 18. Palm Beach                       | •36. Oahu, Hawaii                      |
|                                      | •37. Puerto Rico                       |
|                                      | •38. Virgin Islands                    |
|                                      | •39. Guam                              |

•Elliptical / Hyperbolic Grid





# Hurricane Katrina SLOSH vs HWM Gulf Coast



**What happens when ...**

**reality departs from the  
forecast?**

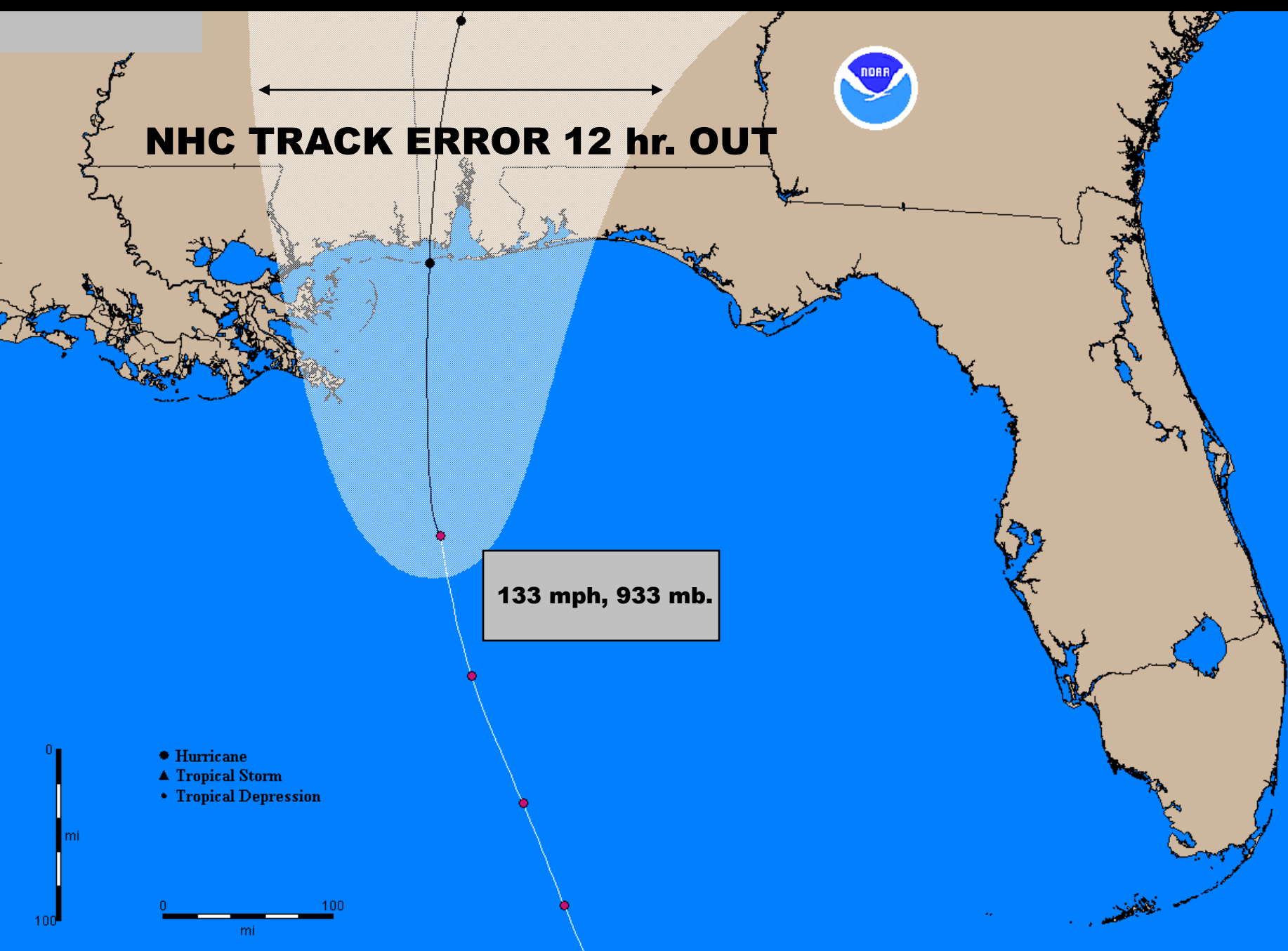
# Storms depart from their forecasts in:

- Track (speed, direction)
- Intensity
- Radius of Maximum Wind (RMW)
- Internal structure (e.g. extent of wind field)

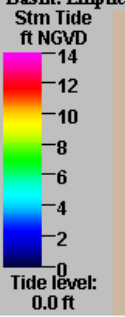
# TRACK DIFFERENCES

# What if ...

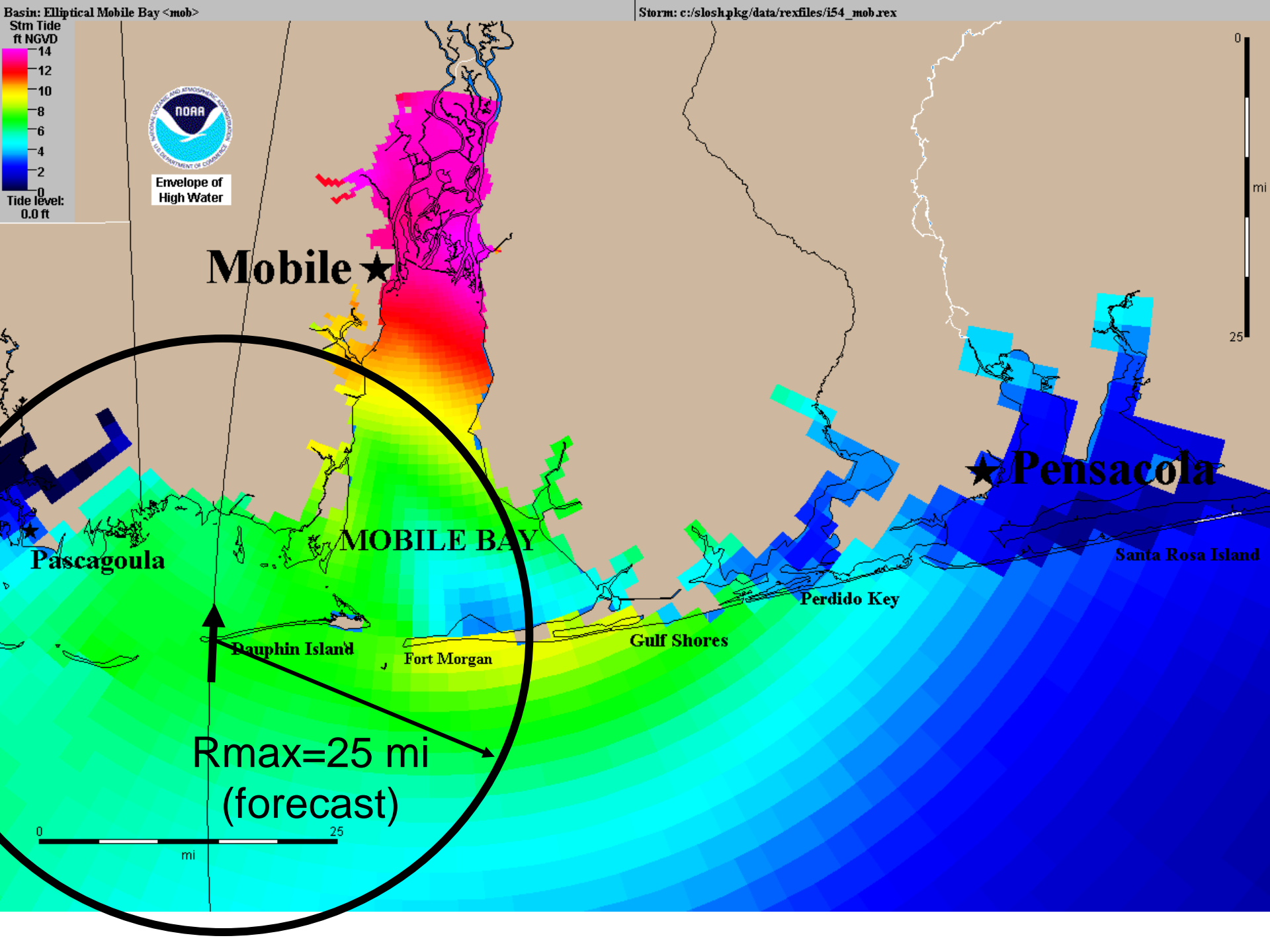
An NHC advisory 12 hours before landfall forecasts a storm to move northward, west of Mobile Bay, and you are the E.M. for Pensacola/Escambia County!



Hurricane Advisory – Approximately 12 h before landfall



Envelope of  
High Water



**Mobile** ★

★ **Pensacola**

**Pascagoula**

**MOBILE BAY**

**Santa Rosa Island**

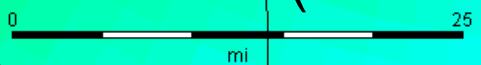
**Perdido Key**

**Dauphin Island**

**Fort Morgan**

**Gulf Shores**

**Rmax=25 mi  
(forecast)**



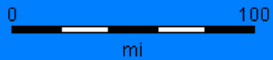


**TRACK FORECAST**

**ACTUAL TRACK**

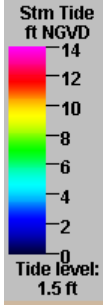
**133 mph, 933 mb.**

- Hurricane
- ▲ Tropical Storm
- Tropical Depression

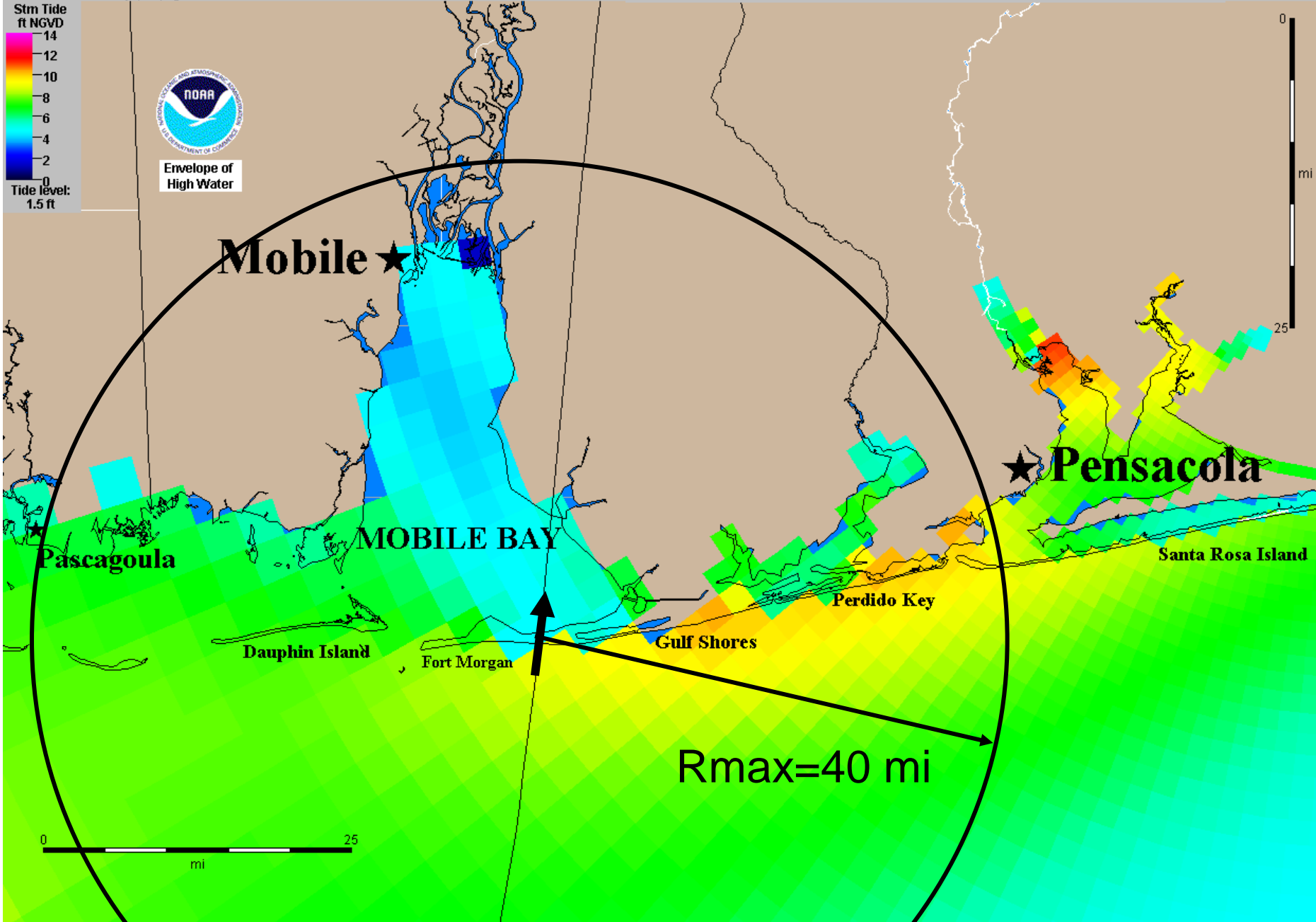




Basin: Pensacola Bay (Old) <pns>



Envelope of  
High Water



**Mobile** ★

★ **Pensacola**

Pascagoula

**MOBILE BAY**

Santa Rosa Island

Dauphin Island

Fort Morgan

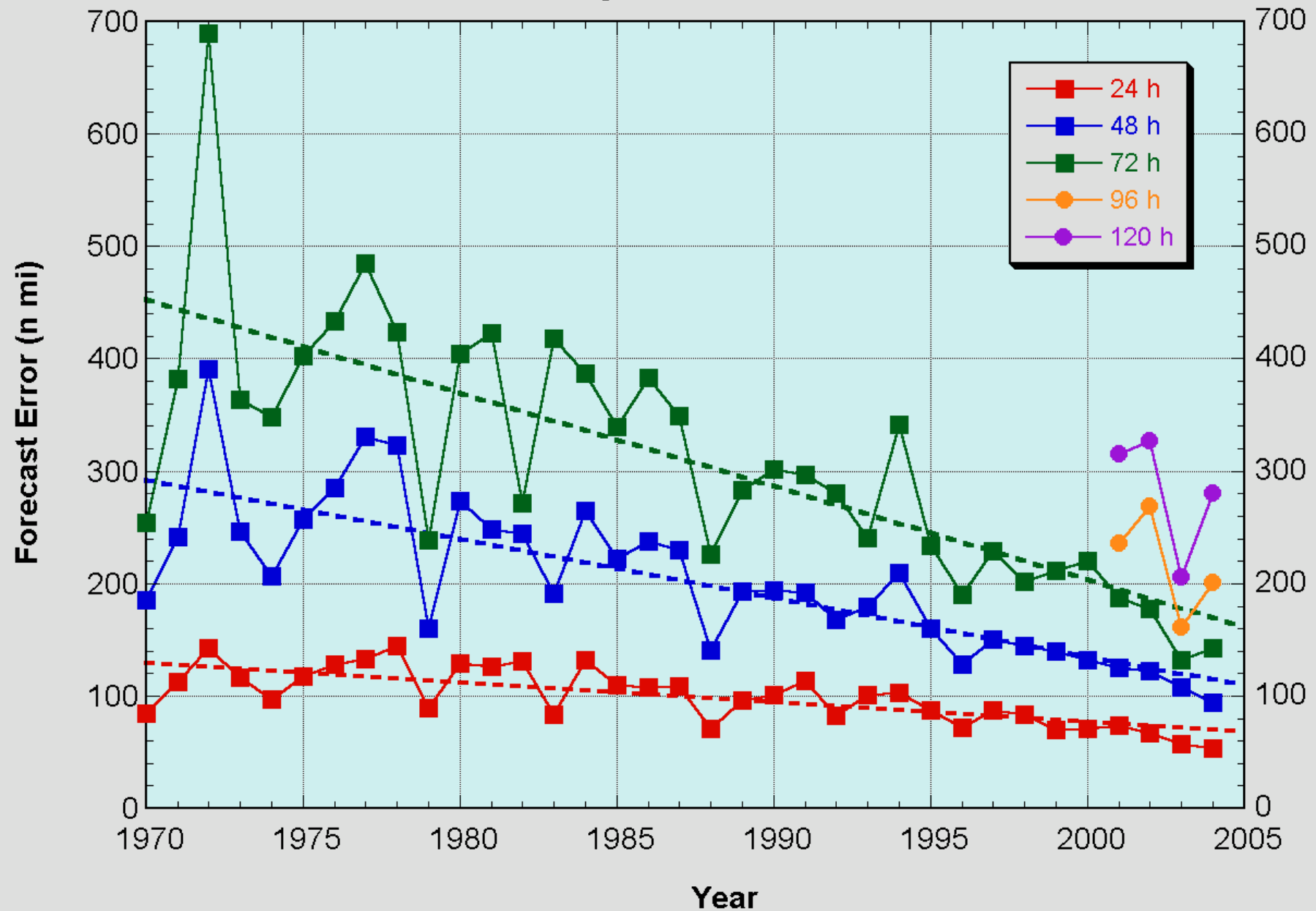
Gulf Shores

Perdido Key

Rmax=40 mi



# NHC Official Annual Average Track Errors Atlantic Basin Tropical Storms and Hurricanes



# INTENSITY & RMW

## What if ...

An NHC advisory 12 hours before landfall forecasts a storm to move northward in the Eastern Gulf of Mexico, at S-S Cat 2, and you are the E.M. for Lee County.

Charlotte



Captiva★

★ Fort Myers

★ Cape Coral

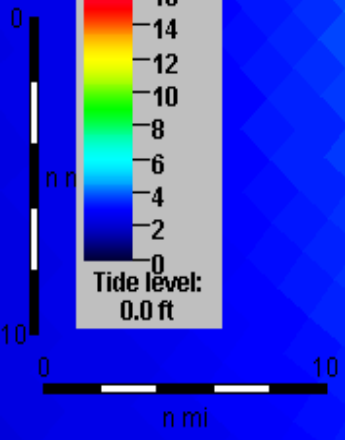
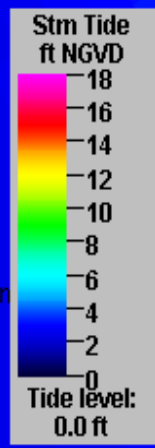
Lee

Sanibel Island

9.9

9.7

Naples★

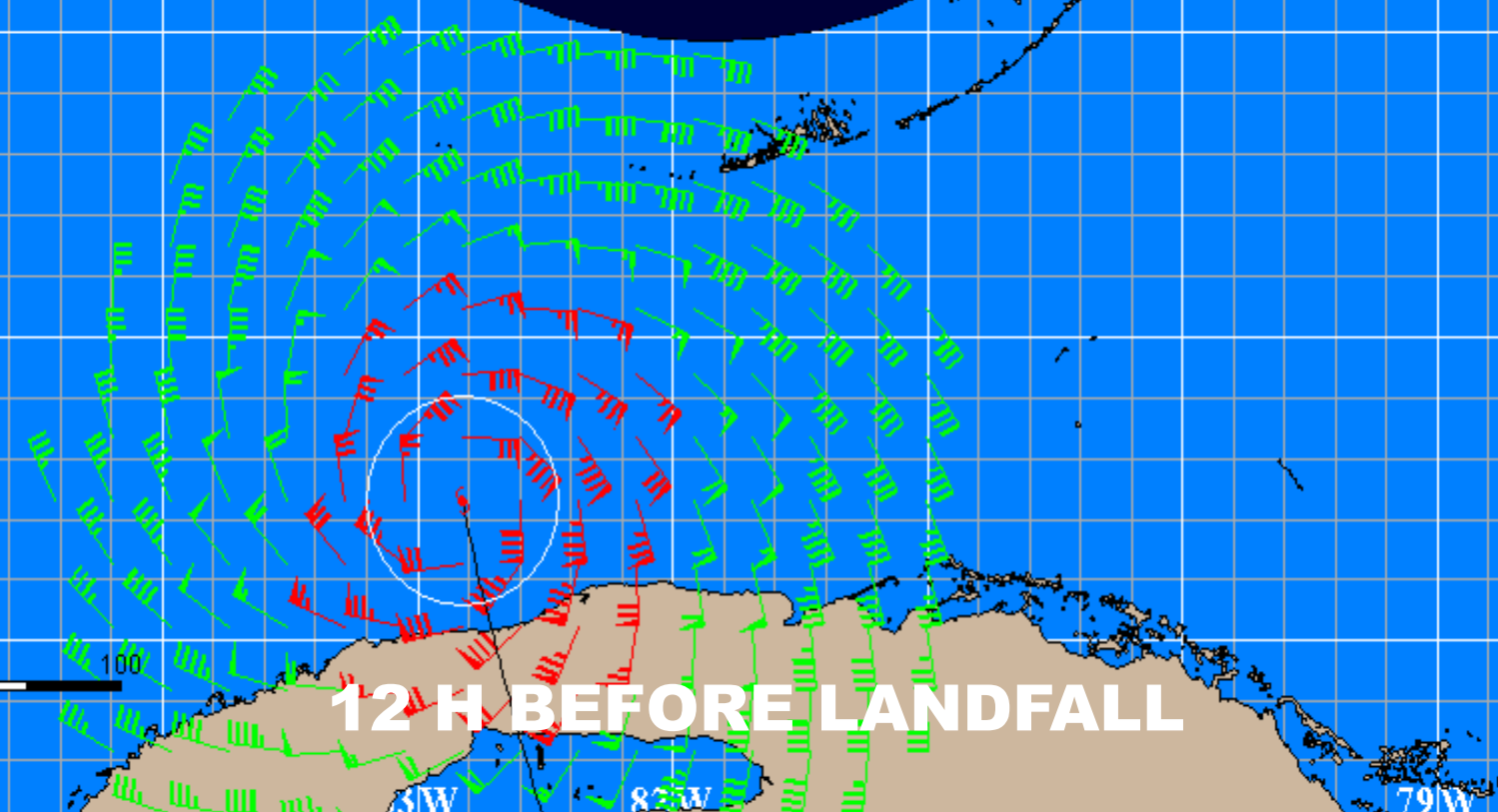
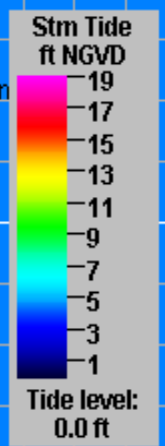
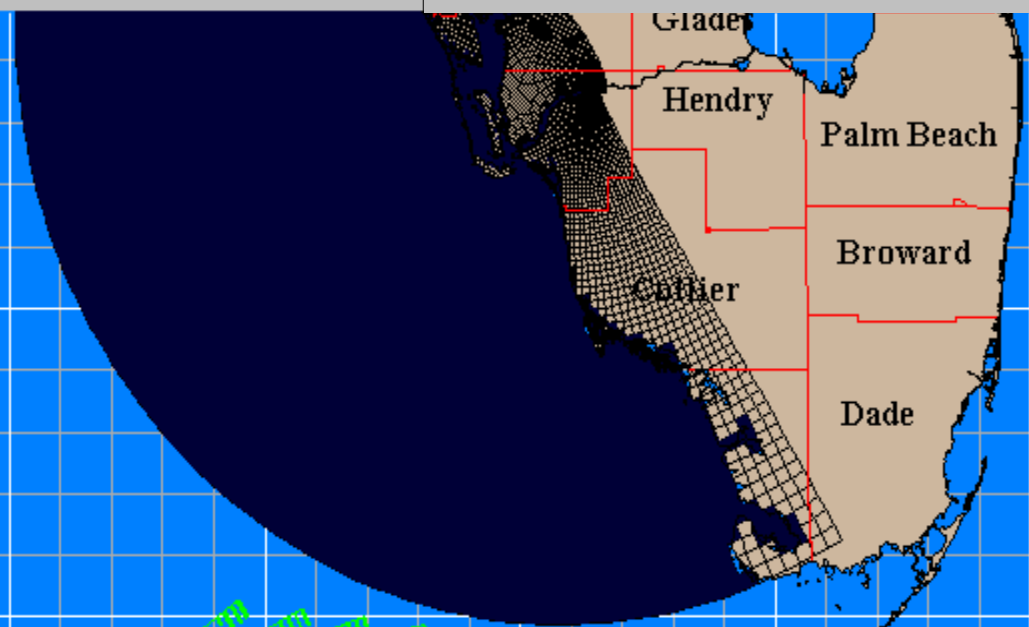


asin: Elliptical Fort Myers <fmy>

SLOSH Wind field  
1 min avg KTS(MPH)  
1(39) 65(75) 100(115)



08/13/2004  
08:00:00 UTC



**12 H BEFORE LANDFALL**

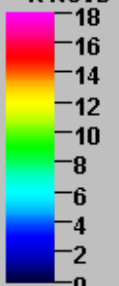
86W 85W 84W 83W 82W 79W

Basin: Elliptical Fort Myers <fny>

SLOSH Wind field  
1 min avg KTS(MPH)

34(39) 65(75) 100(115)

Strm Tide  
ft NGVD



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

★ Fort Myers

Hendry

Captiva ★

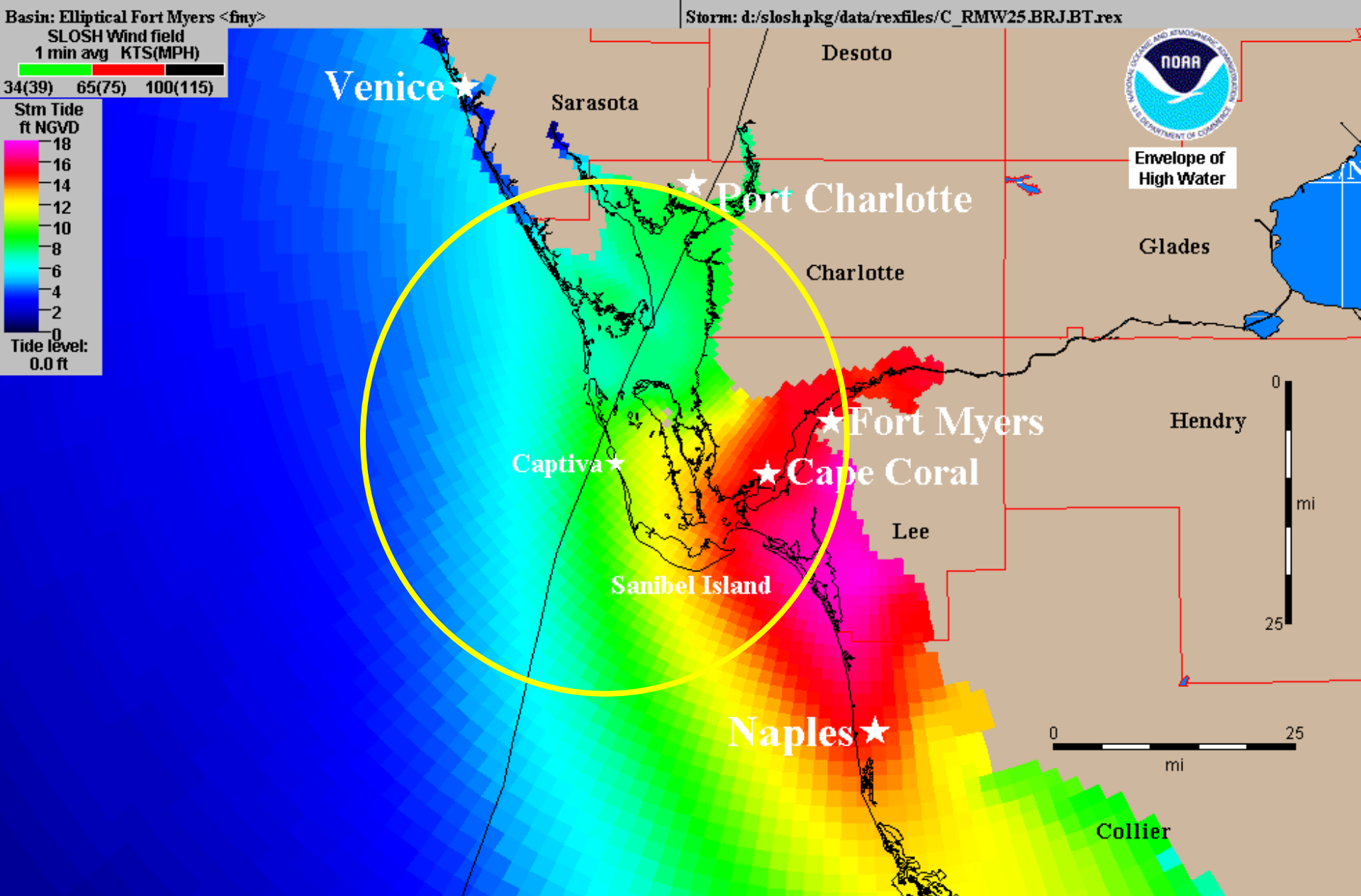
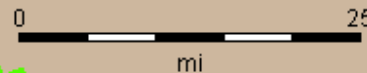
★ Cape Coral

Lee

Sanibel Island

Naples ★

Collier



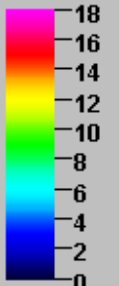
Basin: Elliptical Fort Myers <fny>

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)

Strm Tide  
ft NGVD



Tide level:  
0.0 ft



Envelope of  
High Water

Venice ★

Sarasota

Desoto

★ Port Charlotte

Charlotte

Glades

★ Fort Myers

★ Cape Coral

Hendry

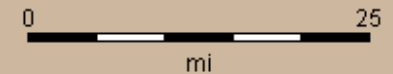
★ Captiva

Lee

Sanibel Island

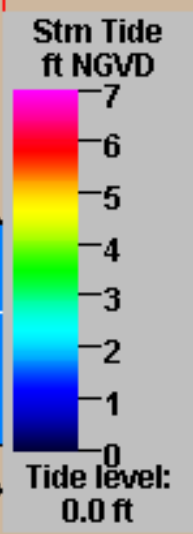
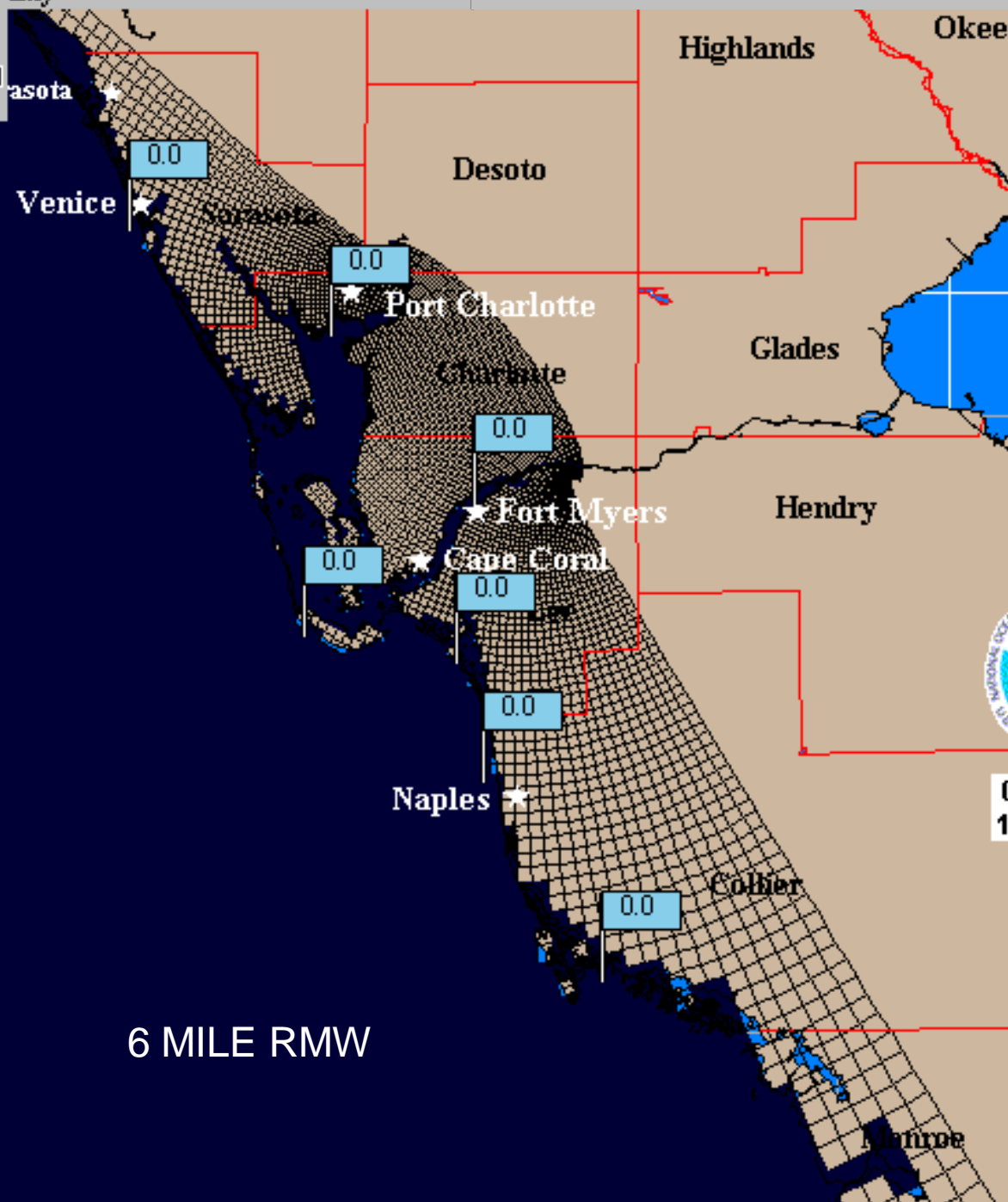
★ Naples

Collier





Basin: Elliptical Fort Myers  
SLOSH Wind field  
1 min avg KTS(MPH)  
34(39) 65(75) 100(115)



08/13/2004  
11:00:50 UTC

6 MILE RMW

Palm Beach

Broward

Dade

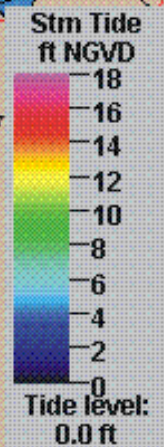
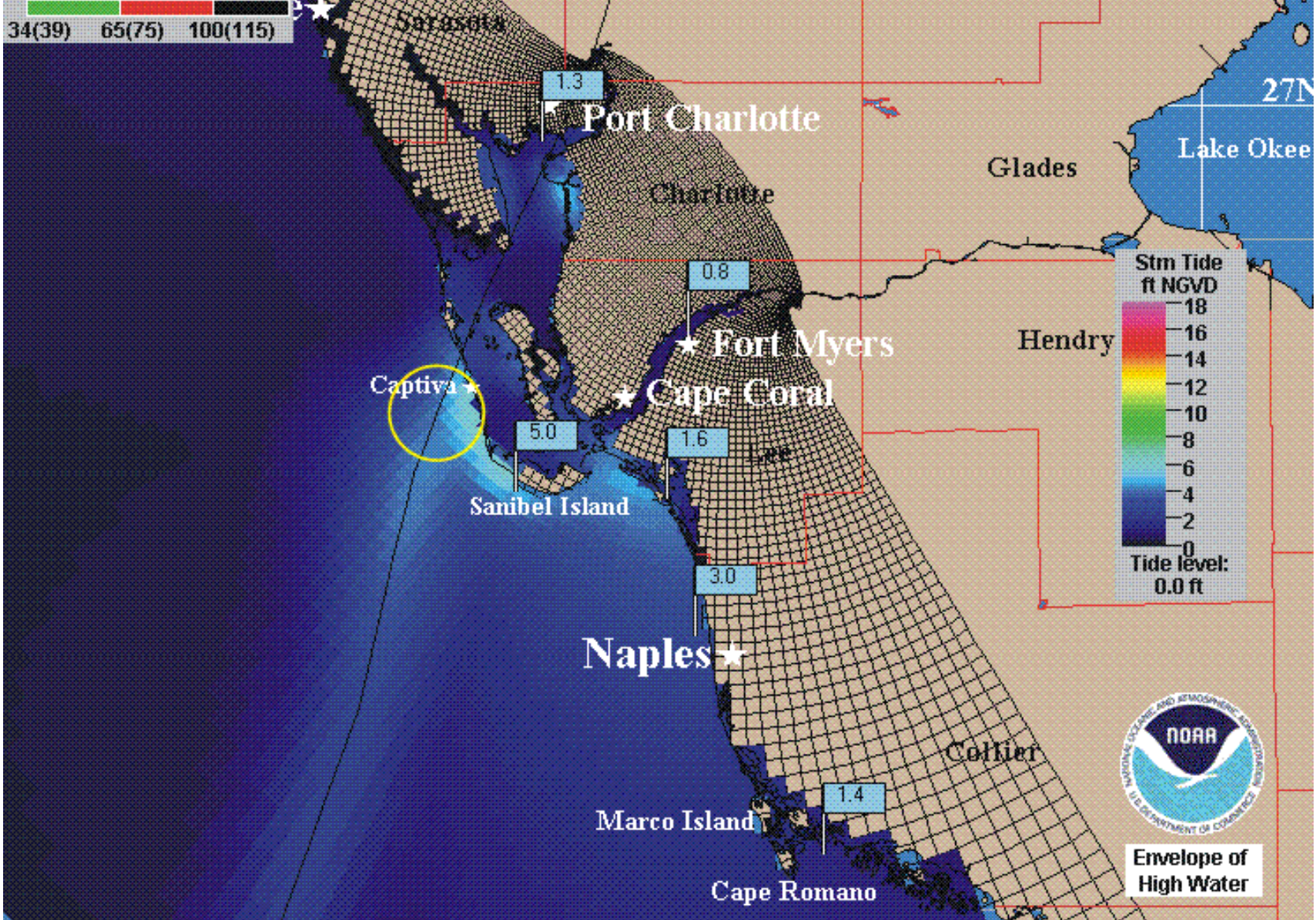
Basin: Elliptical Fort Myers <fny>

SLOSH Wind field  
1 min avg KTS(MPH)

34(39) 65(75) 100(115)

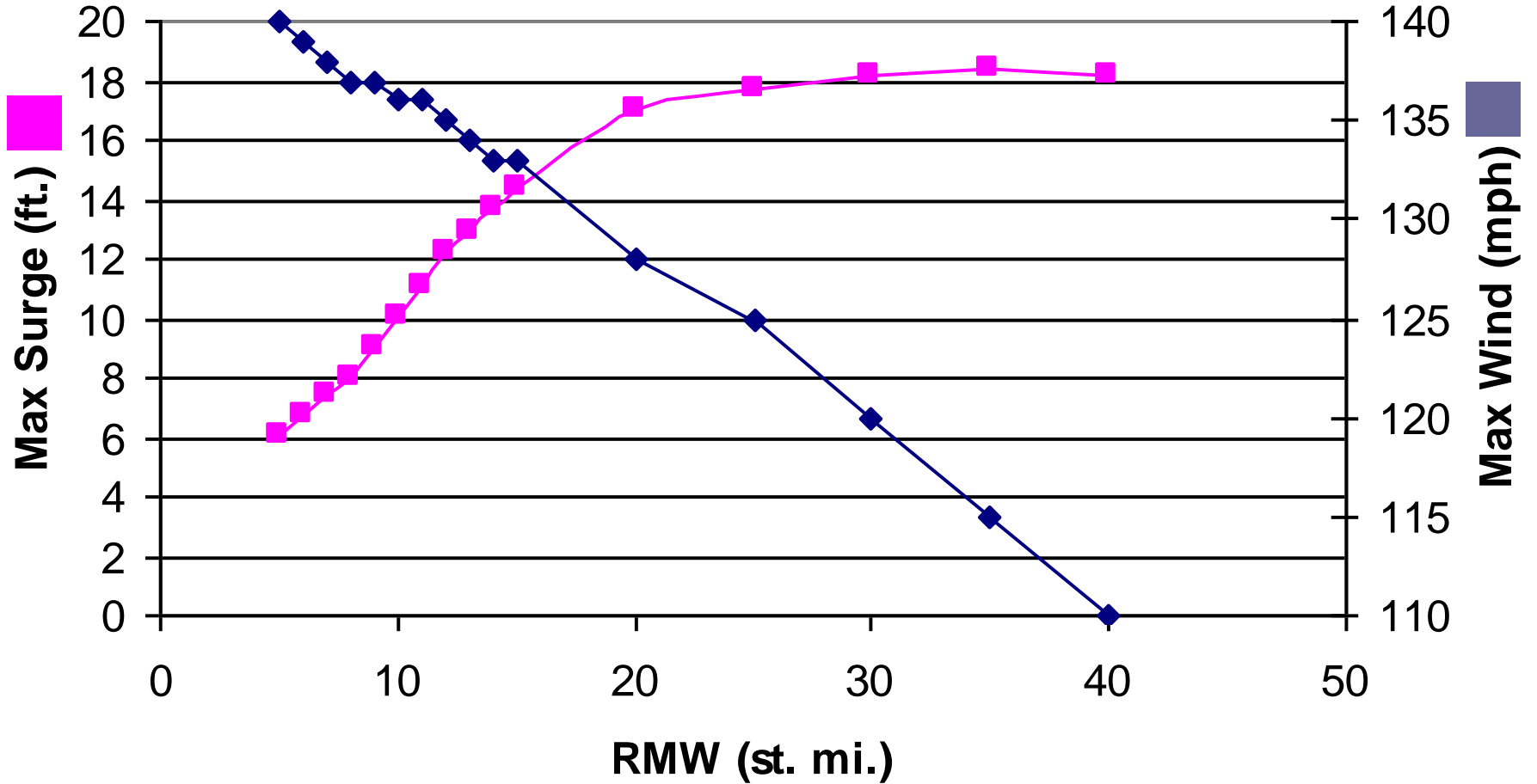
Storm: c:/slosh/pkg/data/rexfiles/C\_RMWO5.BRJ.BT.rex

Desoto

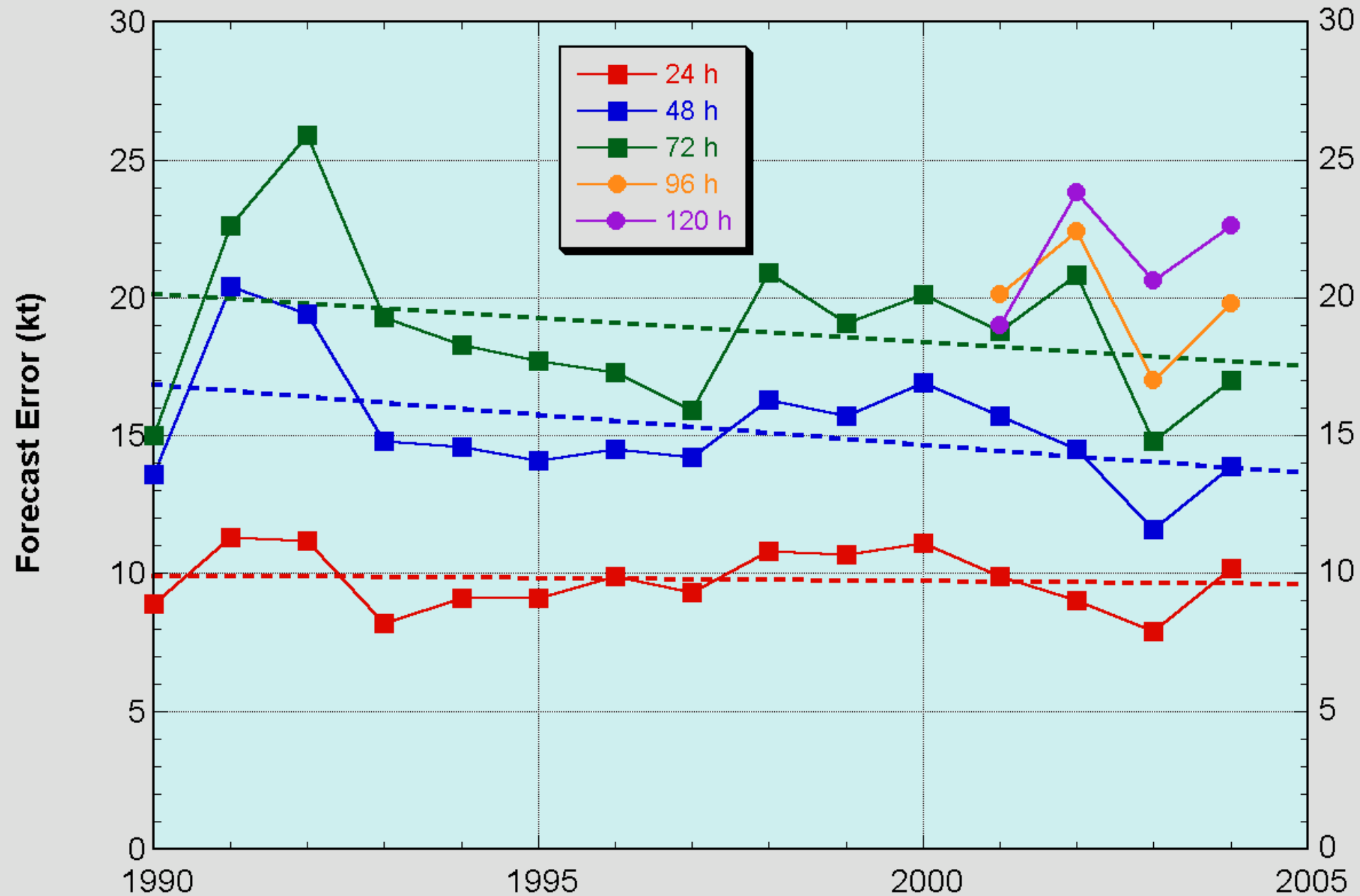


Envelope of  
High Water

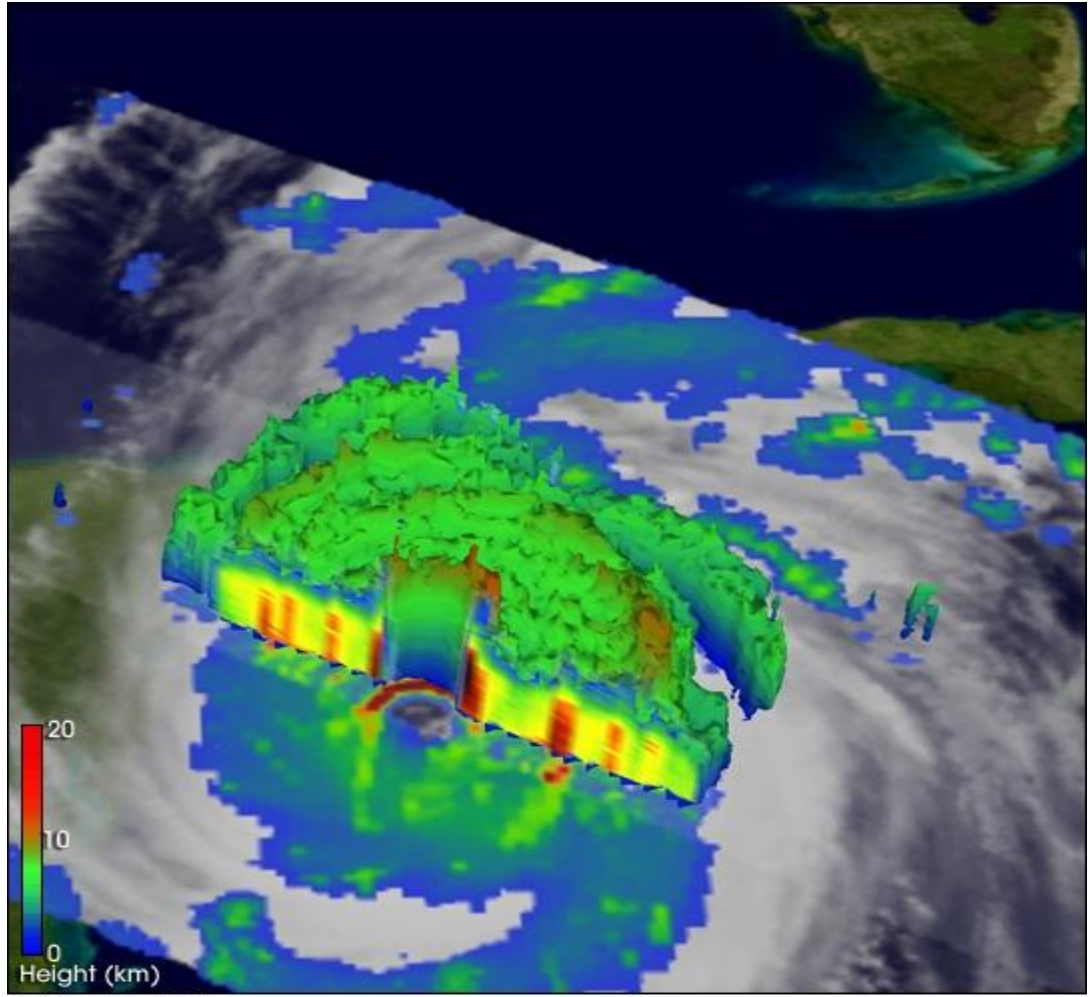
# Hurricane Charley (2004)



# NHC Official Annual Average Intensity Errors Atlantic Basin Tropical Cyclones



STRUCTURE



October 21, 2005

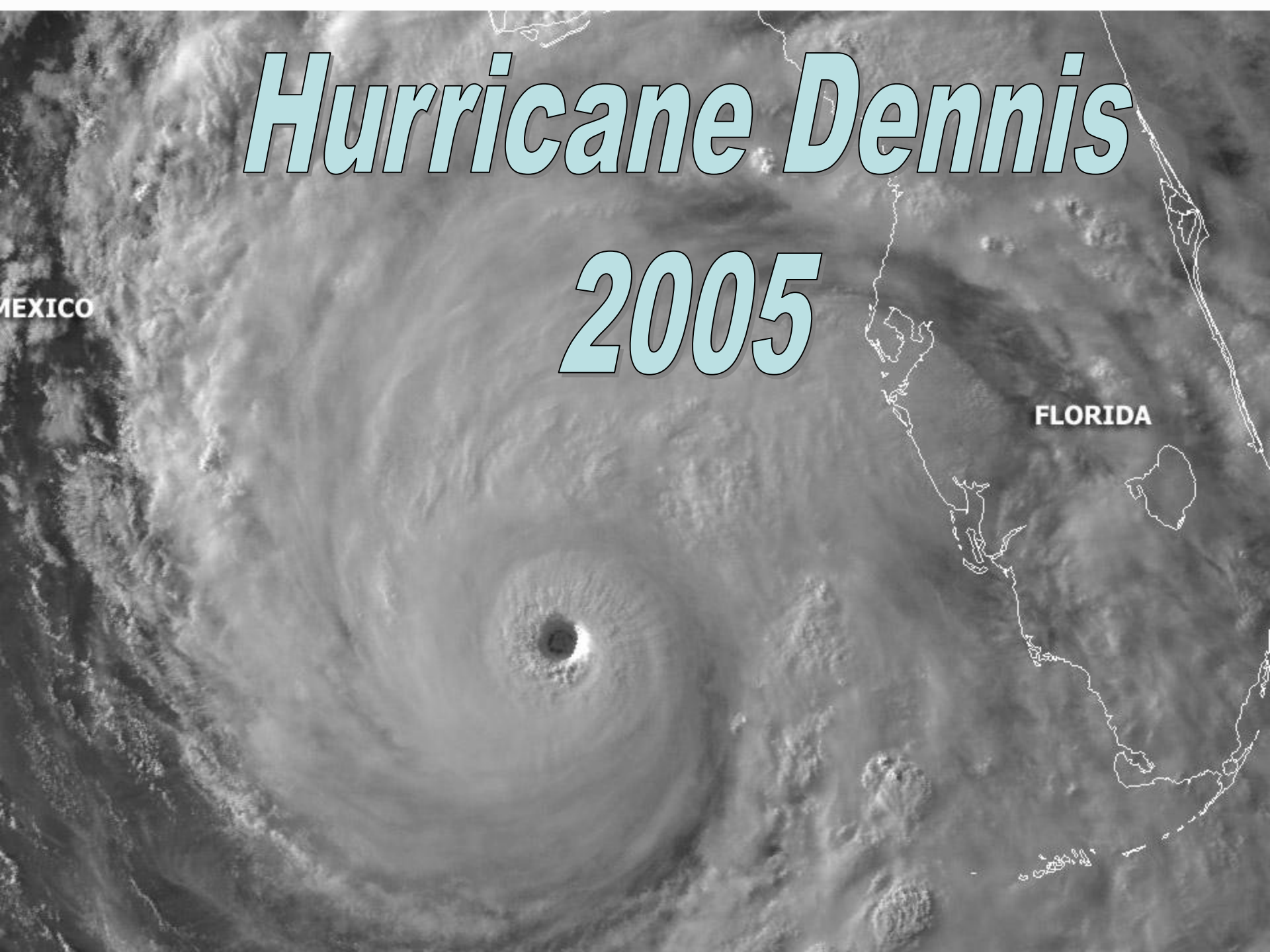


# *Hurricane Dennis*

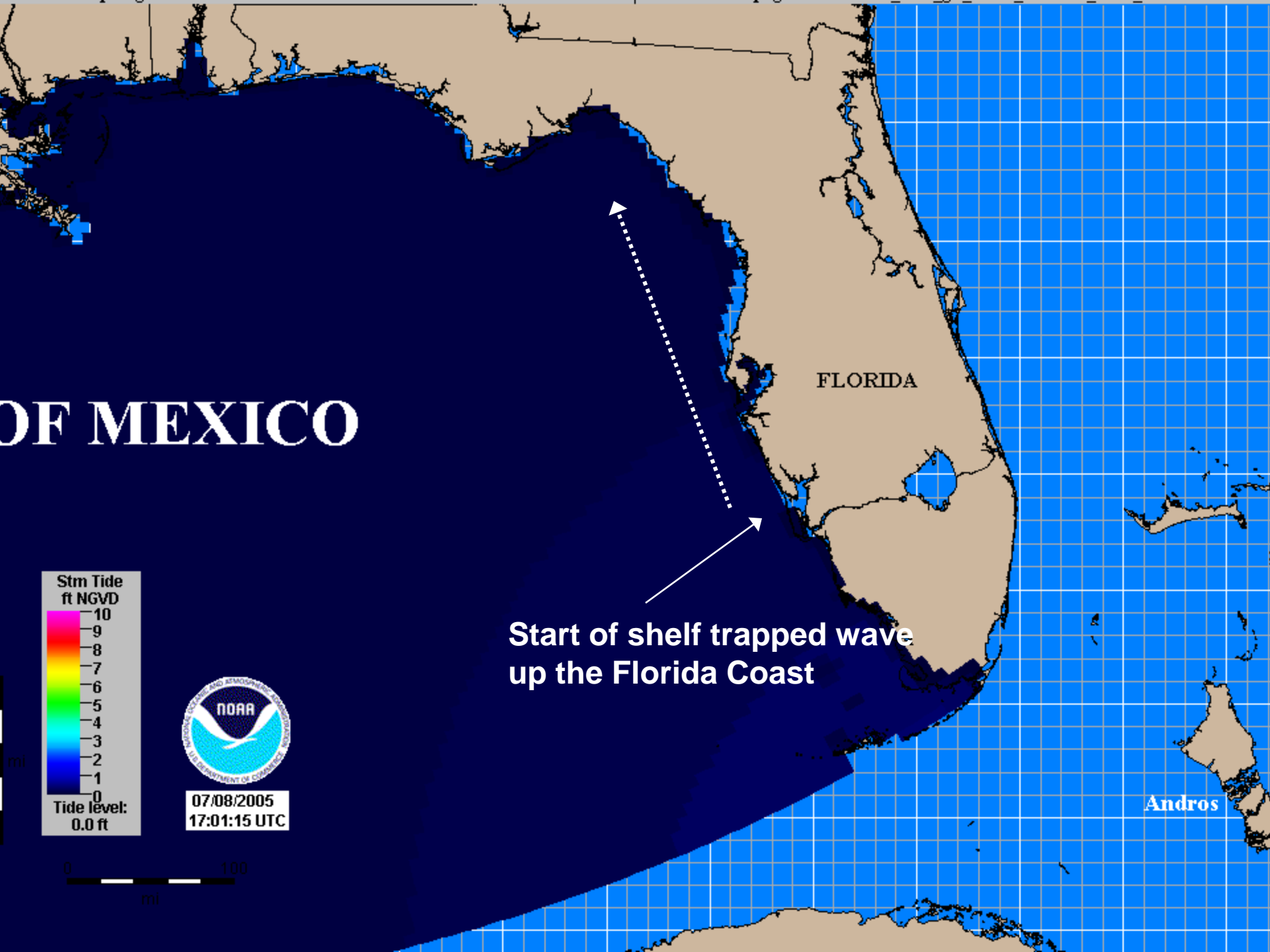
## *2005*

MEXICO

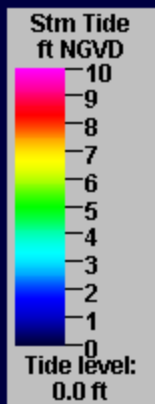
FLORIDA



# OF MEXICO



Start of shelf trapped wave  
up the Florida Coast

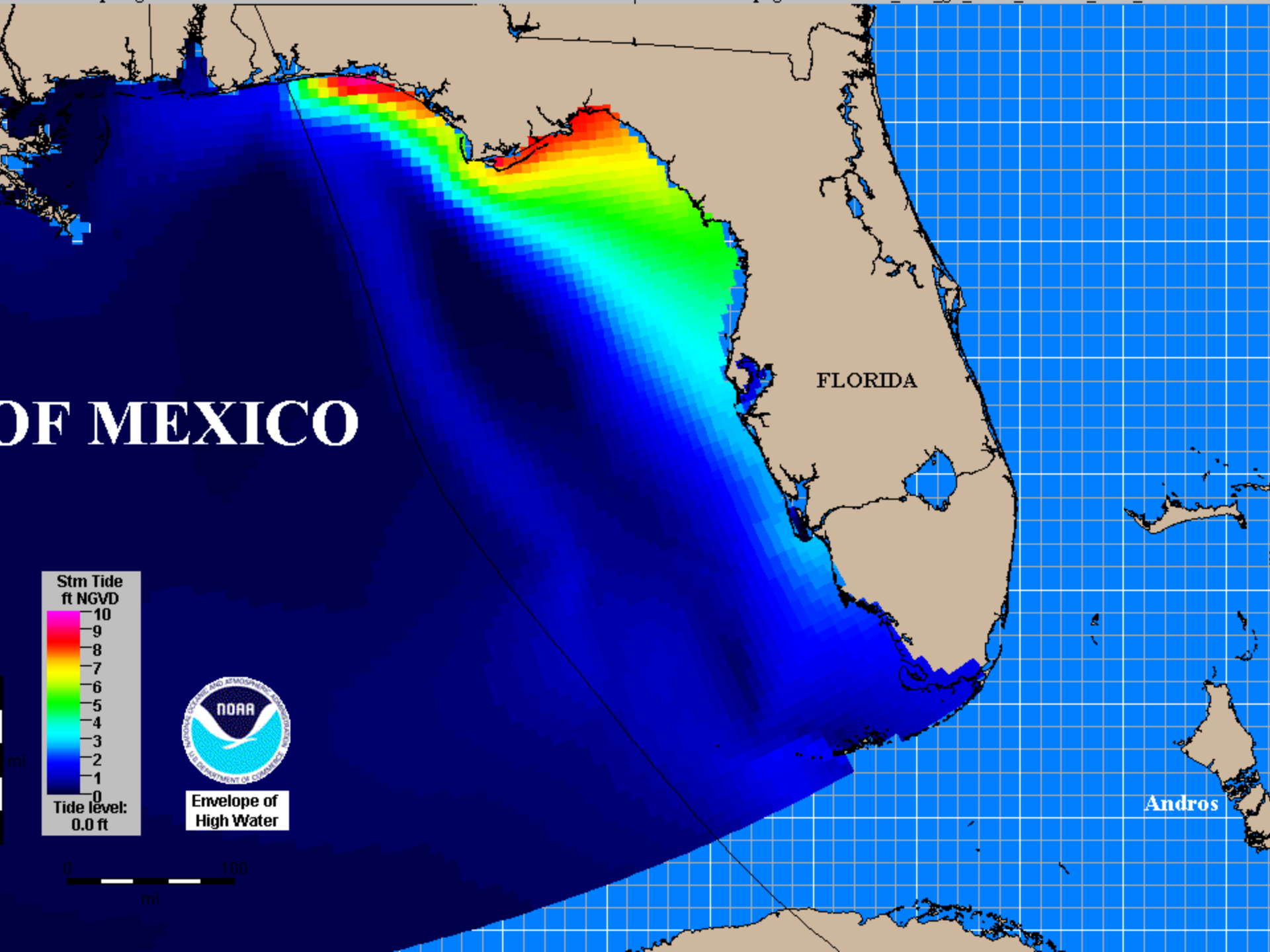


07/08/2005  
17:01:15 UTC

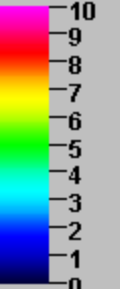




# OF MEXICO



Stm Tide  
ft NGVD



Tide level:  
0.0 ft



Envelope of  
High Water



Basin: Gulf Coast ExtraTropic <gII>

Storm: c:/slosh/pkg/data/rexfiles/d\_final\_gll\_30-10\_2rmw0.0\_in3.7\_02-01-06.rex

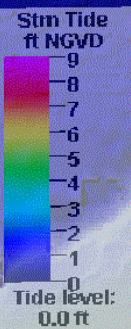
SLOSH Wind field  
1 min avg KTS(MPH)

34(39) 65(75) 100(115)

# GULF OF MEXICO



Envelope of  
High Water



8.7

8.2

6.9

5.2

3.2

FLORIDA

2.6

1.7

31N

30N

29N

28N

27N

26N

25N

Andros

23N

87W

86W

85W

84W

83W

82W

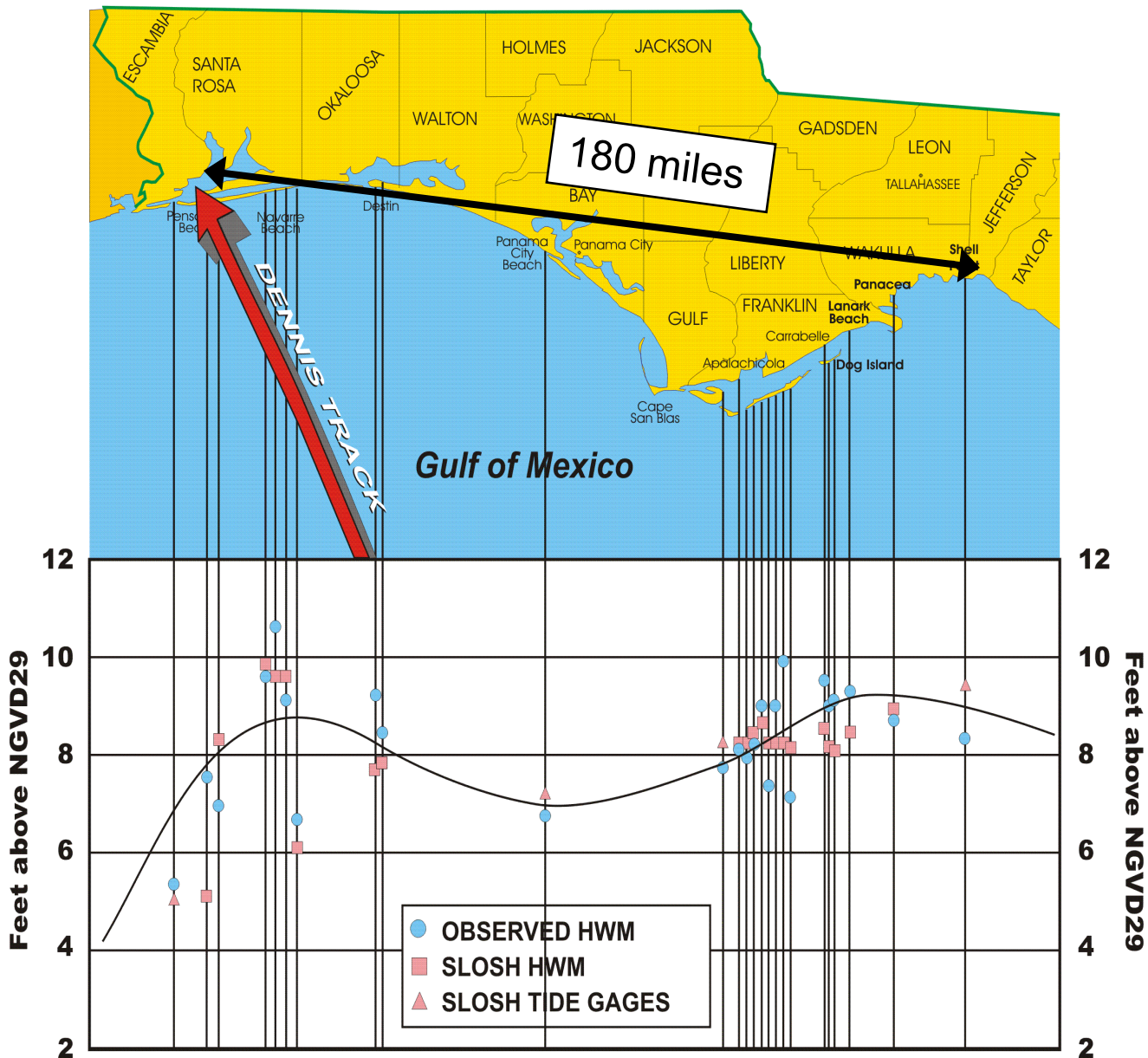
81W

80W

79W

78W

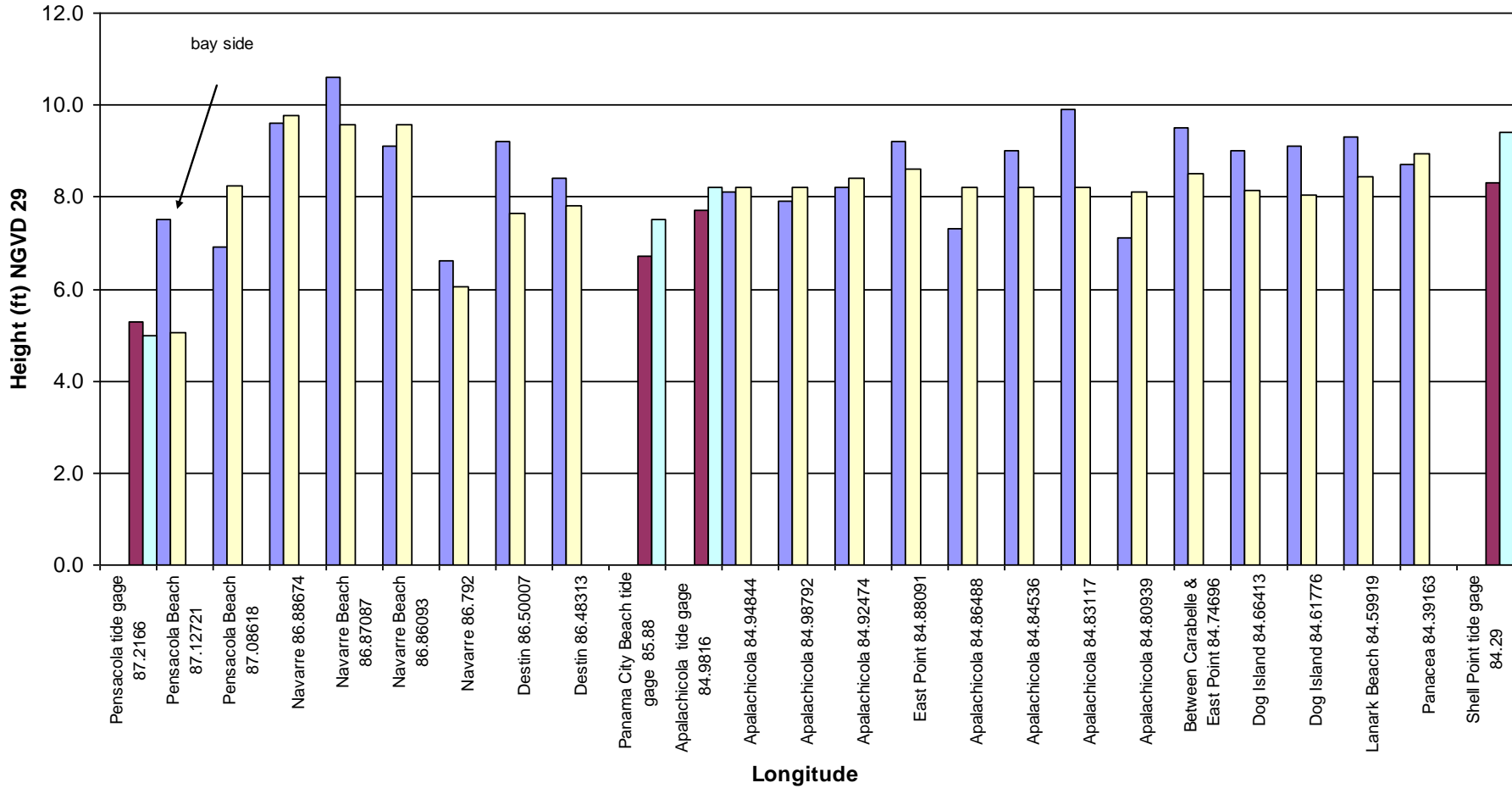
# OBSERVED VERSUS SLOSH MODEL CALCULATED SHORELINE STORM SURGE PROFILES FOR HURRICANE DENNIS (2005)



# of Observations = 25  
 Mean Error = + 0.186  
 STD Deviation = 1.07  
 Range = -2.44 to +2.31

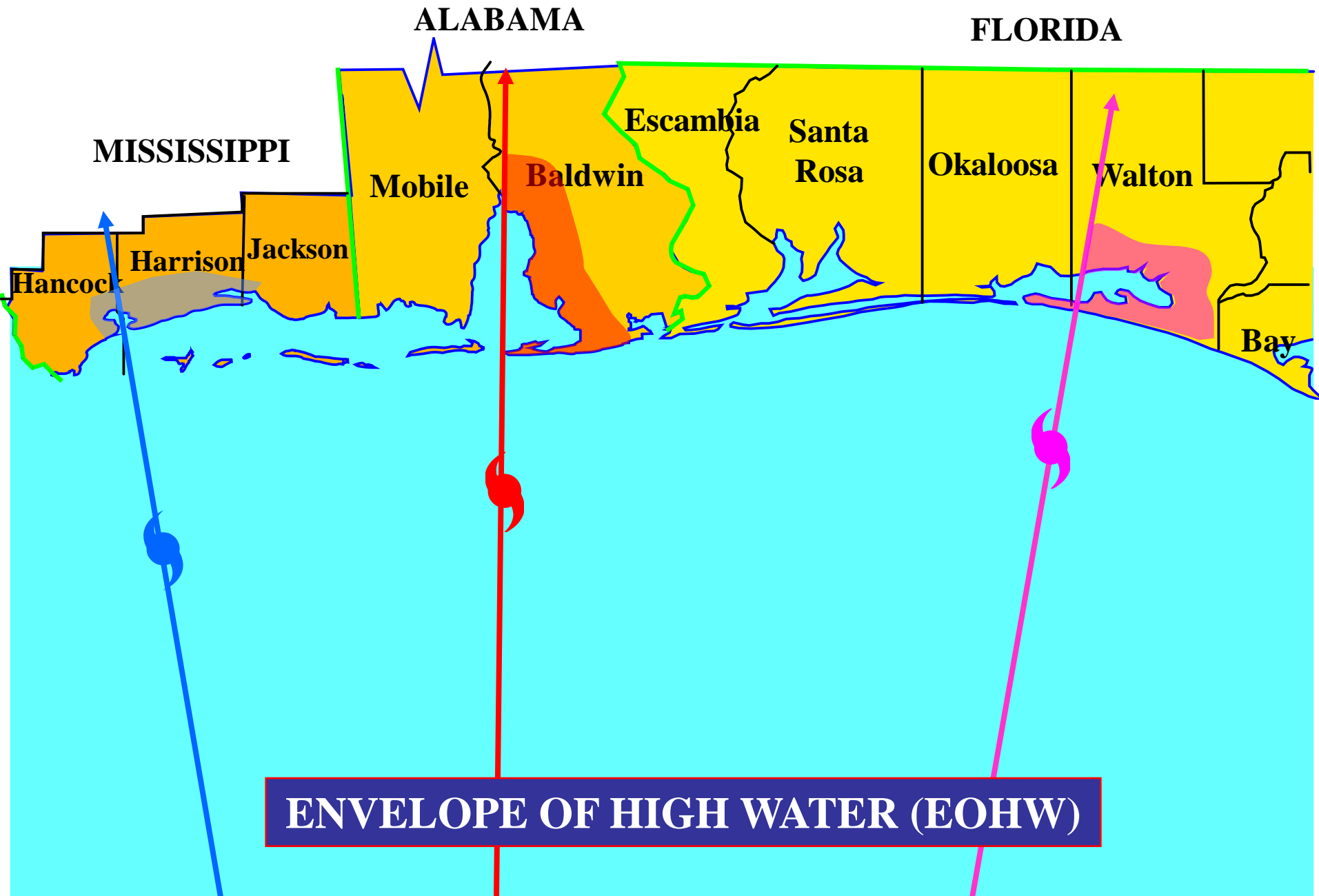
### Hurricane Dennis HWM

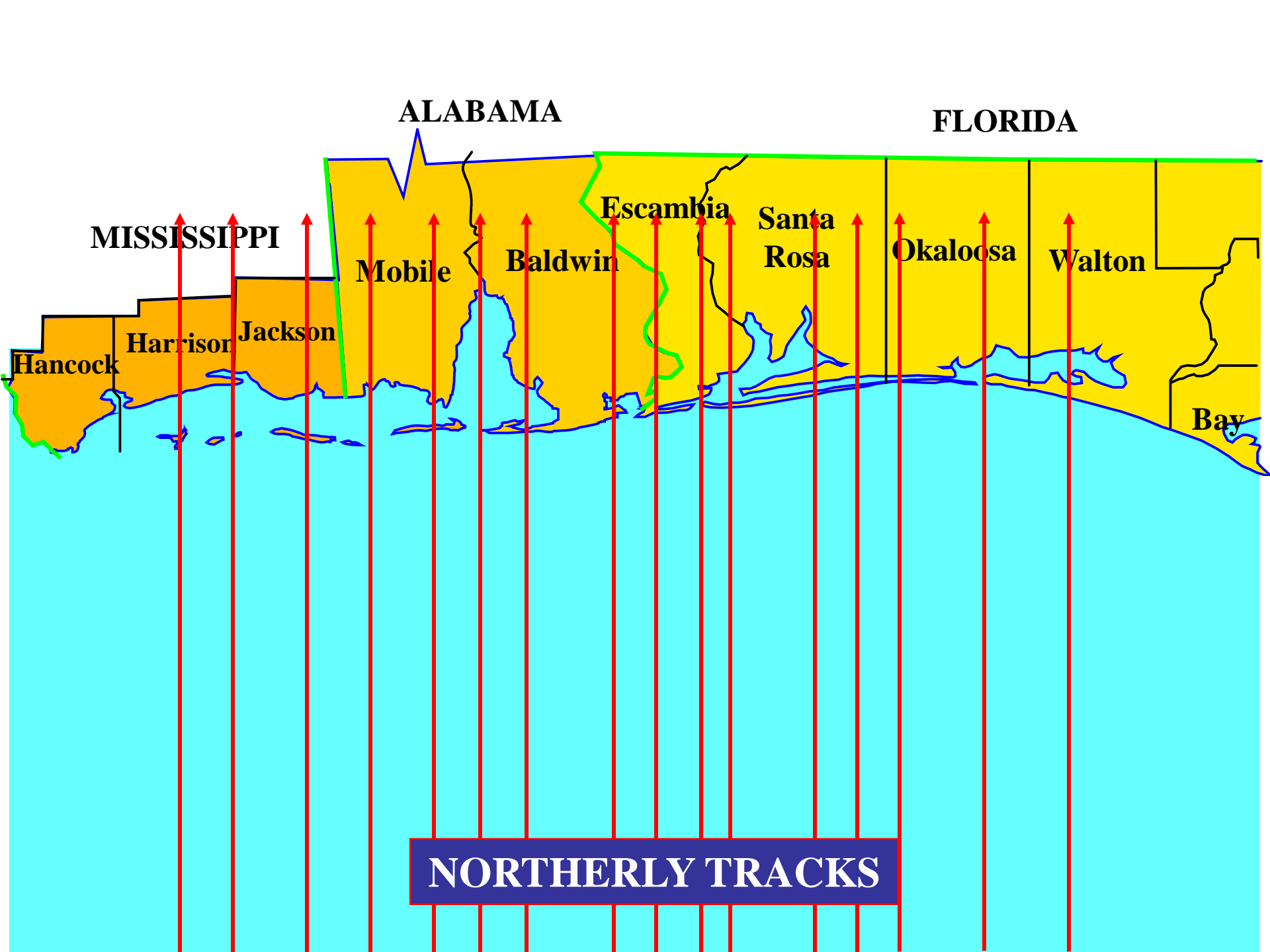
Interior HWM SLOSH Tide Gages SLOSH



If you want *better*  
storm surge forecasts –

**then you must provide *better*  
meteorological input!**





**ALABAMA**

**FLORIDA**

**MISSISSIPPI**

**Hancock**

**Harrison**

**Jackson**

**Mobile**

**Baldwin**

**Escambia**

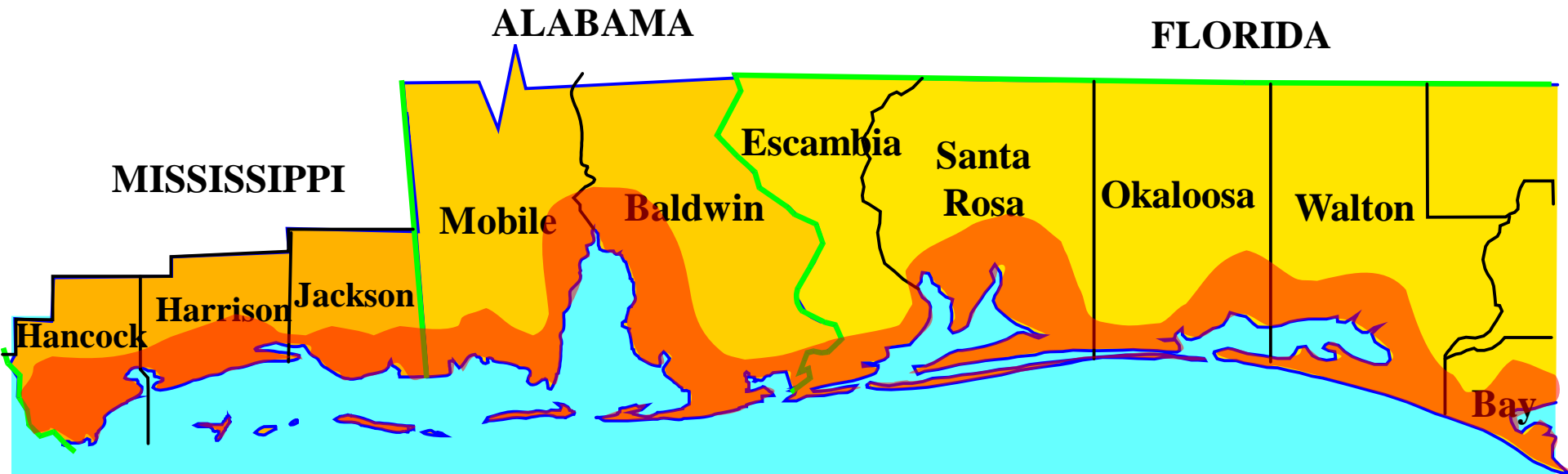
**Santa  
Rosa**

**Okaloosa**

**Walton**

**Bay**

**NORTHERLY TRACKS**



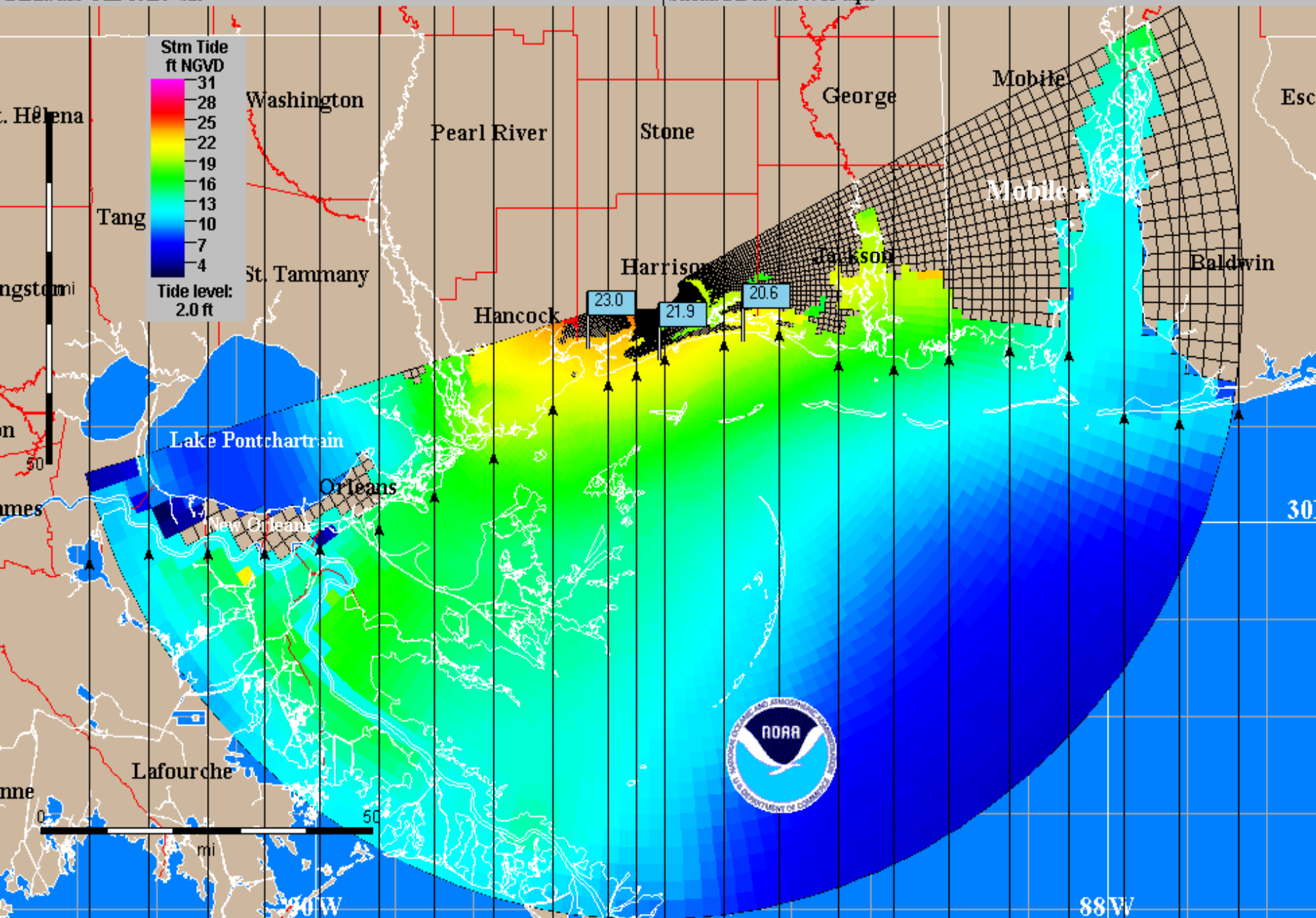
**MAXIMUM ENVELOPE OF WATER (MEOW)**



# What is a 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**
  - **Radius of Maximum Wind (RMW)**
- **Composite achieved by reviewing parallel tracks that make landfall at different locations**
- **Over 80 MEOWs have been generated for some basins**

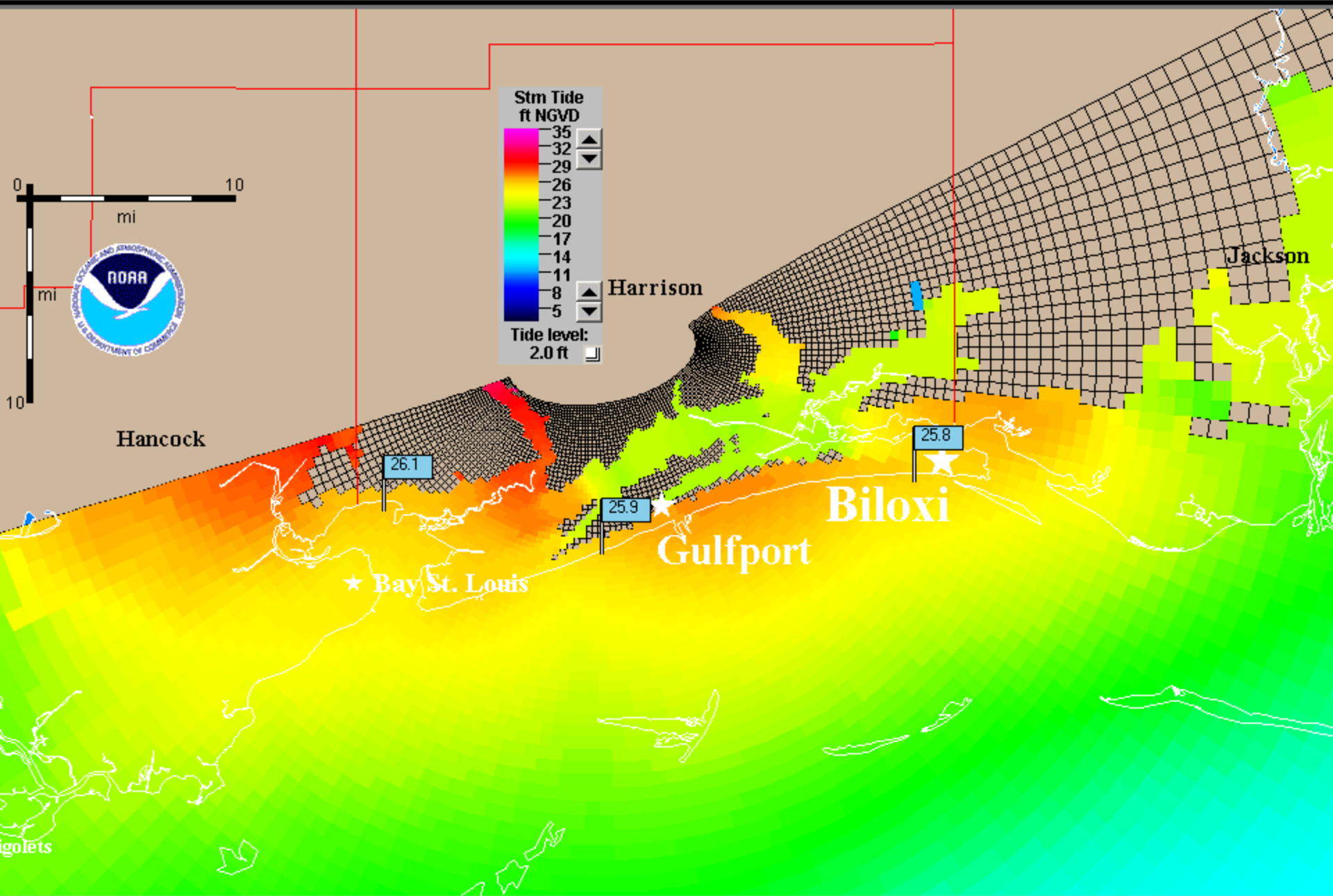


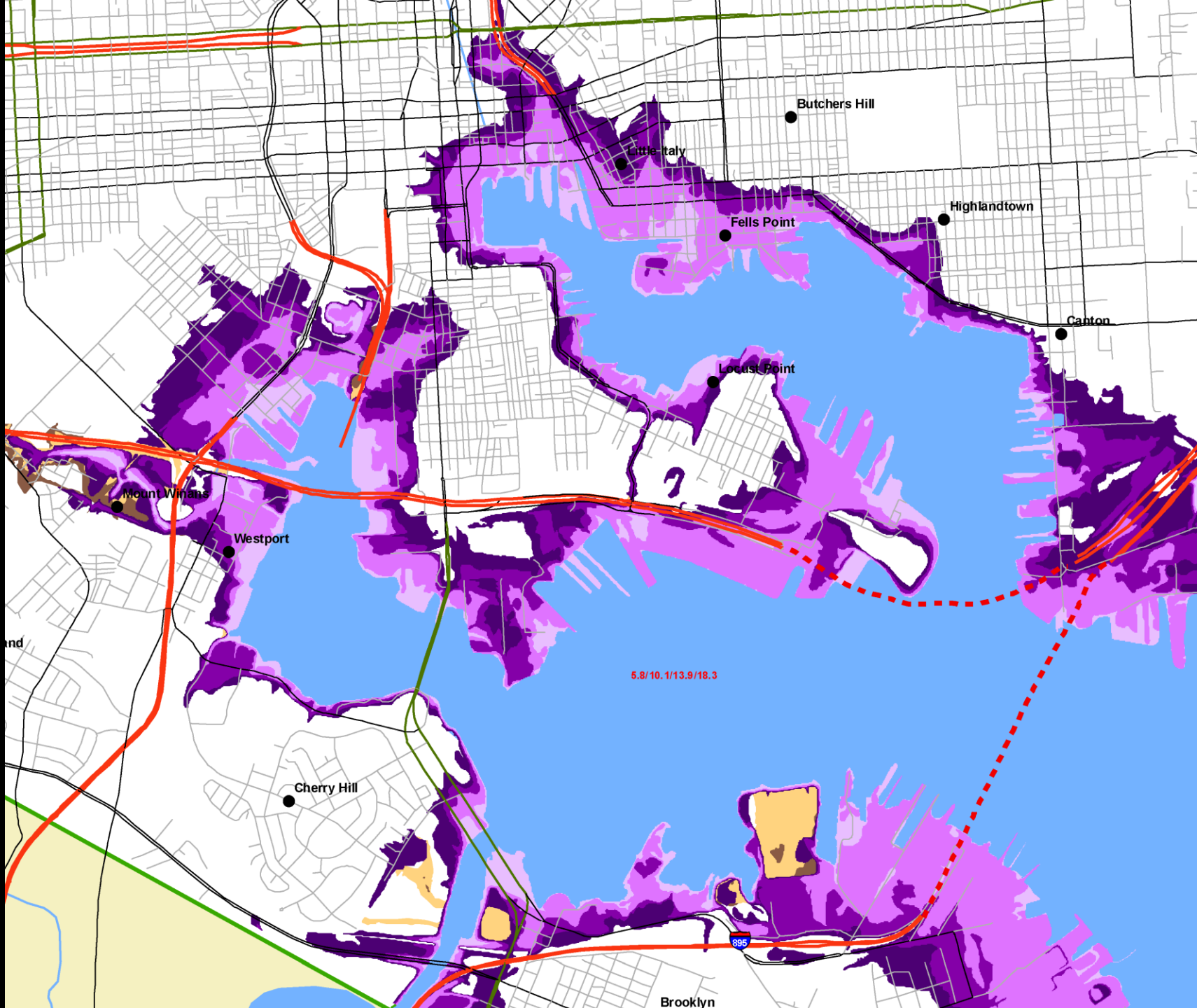


# What is a MOM?

- **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**







Butchers Hill

Little Italy

Fells Point

Highlandtown

Canton

Locust Point

Mount Winans

Westport

Cherry Hill

5.8/10.1/13.9/18.3

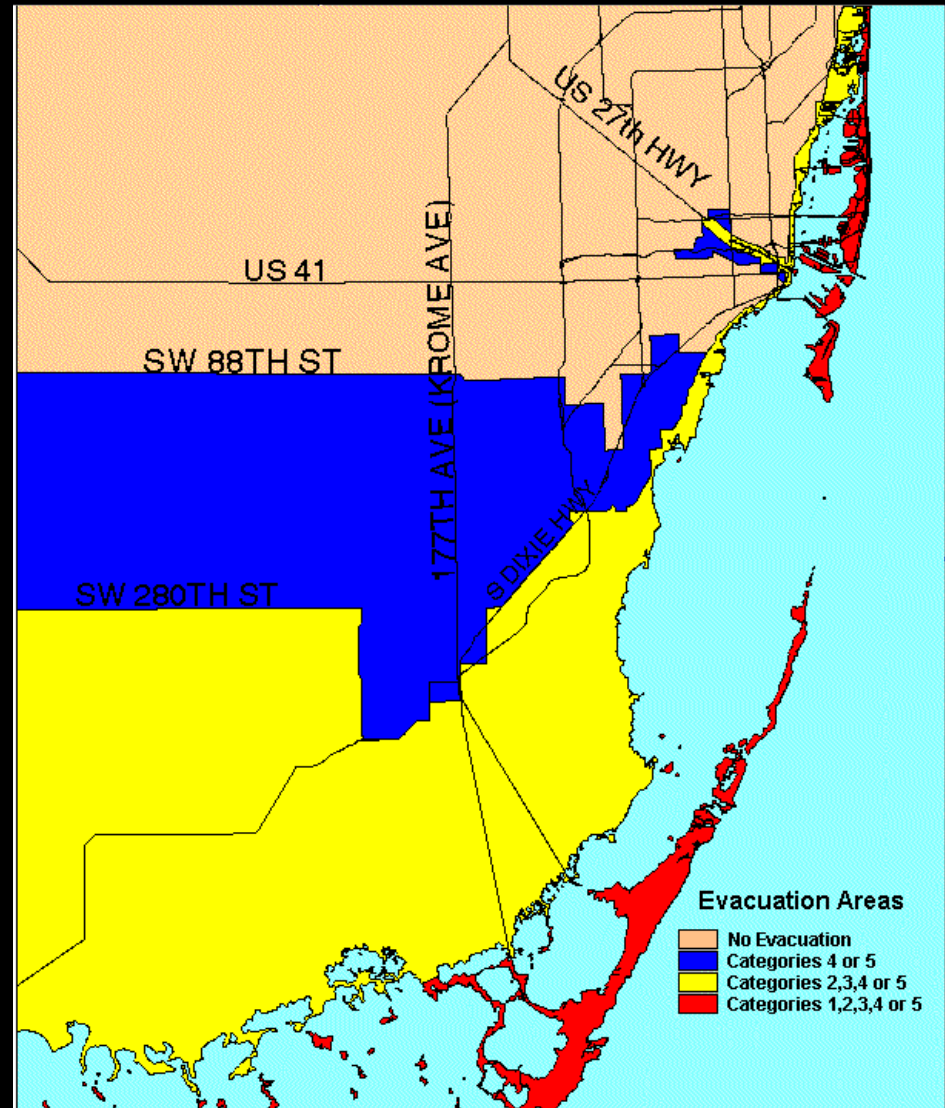
Brooklyn

895

# Evacuation Zones

**1. Delineated  
by  
major  
geographic  
features**

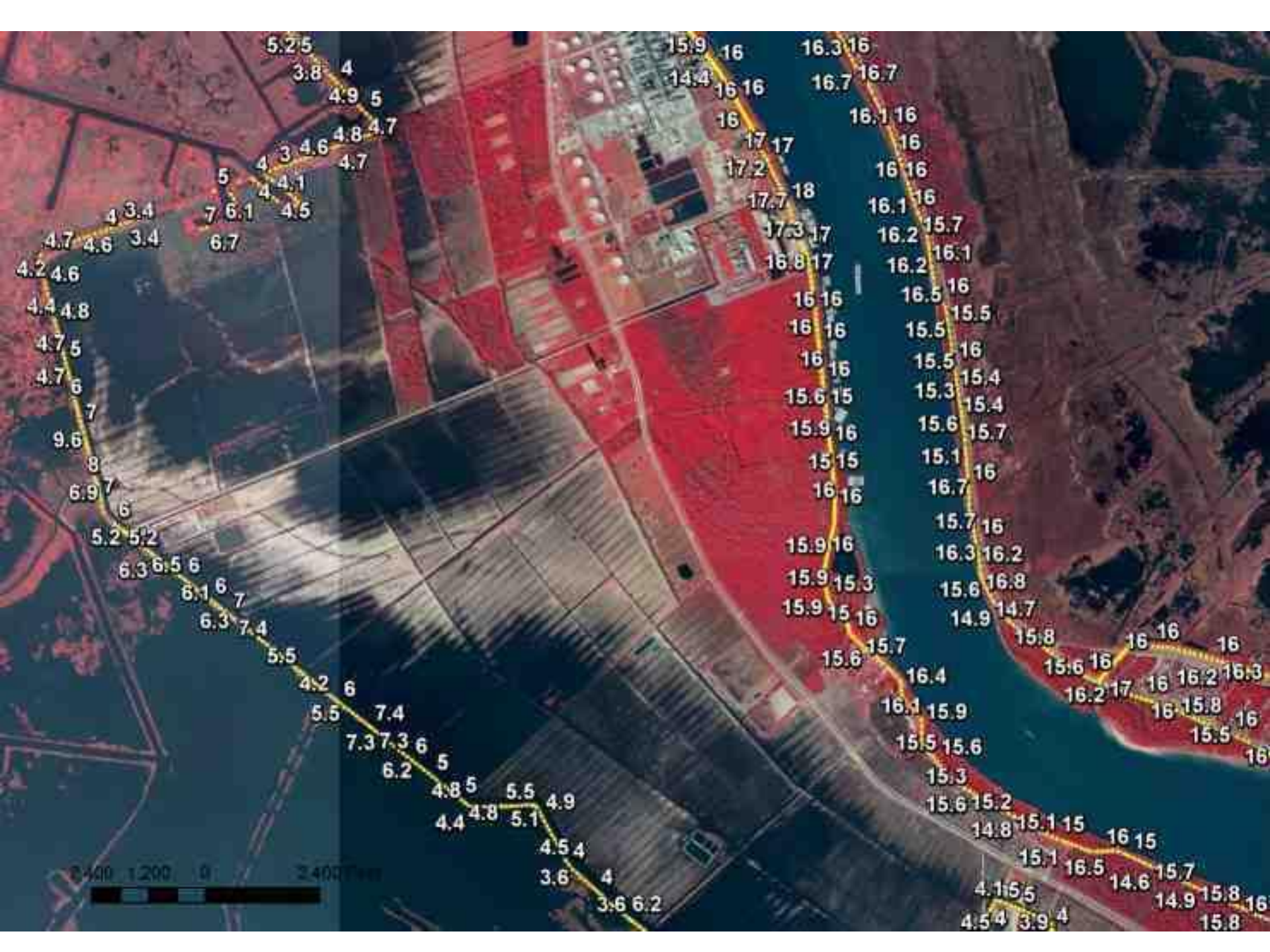
**2. Conform  
to existing  
political  
or  
demographic  
boundaries**





# Hurricane Evacuation Studies





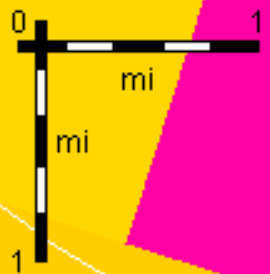




11.9

11.2

12.1



What is the risk?

SLOSH accurately calculates storm surge.

MEOW's and MOM's  
remove storm surge  
as a risk!

The risk is

**uncertainty  
of  
exposure!**

- risk identification
- risk measurement
- risk reduction
- risk management