

An aerial photograph capturing the aftermath of Hurricane Ike. A major road, likely a highway, runs diagonally from the top left towards the bottom right. A significant section of this road is submerged under a large volume of brown, turbid water, indicating a major breach or flooding. To the left of the flooded section, a two-story house with a blue roof and white trim stands isolated, surrounded by water. The surrounding landscape is a mix of sandy soil, scattered debris, and some remaining vegetation like palm trees. In the background, the ocean is visible with white-capped waves breaking against a shoreline. The overall scene depicts extensive coastal flooding and infrastructure damage.

**HURRICANE IKE**  
**STORM SURGE**

# Storm Surge

- The Greatest Potential for loss of life in a hurricane.
- Historically, storm surge claims 9 of 10 victims in a hurricane.
- Over 1500 people lost their lives in Hurricane Katrina...mostly due to Storm Surge.
- Over 8000 people died in the 1900 Storm mainly due to the Storm Surge.

# DEFINITIONS:

***STORM SURGE*** is the increase in water level due to a storm (hurricane / tropical storm / high winds).

***STORM TIDE*** is the total water level, relative to a reference datum, during a storm

$$\begin{aligned} &= \text{Astro Tide} + \text{STORM SURGE} \\ &+ \text{Rainfall Runoff} + \text{Anomaly} \end{aligned}$$

# Saffir-Simpson Intensity Scale

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Expresses hurricane in terms of wind speed and potential damage—Major Hurricanes CAT 3-5

<i>Cat.</i>	<i>Pressure</i>	<i>Winds</i>	<i>Surge</i>	<i>Bay Surge</i>	<i>Damage</i>	<i>Storm Examples</i>
1	980 +	74 - 95	4 - 5	4 - 7	Minimal	Jerry 1989 Claudette 2003
2	965 – 979	96 - 110	6 – 8	8 – 12	Moderate	Ike 2008
3	945 – 964	111 - 130	9 – 12	13 – 18	Extensive	Alicia 1983 Katrina 2005 Rita 2005
4	920 – 944	131 - 155	13 – 18	19 – 24	Extreme	1900 - Galveston Carla 1961
5	< 920	> 156	18 +	24 +	Catastrophic	Labor Day 1935 Camille 1969 Andrew 1992

The background is a monochromatic blue with a grainy, textured appearance, resembling a close-up of a surface or a satellite image. A small, dark, circular spot is centered in the lower half of the frame. The text 'GENERALIZATIONS:' is overlaid in the upper left quadrant in a bright yellow, sans-serif font.

GENERALIZATIONS:

# GENERALIZATIONS:

**The higher the hurricane's category, the higher the storm surge.**



## GENERALIZATIONS:

**Maximum storm surge occurs to the right of the storm track, roughly at the radius of max winds.**



# GENERALIZATIONS:

**Landfall direction affects storm surge height.**



# GENERALIZATIONS:

**Faster-moving hurricanes cause higher surges AT THE COASTLINE than do slower-moving hurricanes.**

# GENERALIZATIONS:

**For areas with gentle slopes of the continental shelf, storm surge is large but waves are small.**

# GENERALIZATIONS:

**Areas with deep water just offshore experience large waves, but little storm surge.**

# GENERALIZATIONS:

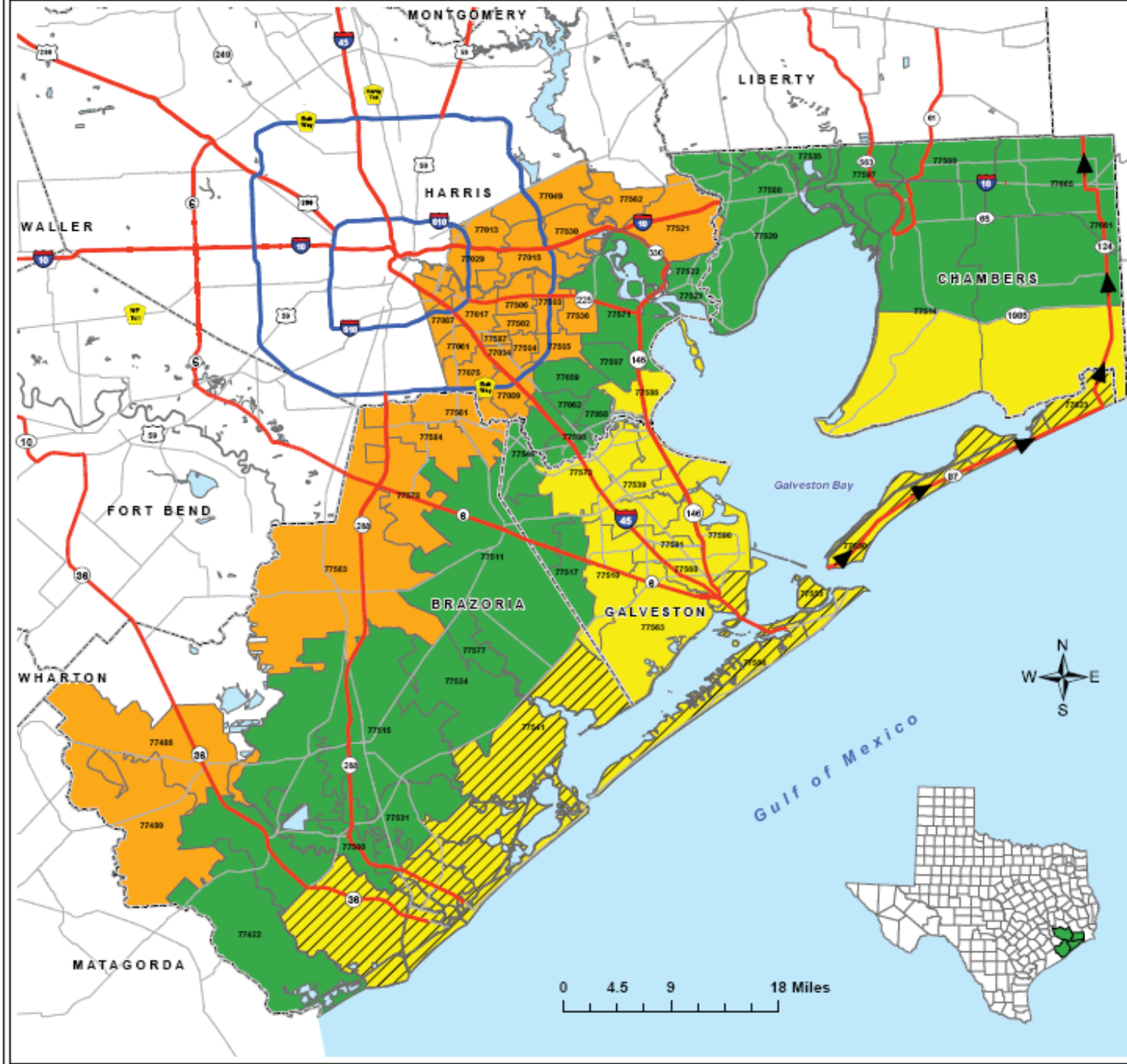
**Very small, compact hurricanes cause less storm surge than do large-sized hurricanes.**

(Charlie, 2004)

**Larger storms impact more coastline and produce larger storm surge.**

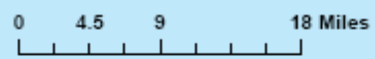
(Katrina, 2005...Carla, 1961...Ike, 2008)

# Brazoria, Chambers, Galveston and Harris Hurricane Evacuation Zip-Zones Coastal A, B, C



Zip-Zone A				
77541	77550	77554	77517	77550
77523	77551			
Zip-Zone B				
77510	77565	77539	77539	77591
77563	77586	77568	77573	
77514s	77518			
Zip-Zone C				
77011	77012	77013	77015	77017
77023	77029	77034	77049	77061
77075	77087	77089	77463	77480
77486	77502	77503	77504	77505
77506	77521	77530	77536	77547
77562	77578	77580	77581	77583
77584	77587			

- ### Route Designation
- Evacuation Corridors
  - Evacuation Connections
  - Other Roads
  - County Boundary



Expiration Date June 2009  
 Map Created by:  
 Houston-Galveston Area Council

# Sea, Lake, and Overland Surges from Hurricanes

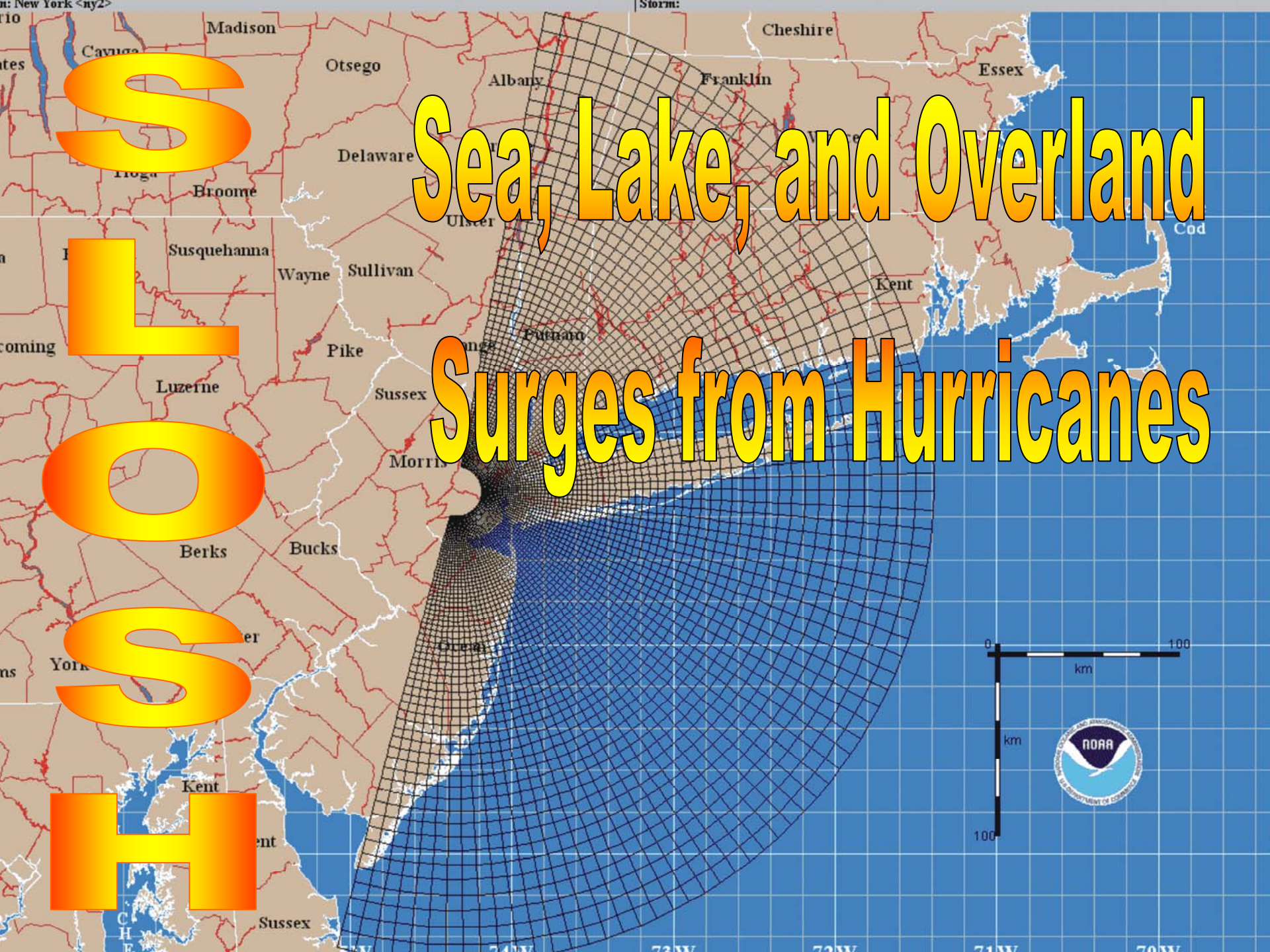
S

L

O

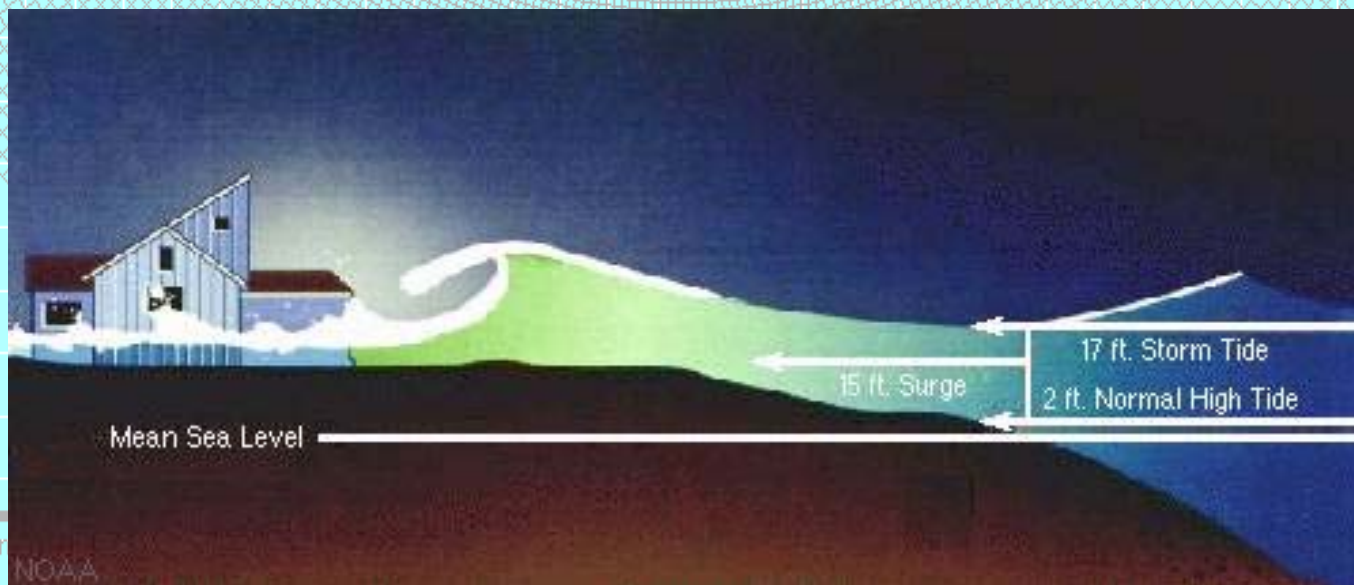
S

H



# What is 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.**



Source: [http://www.nhc.noaa.gov/HAW2/english/storm\\_surge.shtml](http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml)

# The SLOSH Model

- Accuracy - generally within  $\pm 20\%$  of peak storm surge
- Accounts for astronomical tides
- Does not include rainfall amounts, river flow, or wind-driven waves

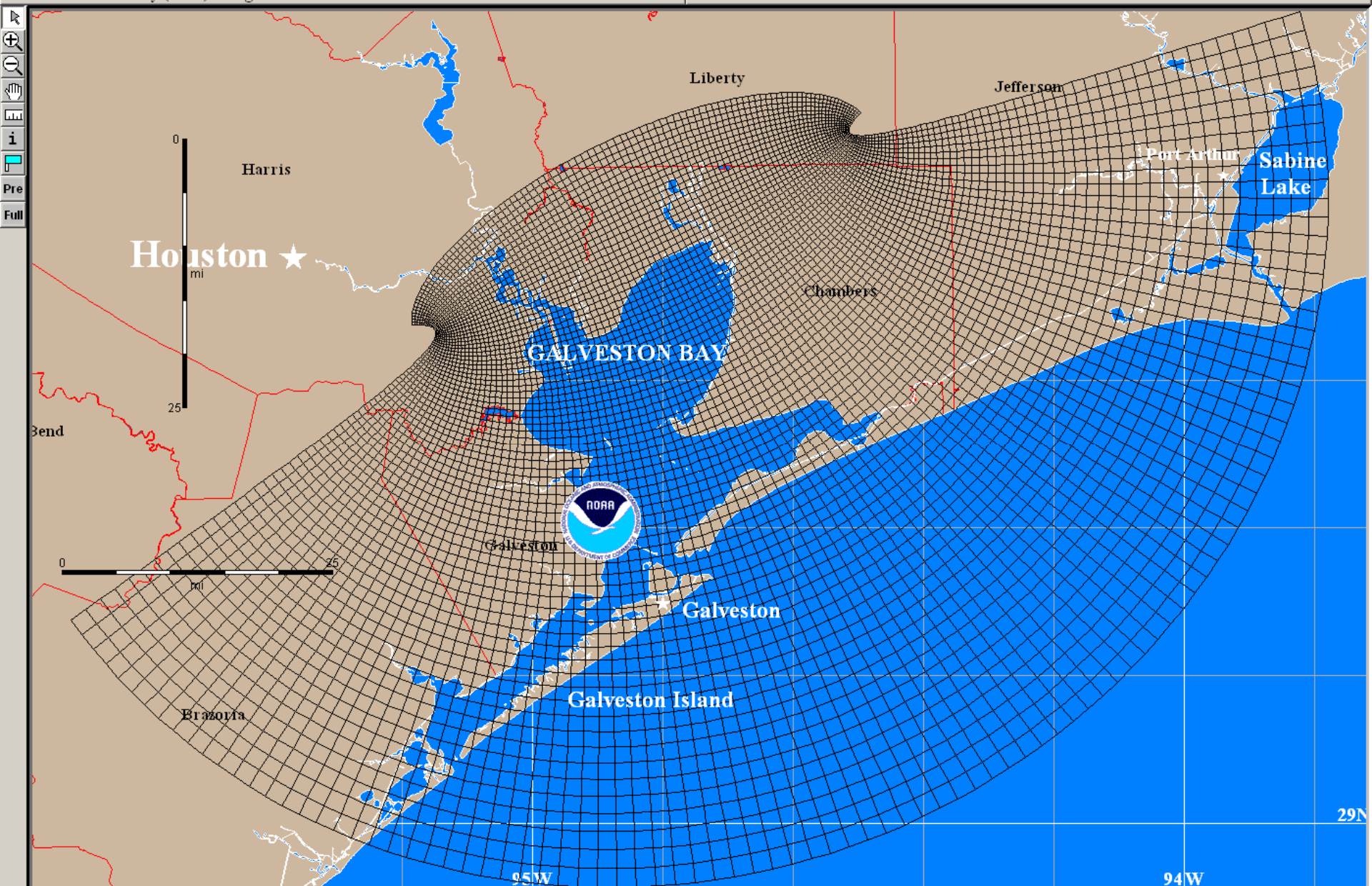




# SLOSH: Purposes

- **Determining the potential surge for a location**
- **Basis for “hazard analysis” portion of coastal hurricane evacuation plans**





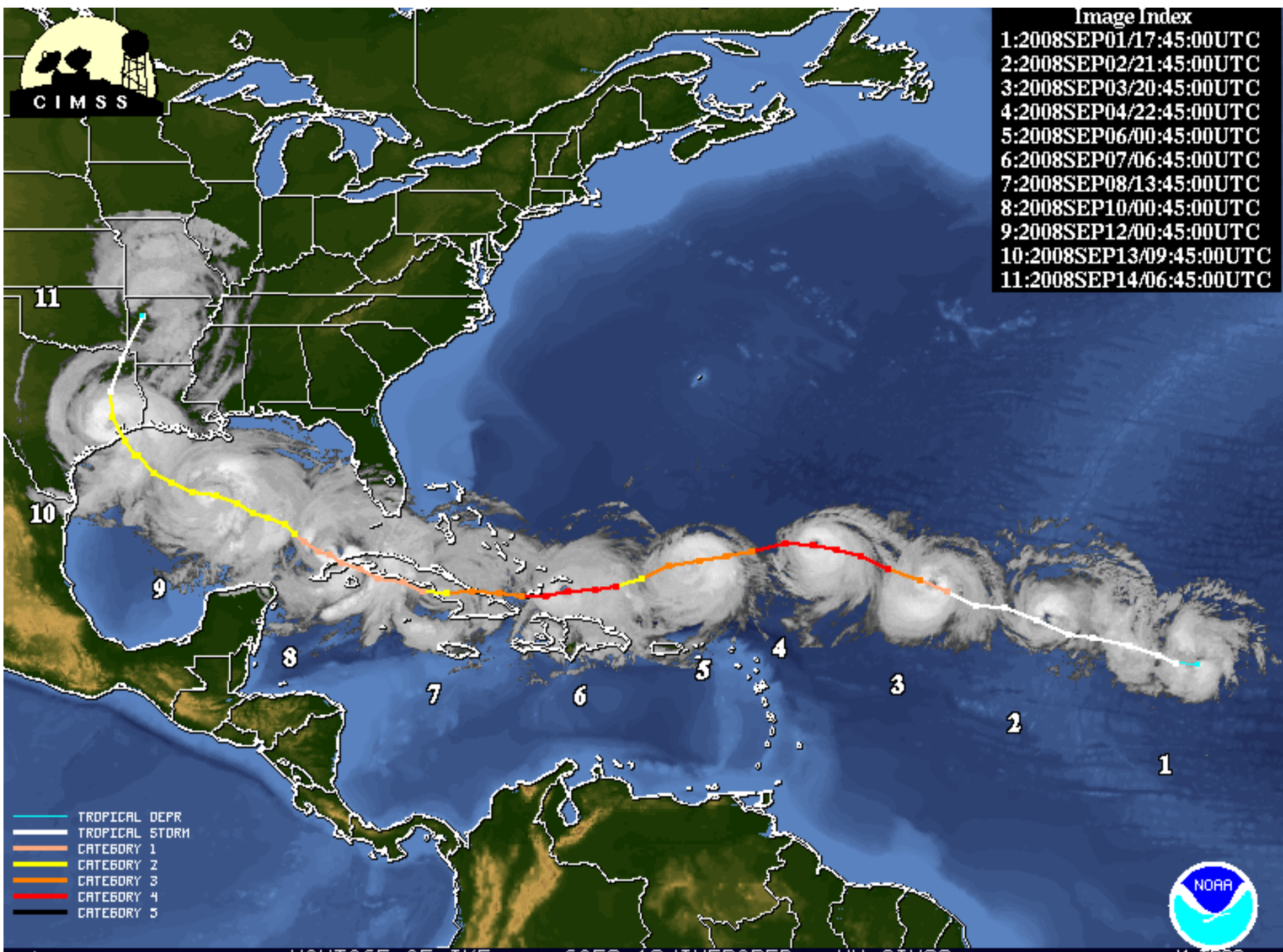
# How does NWS use SLOSH?

- Simulation Studies to support evacuation planning. SLOSH defines the “potential flooding” by category
- Operational runs for a threatening hurricane
- (Experimental) Probabilistic storm surge forecasts



**Image Index**

- 1:2008SEP01/17:45:00UTC
- 2:2008SEP02/21:45:00UTC
- 3:2008SEP03/20:45:00UTC
- 4:2008SEP04/22:45:00UTC
- 5:2008SEP06/00:45:00UTC
- 6:2008SEP07/06:45:00UTC
- 7:2008SEP08/13:45:00UTC
- 8:2008SEP10/00:45:00UTC
- 9:2008SEP12/00:45:00UTC
- 10:2008SEP13/09:45:00UTC
- 11:2008SEP14/06:45:00UTC



- TROPICAL DEPR
- TROPICAL STORM
- CATEGORY 1
- CATEGORY 2
- CATEGORY 3
- CATEGORY 4
- CATEGORY 5



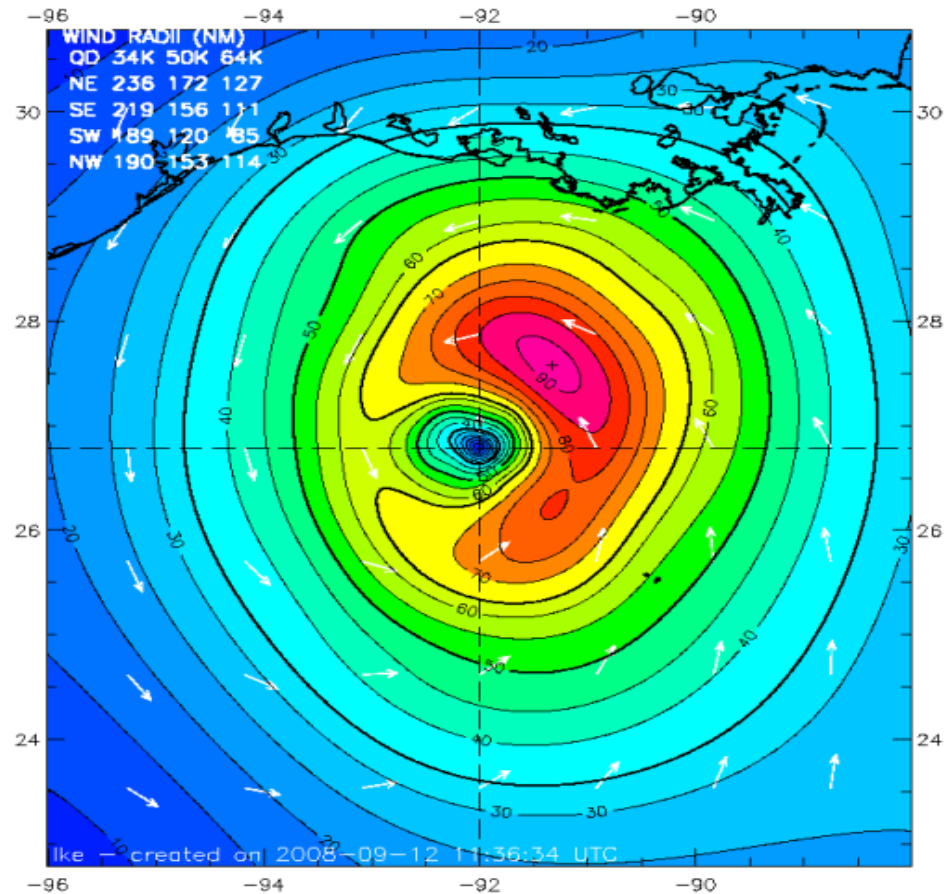
# Hurricane Ike 1030 UTC 12 SEP 2008

Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

Analysis based on GPSSONDE\_WL150 from 0612 - 0844 z; ASOS from 0536 - 1119 z; GPSSONDE\_SFC from 0612 - 0844 z;  
BACKGROUND\_FIELD from 1030 - 1030 z;  
SHIP from 0600 - 1100 z; CMAN from 0539 - 1059 z;  
DRIFTING\_BUOY from 0530 - 0950 z; MOORED\_BUOY from 0530 - 1115 z;  
GOES\_SWIR from 0702 - 1002 z; SFMR\_AFRC from 0227 - 1122 z;

1030 z position extrapolated from 0828 z Vortex wind center using 290 deg @ 12 kts; mslp = 953.0 mb



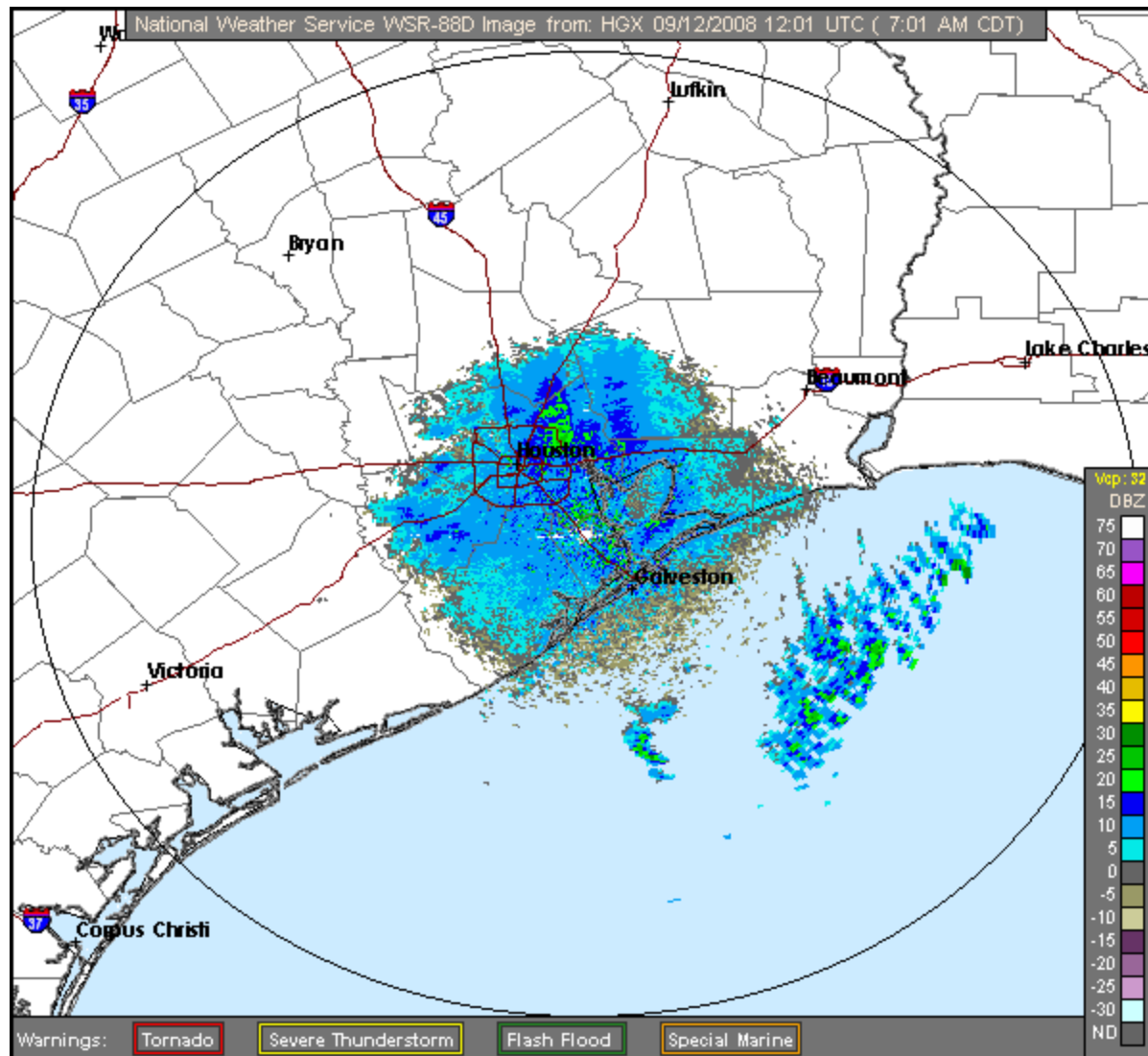
Integrated Kinetic Energy: for Winds > TS force: 157 TJ, for Winds > Hurricane Force: 63 TJ  
Destructive Potential Rating(0-6) Wind: 3.5, Surge/Waves: 5.4

Observed Max. Surface Wind: 92 kts, 63 nm NE of center based on 1030 z BACKGROUND\_FIELD  
Analyzed Max. Wind: 92 kts, 62 nm NE of center

Uncertainty -> mean wind speed error: 2.25 kt, mean direction error: -0.21 deg  
rms wind speed error: 5.18 kt, rms direction error: 5.55 deg

Experimental research product of [NOAA / AOML / Hurricane Research Division](#)

# Radar loop for Ike





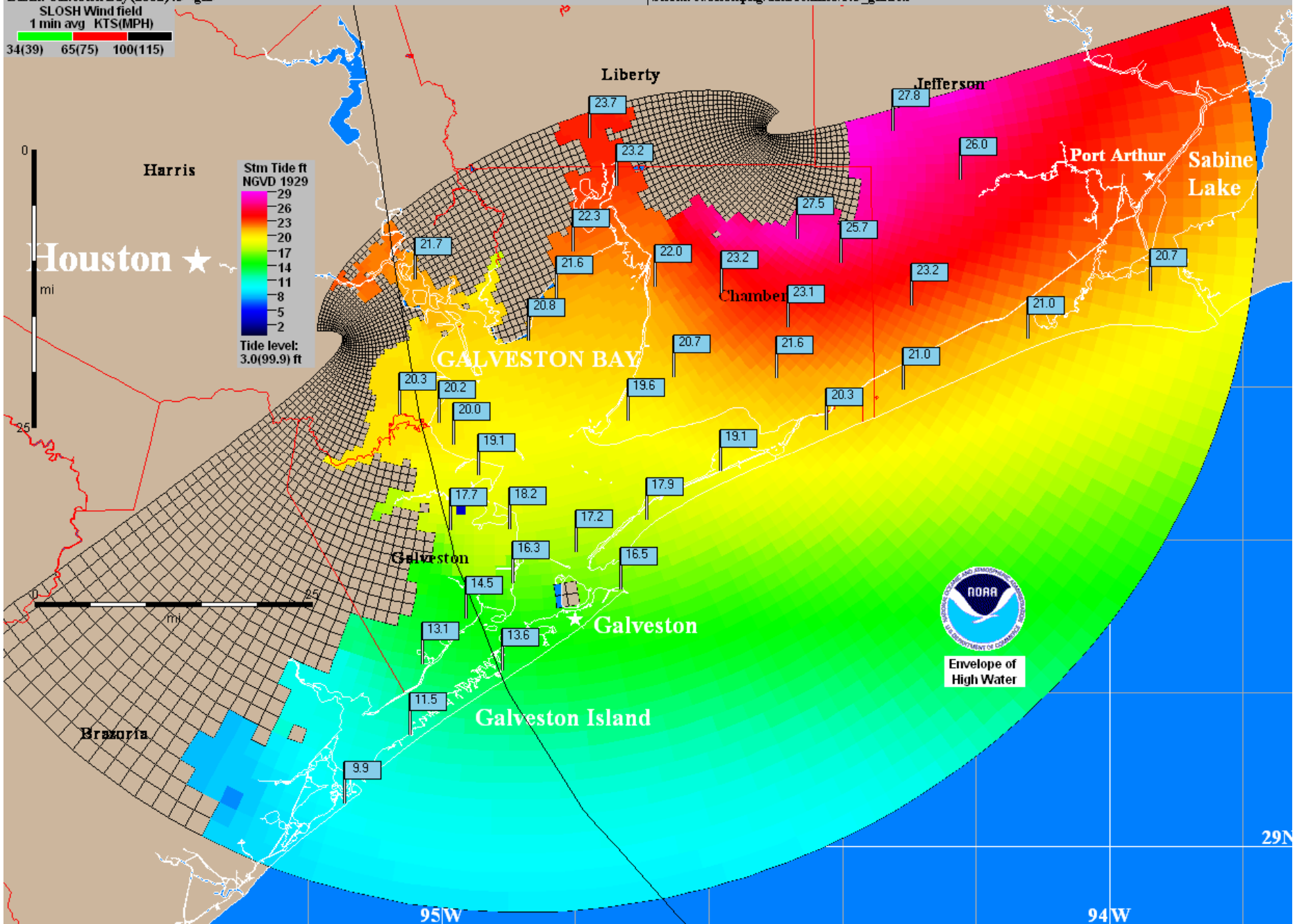
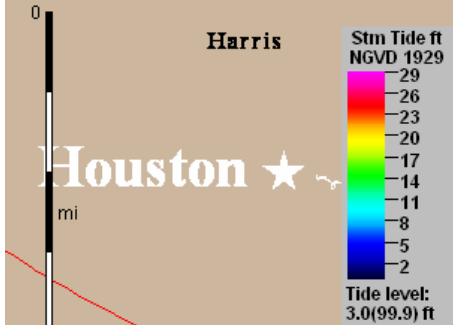
# Real-time SLOSH Runs Start to Become Available

Basin: Galveston Bay (2002)v3 <g12>

Storm: c:/slosh/pkg/data/rexfiles/i43\_g12.rex

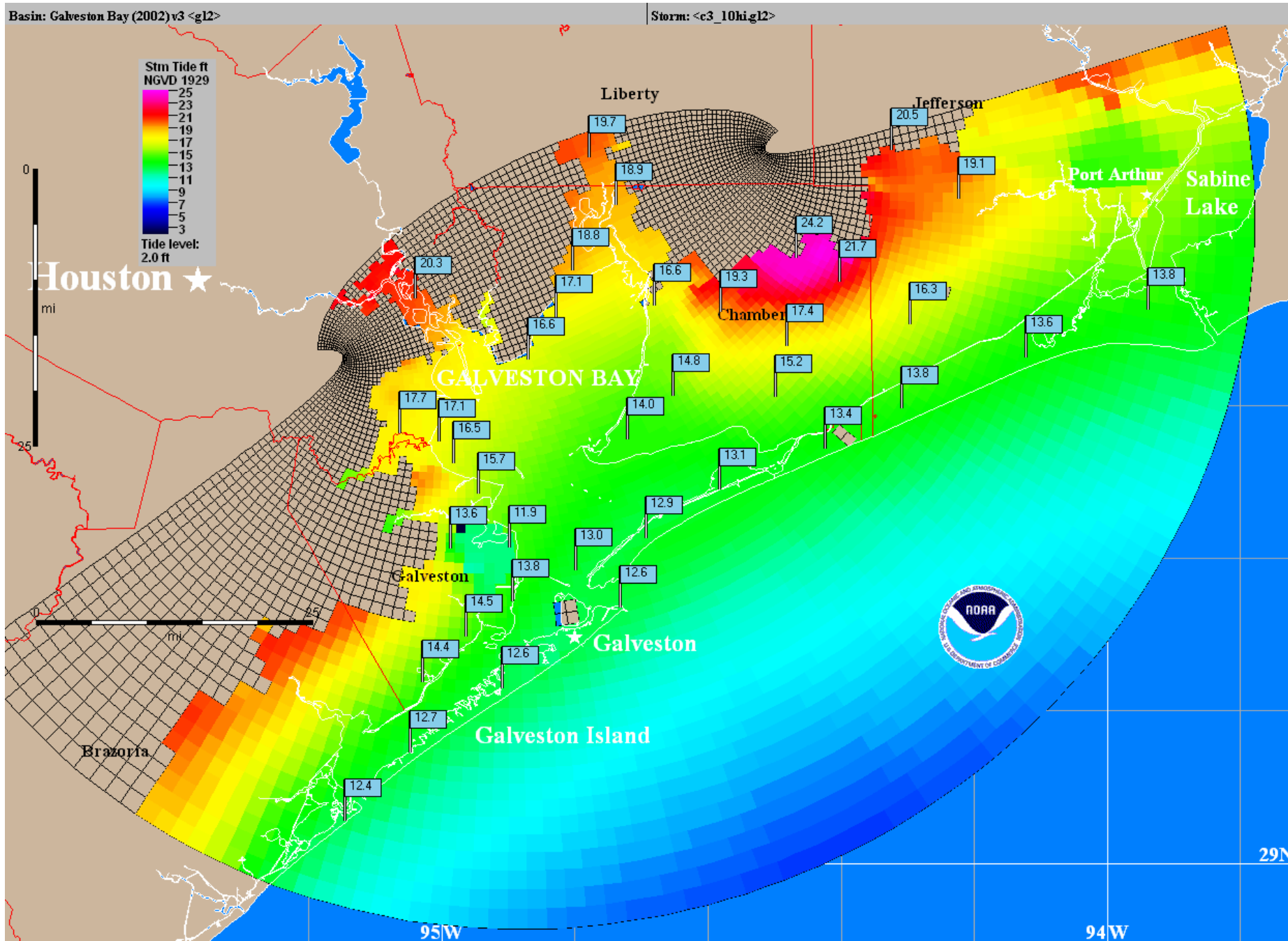
SLOSH Wind field  
1 min avg KTS(MPH)

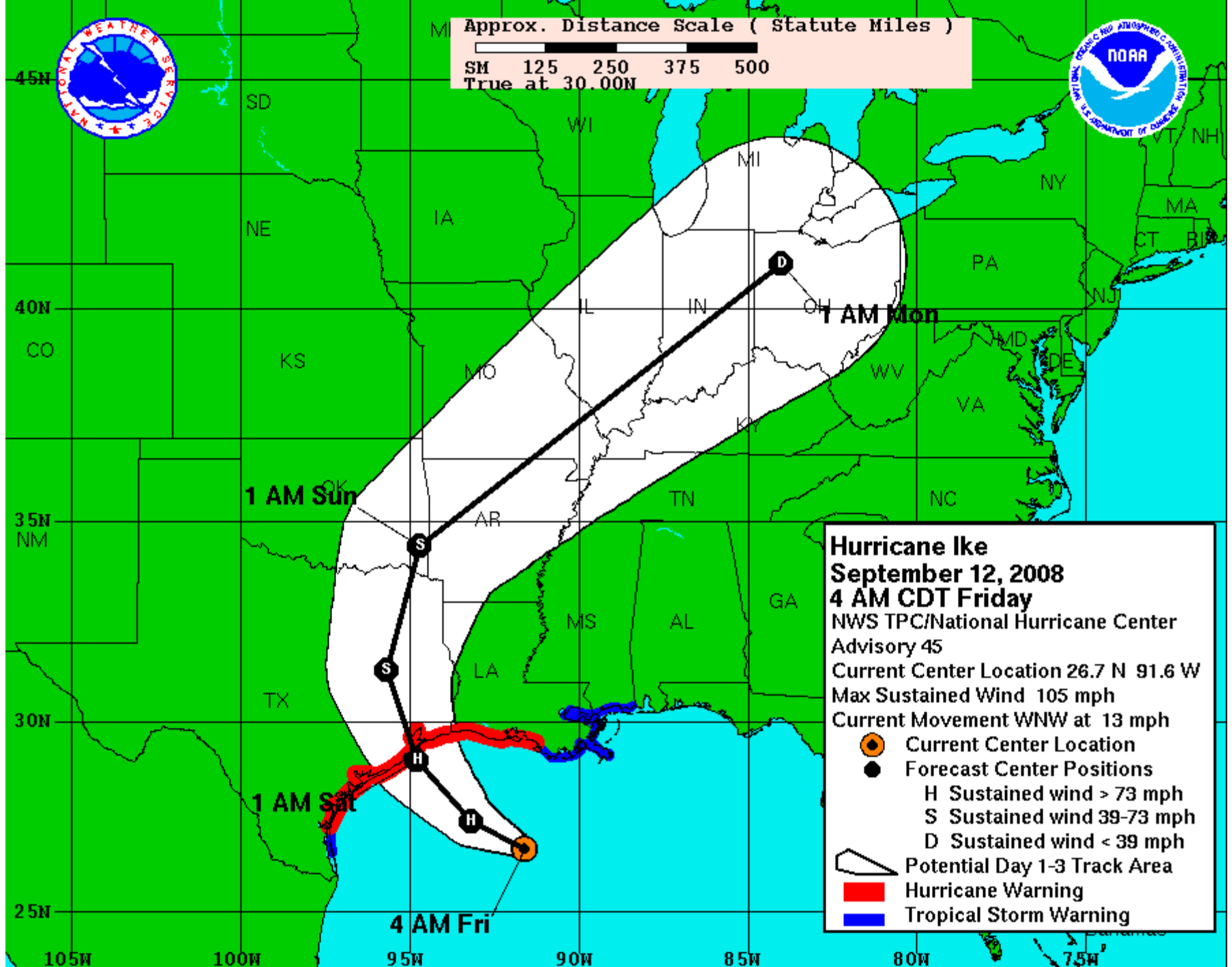
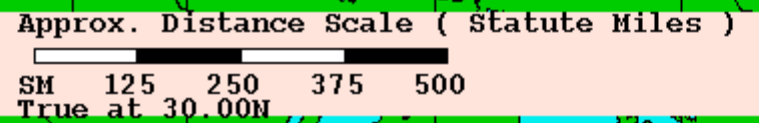
34(39) 65(75) 100(115)





# Real-time runs exceeded Cat 3 MOM 10 mph High Tide





**Hurricane Ike**  
**September 12, 2008**  
**4 AM CDT Friday**  
 NWS TPC/National Hurricane Center  
 Advisory 45  
 Current Center Location 26.7 N 91.6 W  
 Max Sustained Wind 105 mph  
 Current Movement WNW at 13 mph

- Current Center Location
- Forecast Center Positions
  - H Sustained wind > 73 mph
  - S Sustained wind 39-73 mph
  - D Sustained wind < 39 mph
- Potential Day 1-3 Track Area
- Hurricane Warning
- Tropical Storm Warning

1 AM Sun

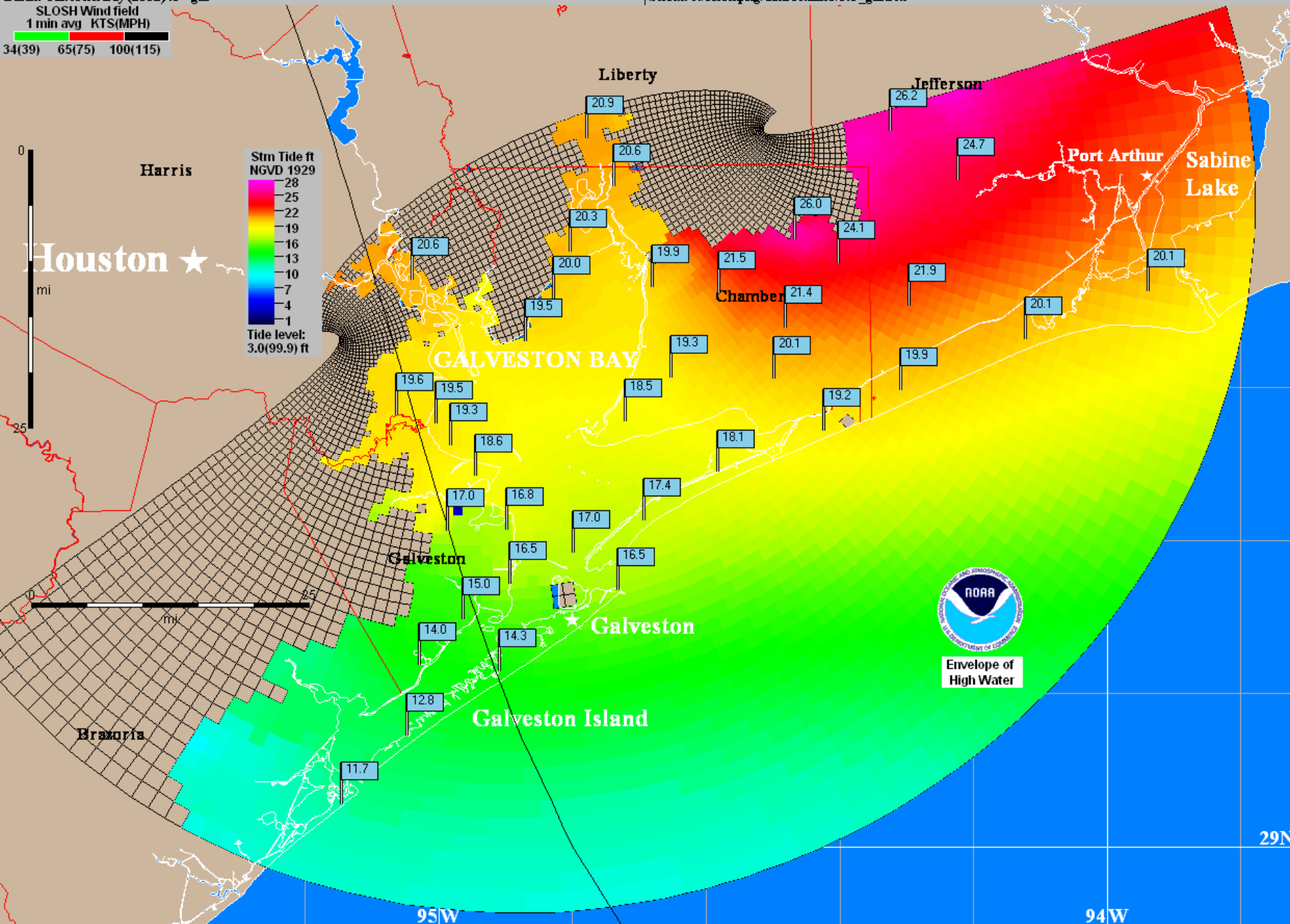
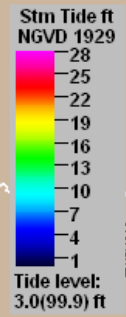
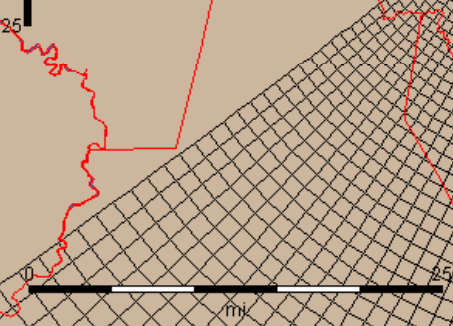
1 AM Mon

1 AM Sat

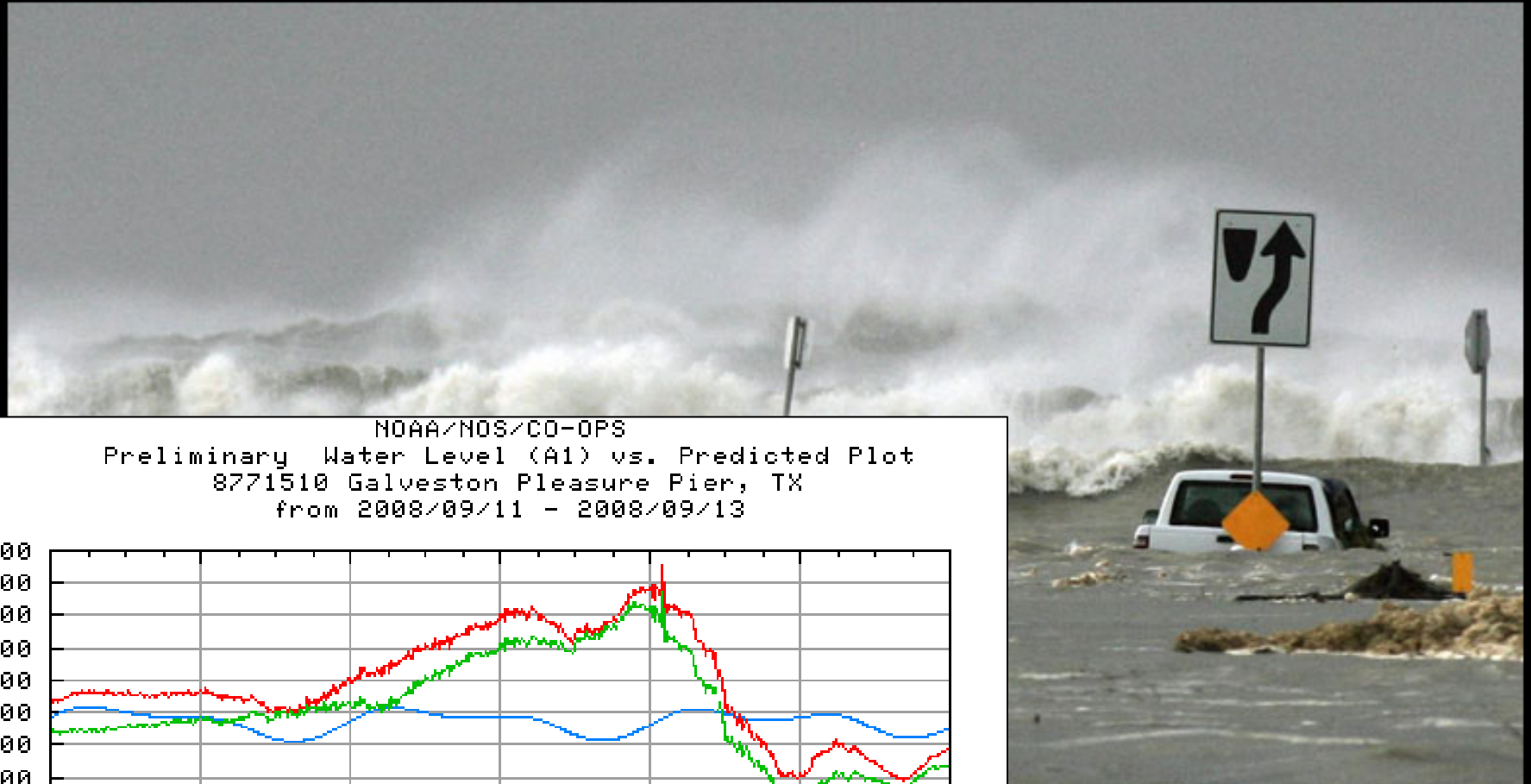
4 AM Fri

45N  
40N  
35N  
30N  
25N

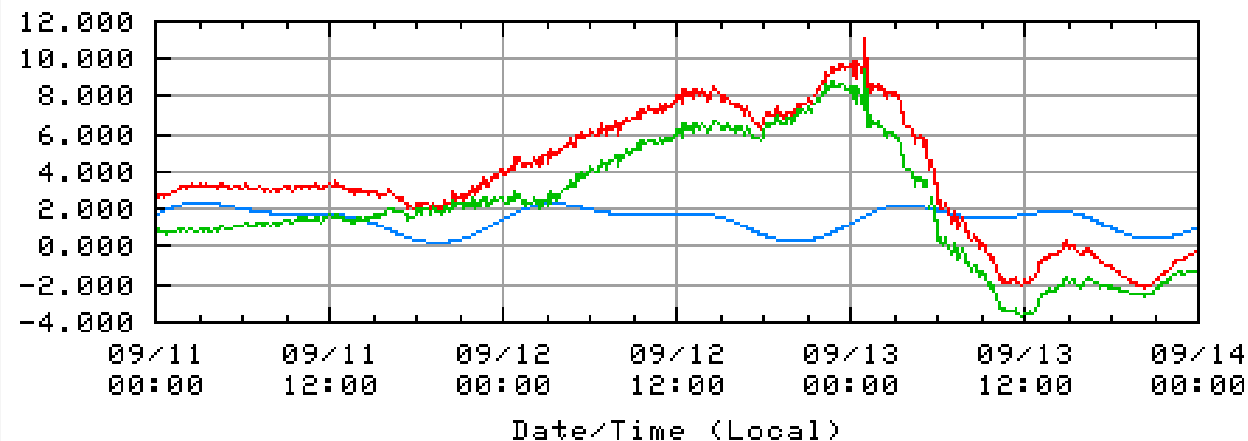
105W 100W 95W 90W 85W 80W 75W



# Friday morning: Its too late!








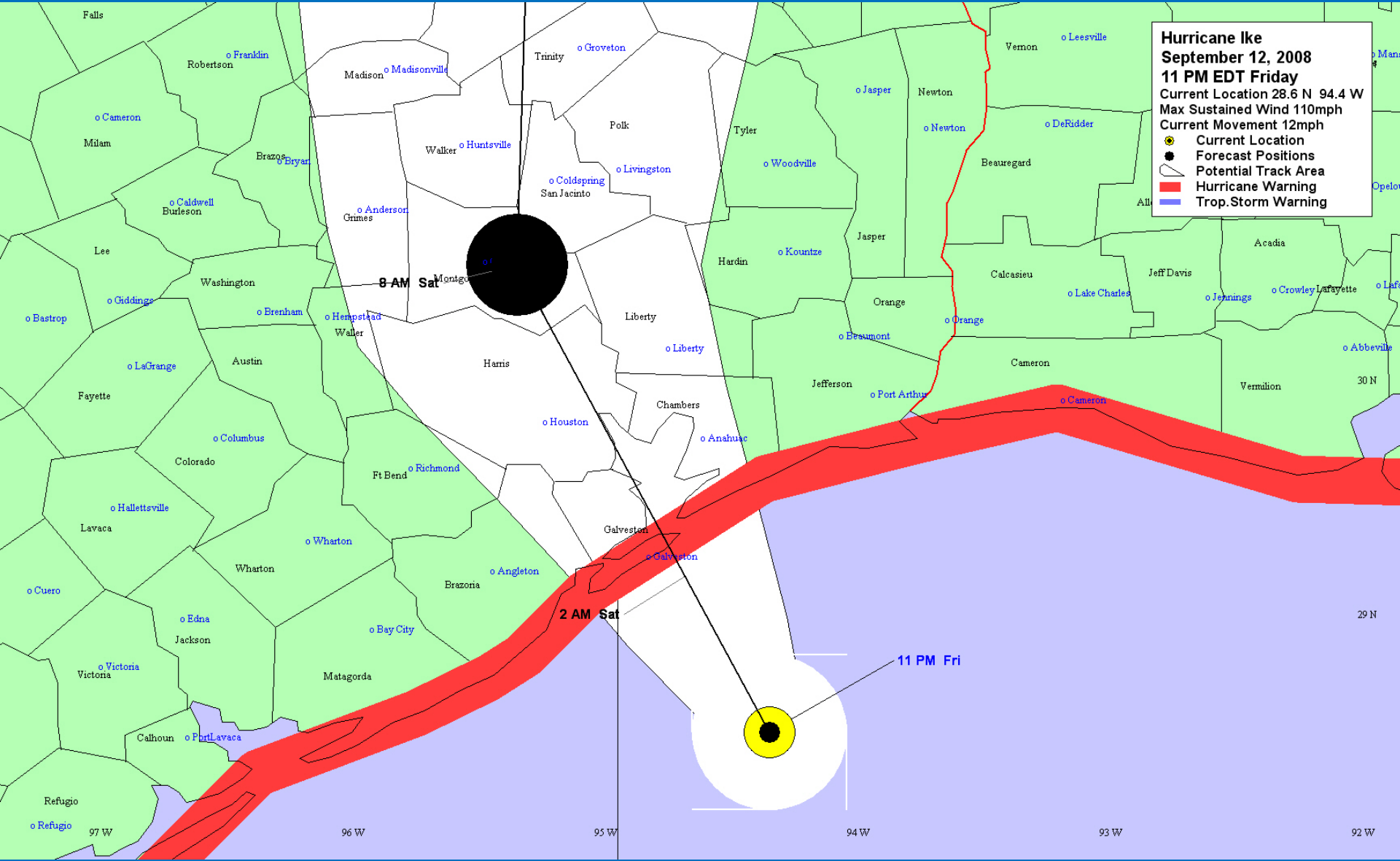
NOAA/NOS/CO-OPS  
Preliminary Water Level (A1) vs. Predicted Plot  
8771510 Galveston Pleasure Pier, TX  
from 2008/09/11 - 2008/09/13

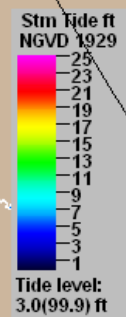


Predicted WL — (Obs-Pred) —  
Observed WL —

**Hurricane Ike**  
**September 12, 2008**  
**11 PM EDT Friday**  
 Current Location 28.6 N 94.4 W  
 Max Sustained Wind 110mph  
 Current Movement 12mph

-  Current Location
-  Forecast Positions
-  Potential Track Area
-  Hurricane Warning
-  Trop. Storm Warning





Houston ★

Harris

Liberty

Jefferson

Port Arthur

Sabine Lake

GALVESTON BAY

Chamberlain

Dry

Galveston

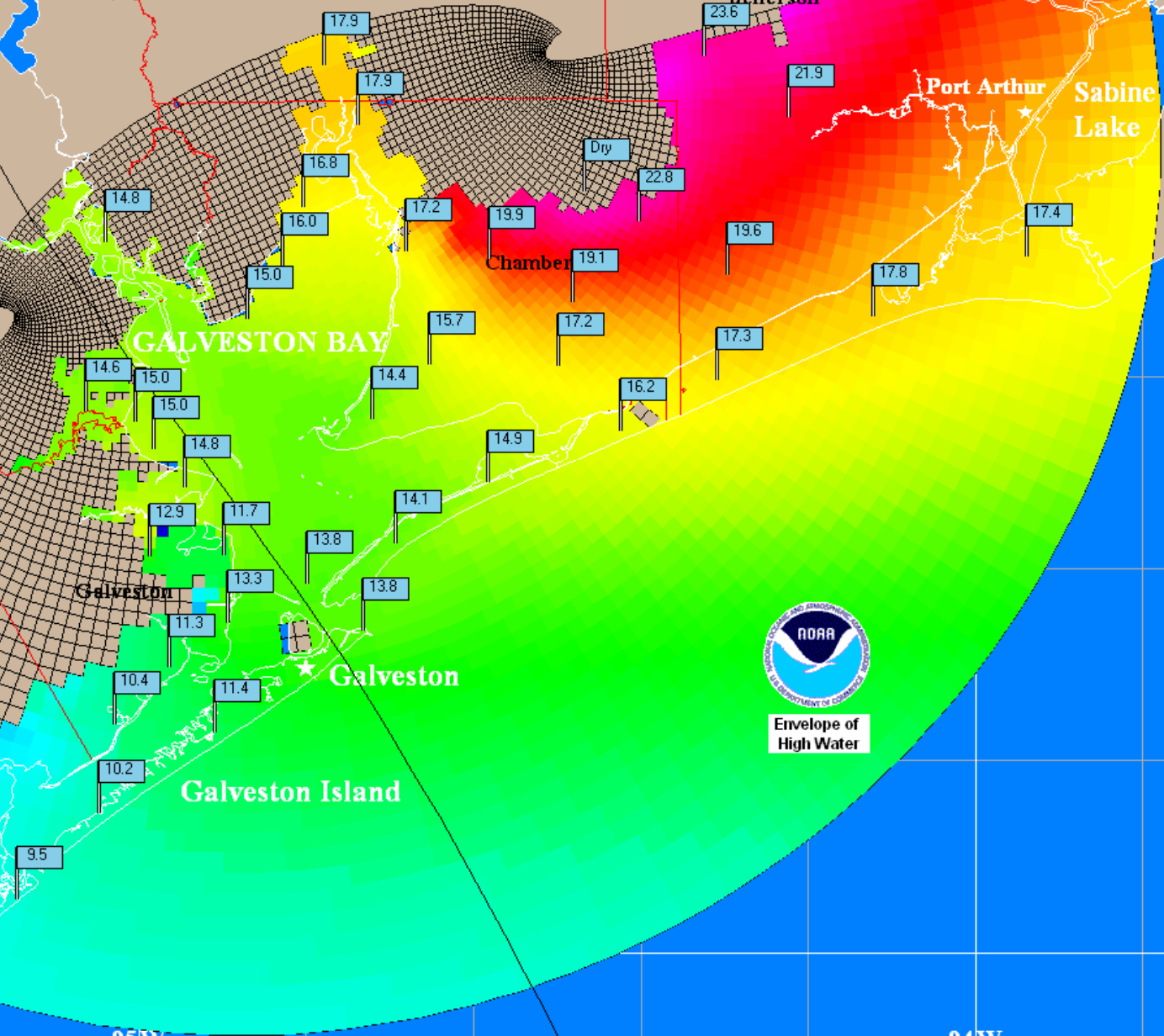
Galveston

Galveston Island

Brazoria



Envelope of High Water

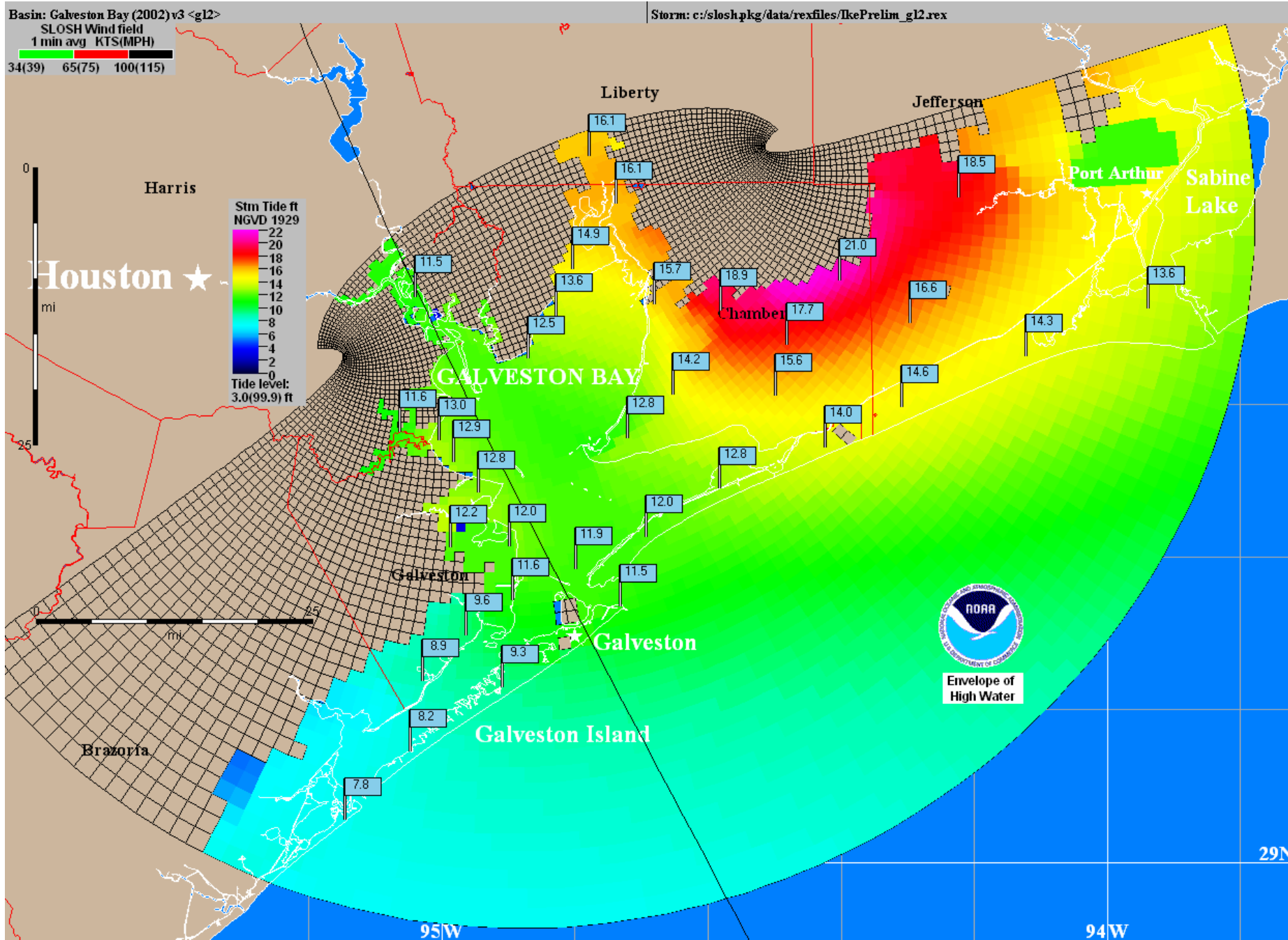


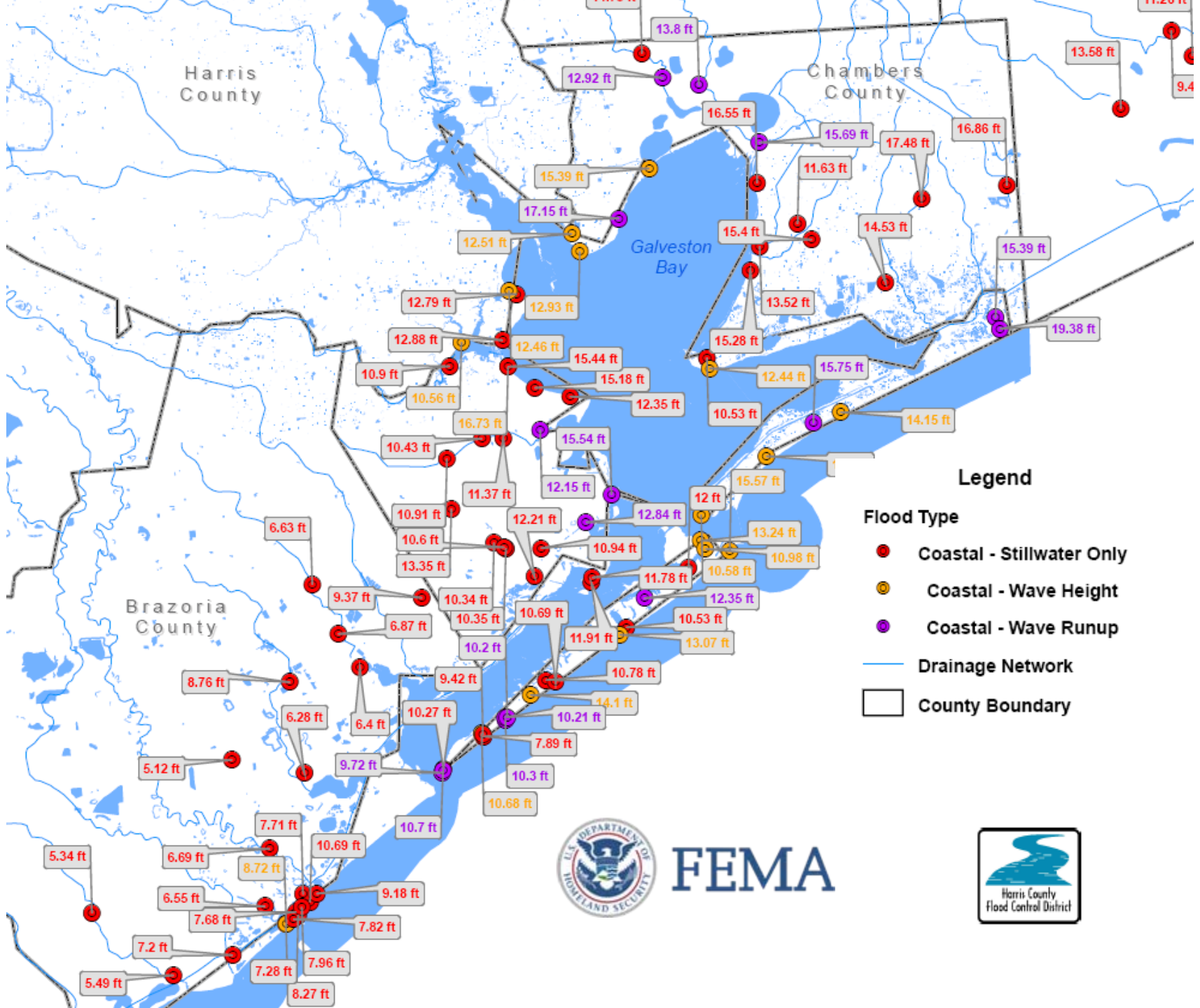
29N

95W

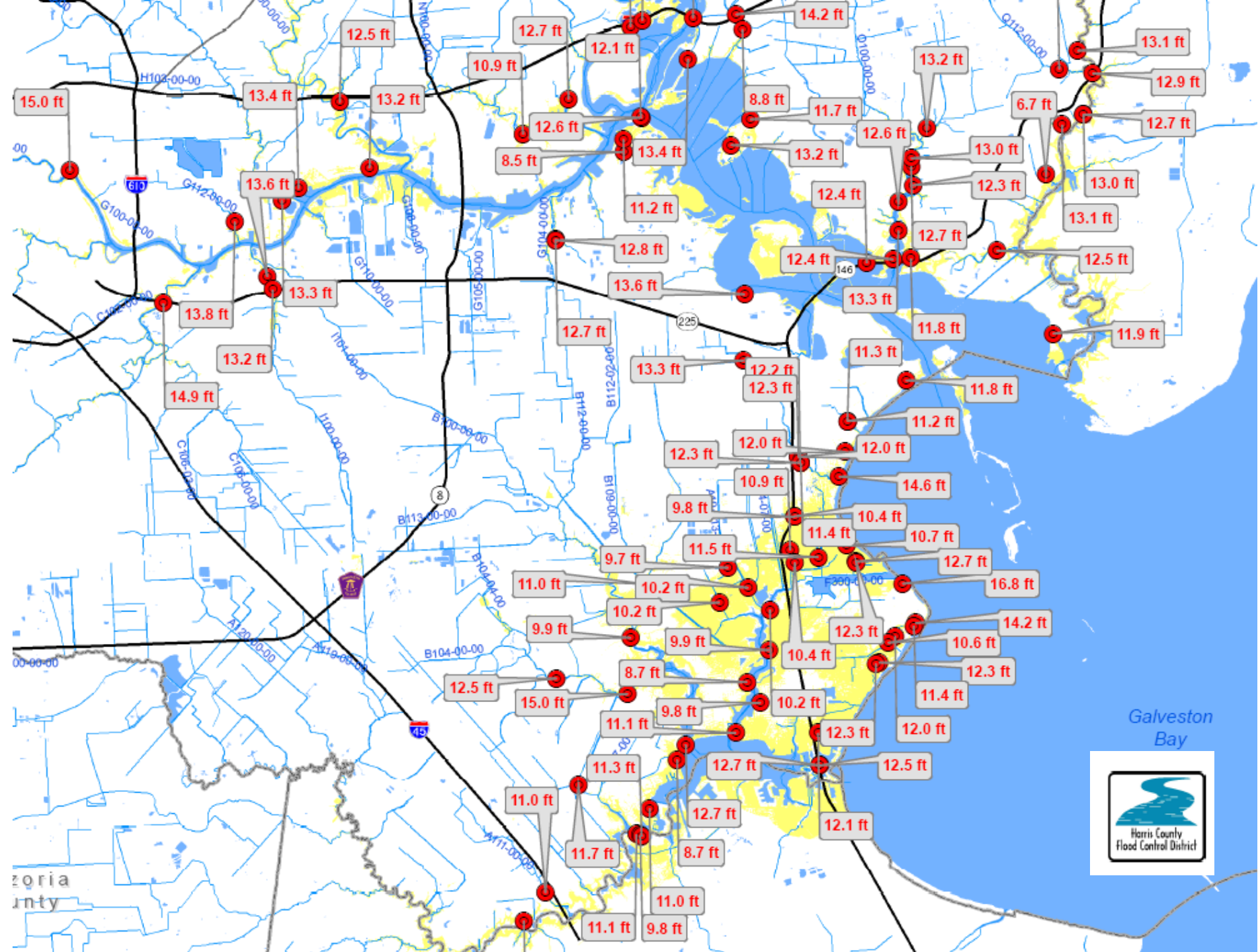
94W

# Post-Storm Run of SLOSH with Actual Track









# Kemah Waterfront Area Before Carla

**Jimmie Walker's Restaurant**

1

2

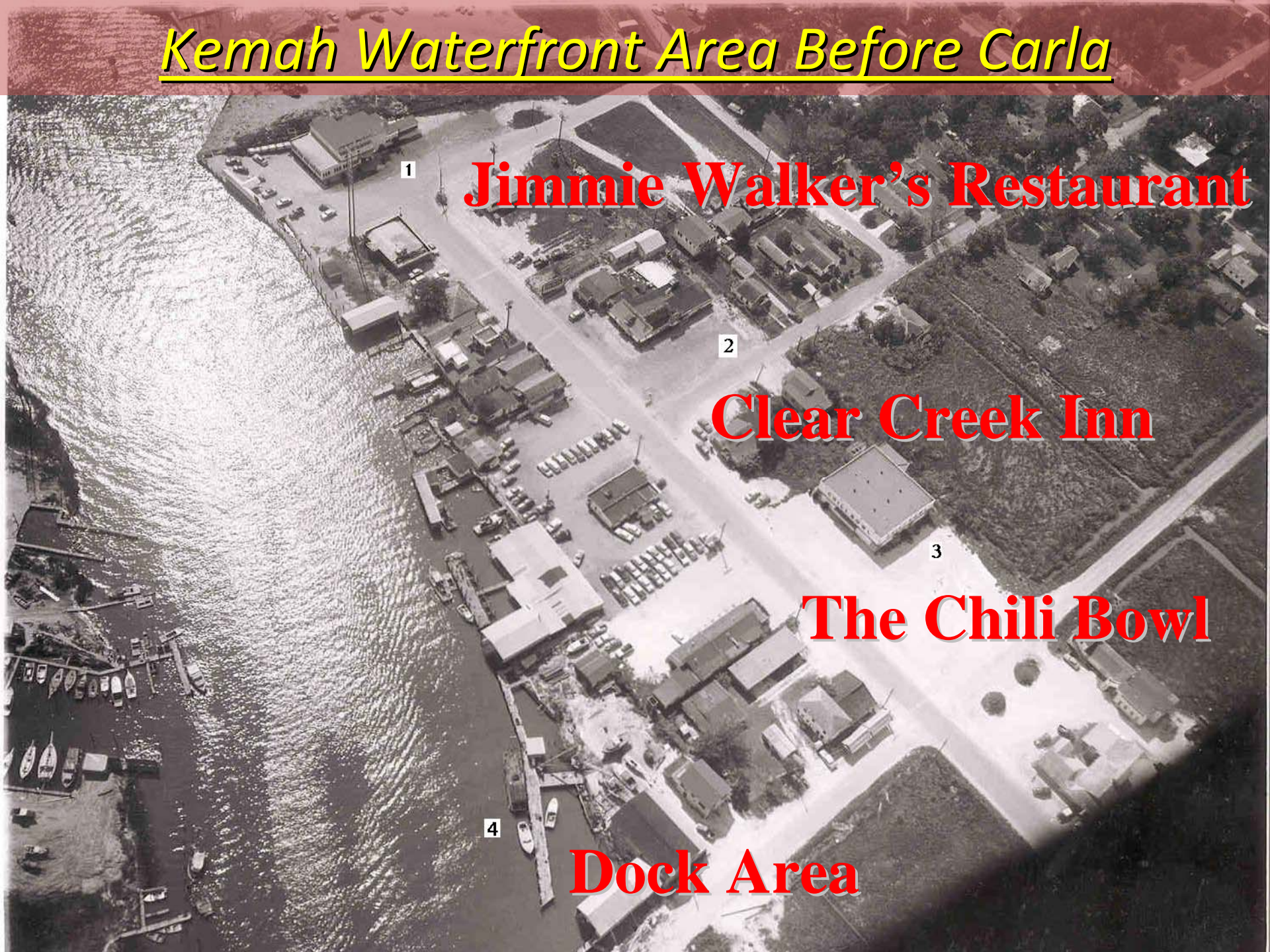
**Clear Creek Inn**

3

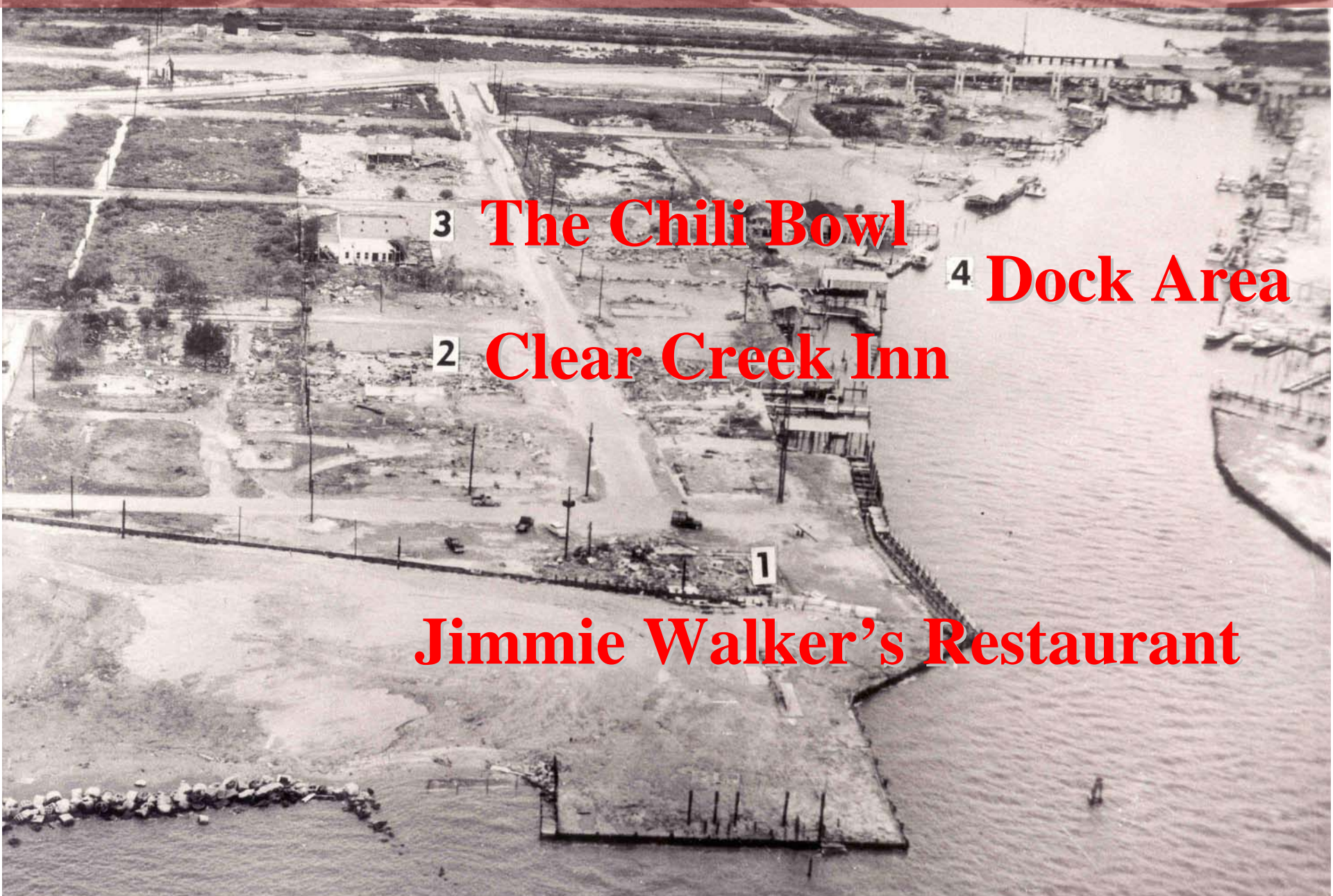
**The Chili Bowl**

4

**Dock Area**



# Kemah Waterfront After Carla



**3 The Chili Bowl**

**4 Dock Area**

**2 Clear Creek Inn**

**1**

**Jimmie Walker's Restaurant**

# Kemah - 2007



# LANDRY'S LANDRY'S

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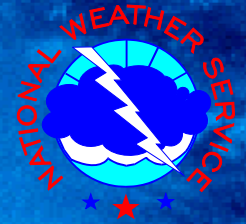


# Changes for 2009

- Modified Saffir-Simpson Scale
- Probabilistic Storm Surge
- Issuance times of Watch and Warnings

# *Saffir-Simpson Hurricane Scale*

CATEGORY	WIND SPEED (MPH)	DAMAGE	HURRICANE NAME
1	74-95	MINIMAL	CLAUDETTE
2	96-110	MODERATE	IKE
3	110-130	MAJOR	ALICIA
4	131-155	EXTREME	CARLA
5	> 155	CATASTROPHIC	1935 FL Keys CAMILLE ANDREW



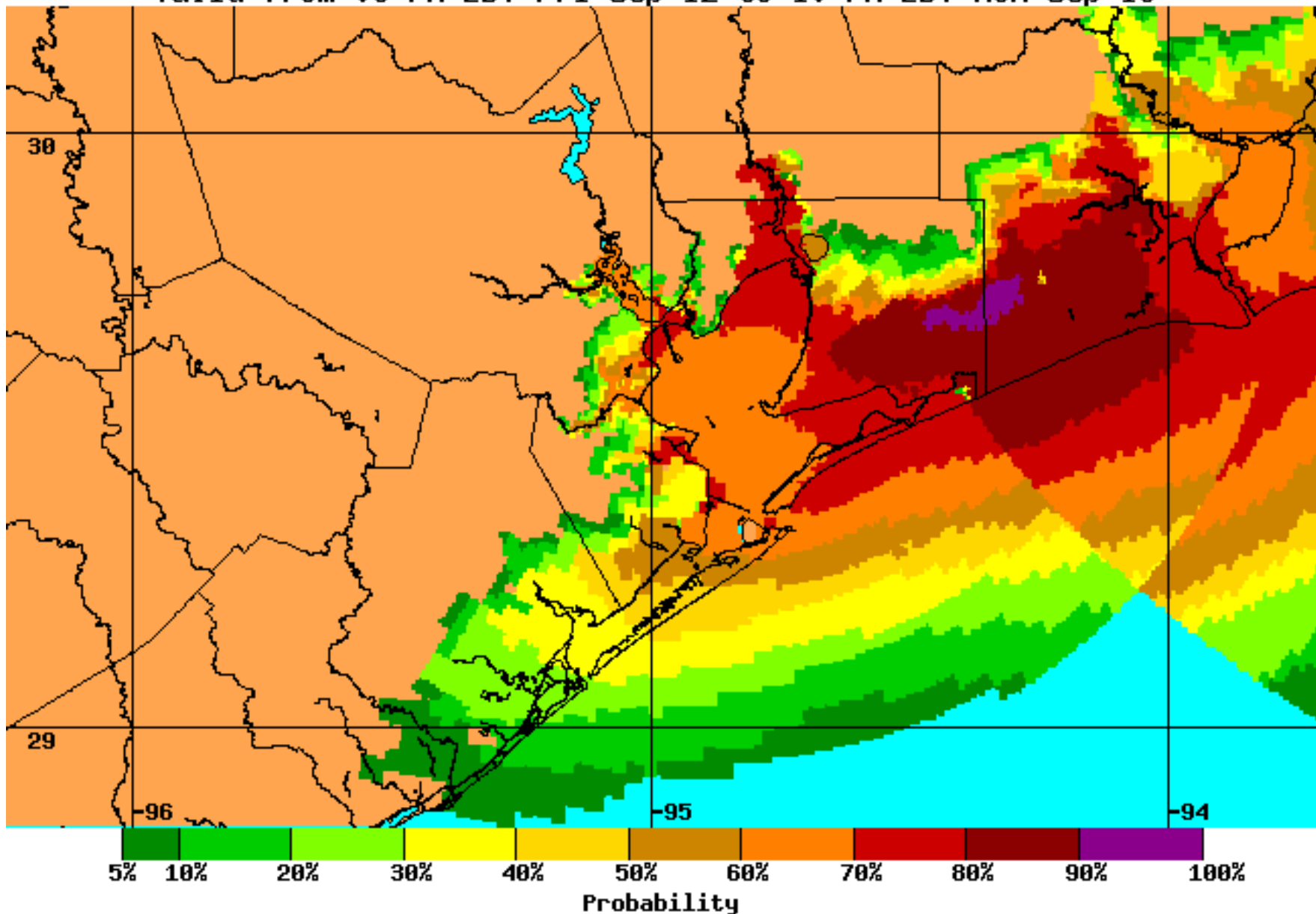
# Probabilistic Storm Surge

## P-Surge



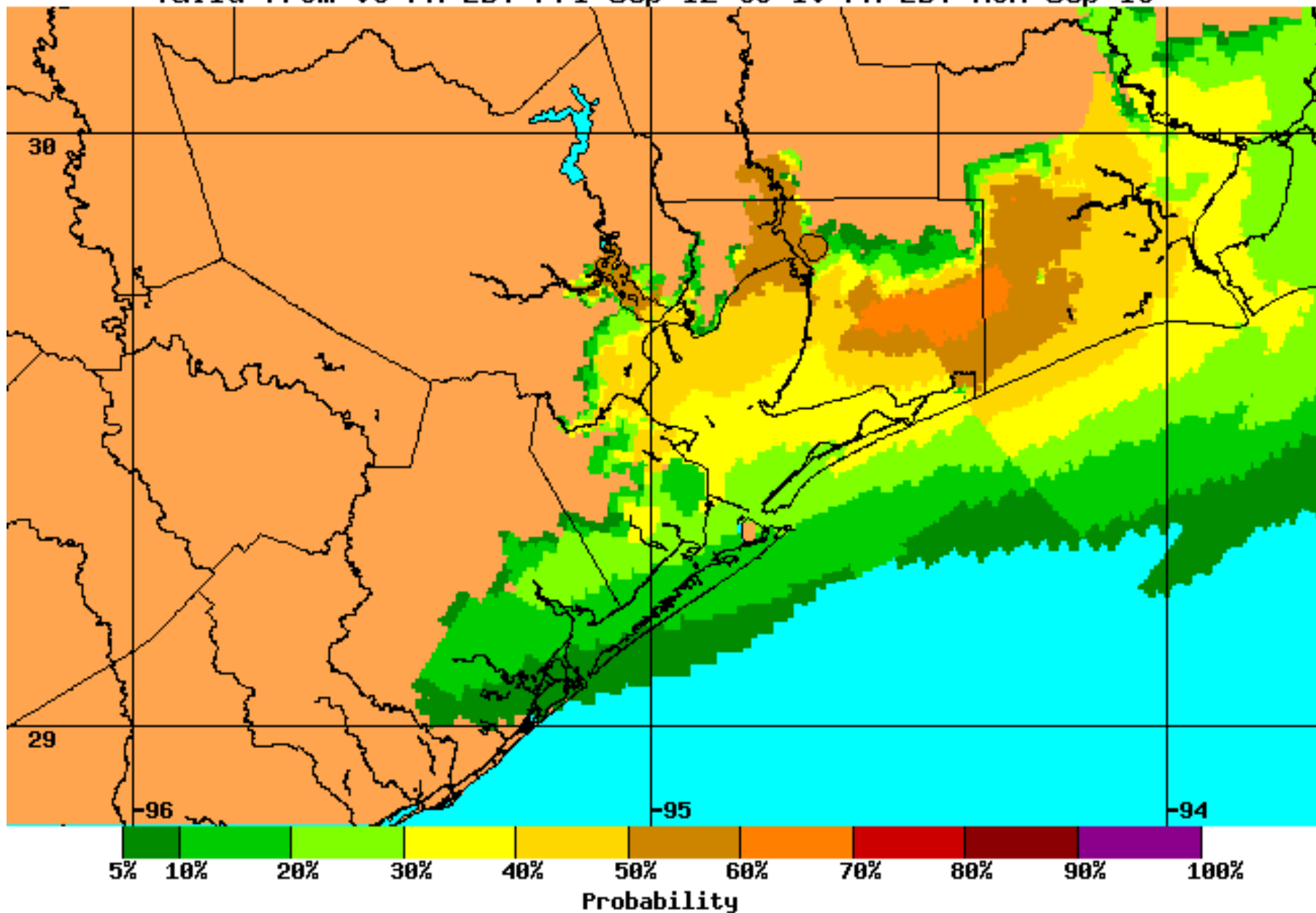


Experimental Tropical Cyclone Storm Surge Probabilities  
Chance of Storm Surge  $\geq 11$  feet at Individual Locations  
Hurricane Ike (2008) Advisory 47  
Valid from 05 PM EDT Fri Sep 12 to 10 PM EDT Mon Sep 15





Experimental Tropical Cyclone Storm Surge Probabilities  
Chance of Storm Surge  $\geq$  15 feet at Individual Locations  
Hurricane Ike (2008) Advisory 47  
Valid from 05 PM EDT Fri Sep 12 to 10 PM EDT Mon Sep 15



# Issuance Times of Watch and Warnings

- Watch - 48 hours in advance
- Warning - 36 hours in advance