SSPEED
Center Update

June 14, 2016

Philip Bedient and Jim Blackburn

The SSPEED Center

The Center is based at Rice University and collaborates with leading academic institutions, the private sector and public entities.

Key Researchers

Dr. John Anderson – Rice University
- *Coastal Geology*

Dr. Philip Bedient – Rice University
- *Urban Flood Analysis*

Mr. Jim Blackburn – Rice University
- *Environmental Impact*

Dr. Sam Brody – Texas A&M University
- *Land Planning and Risk*

Mr. Joe Cibor – Consultant
- *Geotechnical Engineering*

Dr. Clint Dawson – University of Texas
- *Storm Surge Modeling*

Dr. Jamie Padgett – Rice University
- *Bay Area Infrastructure*

Mr. Charles Penland – Walter P Moore
- *Civil Engineering*

Dr. Hanadi Rifai – University of Houston
- *Houston Ship Channel*

Dr. Ron Sass – Rice University
- *Wetlands and Carbon Cycling*

Goals for “Regional Surge Protection”

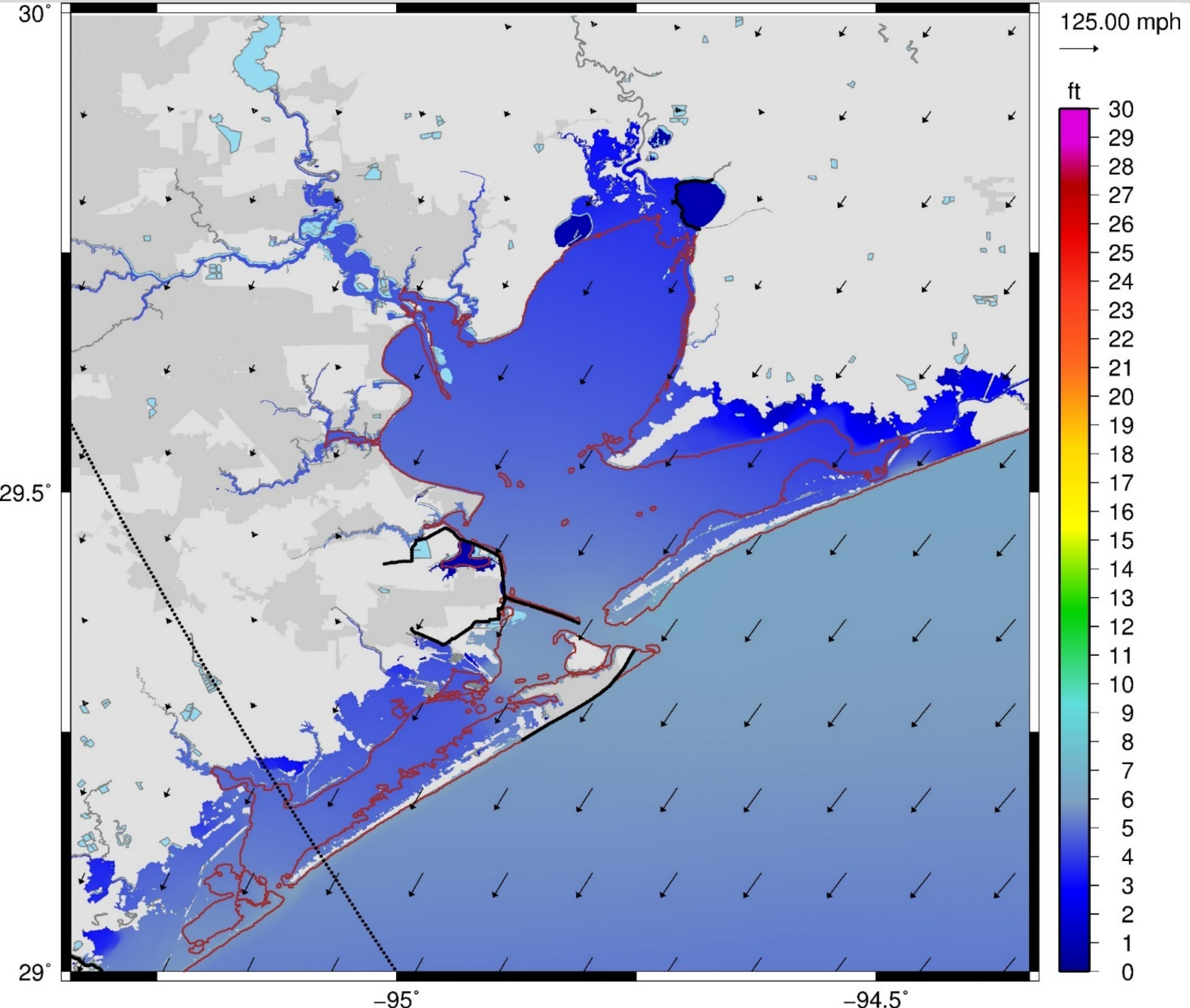
- Develop a **regional surge protection system** for
  - the **population** in the Galveston Bay area,
  - the **industrial complex** along the HSC, and
  - the **preservation of the barrier islands** (Galveston Island and Bolivar Peninsula)

- The **ultimate plan** should include a regional storm surge reduction strategy with “**multiple lines of defense**” – e.g. a coastal barrier and in-bay surge controls

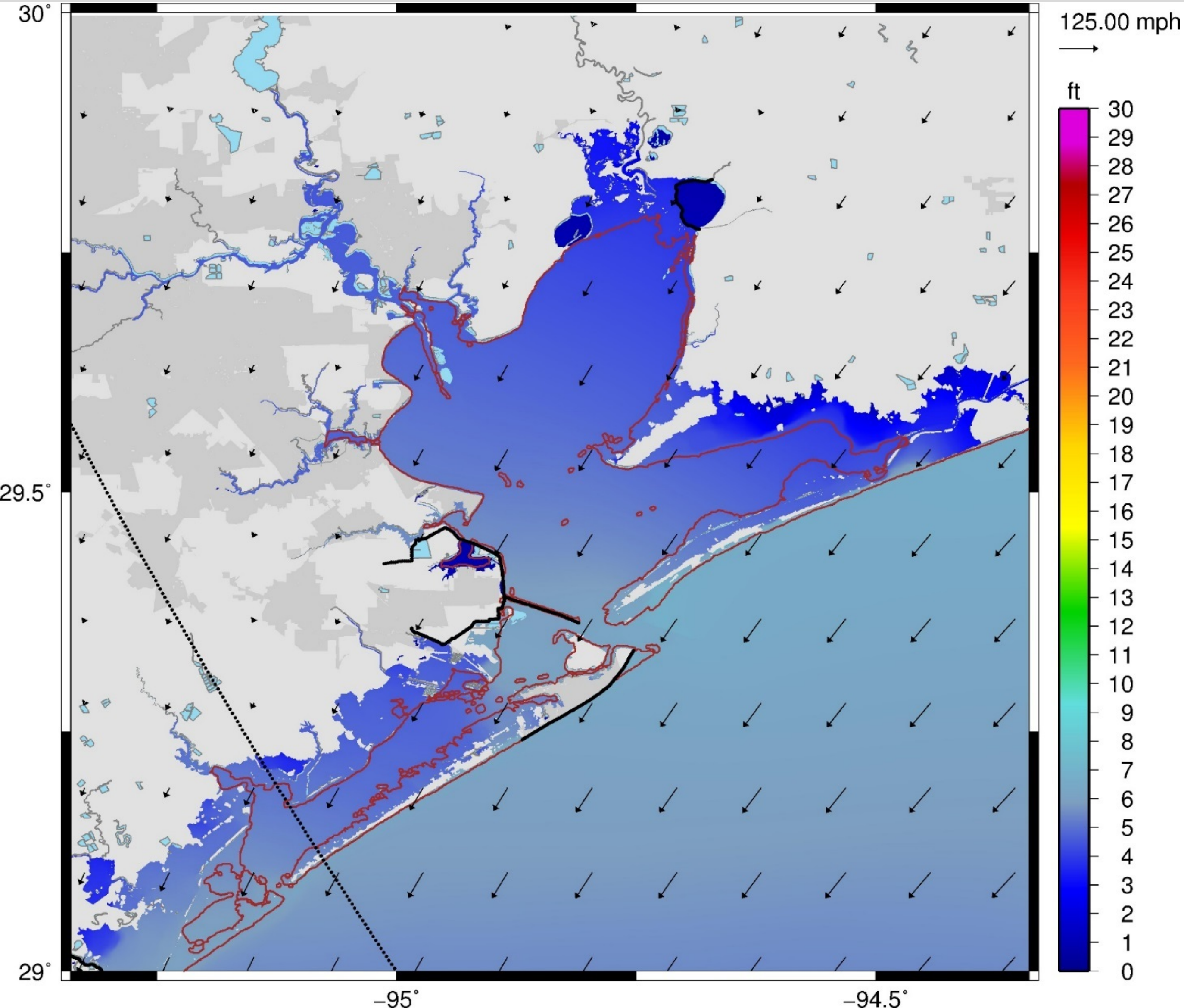
- The regional strategy should **include components** that can be implemented quickly to **provide interim protection**

- The regional strategy must be shown to be **economically, environmentally and socially acceptable**

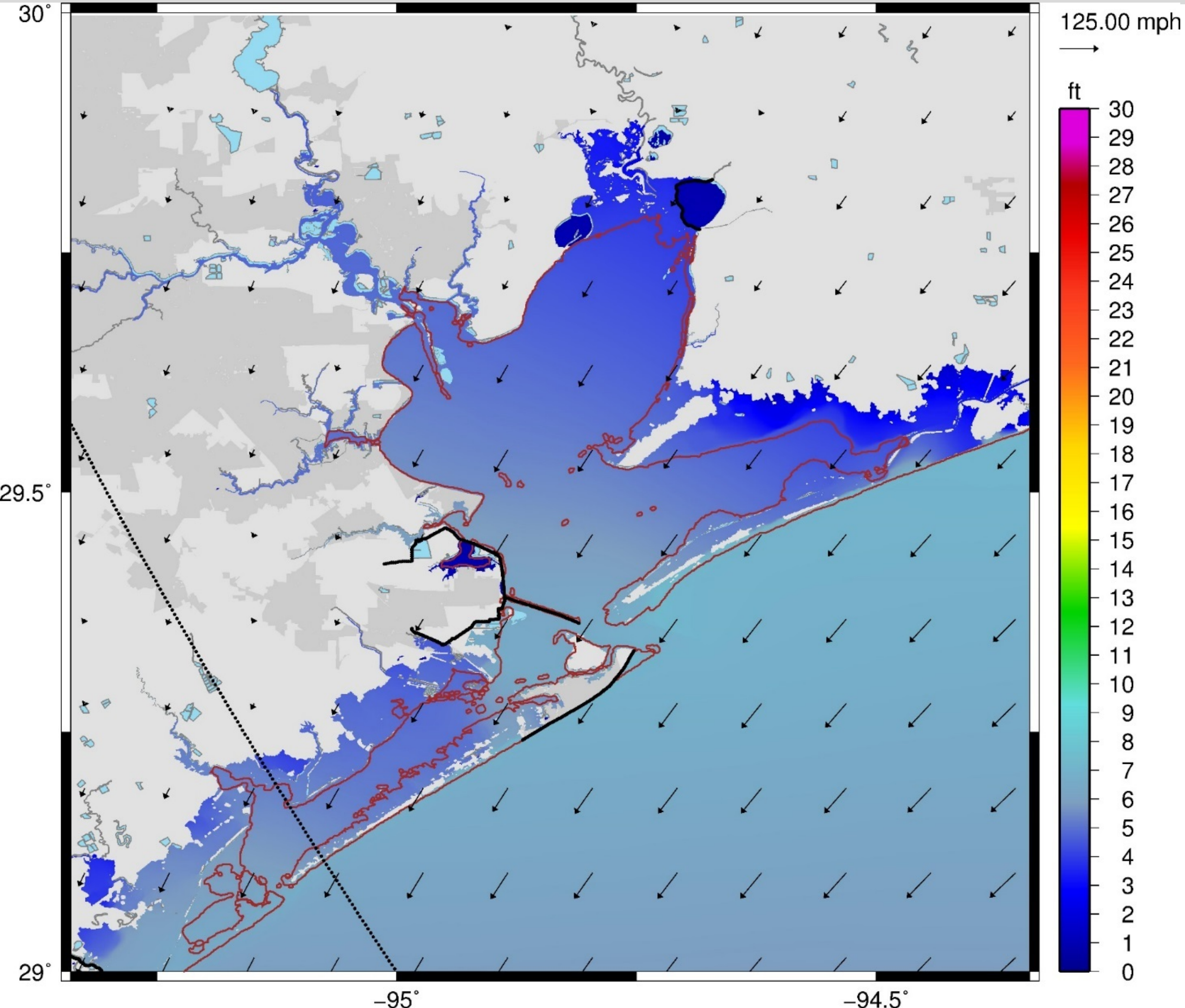
15 hr. prior to landfall



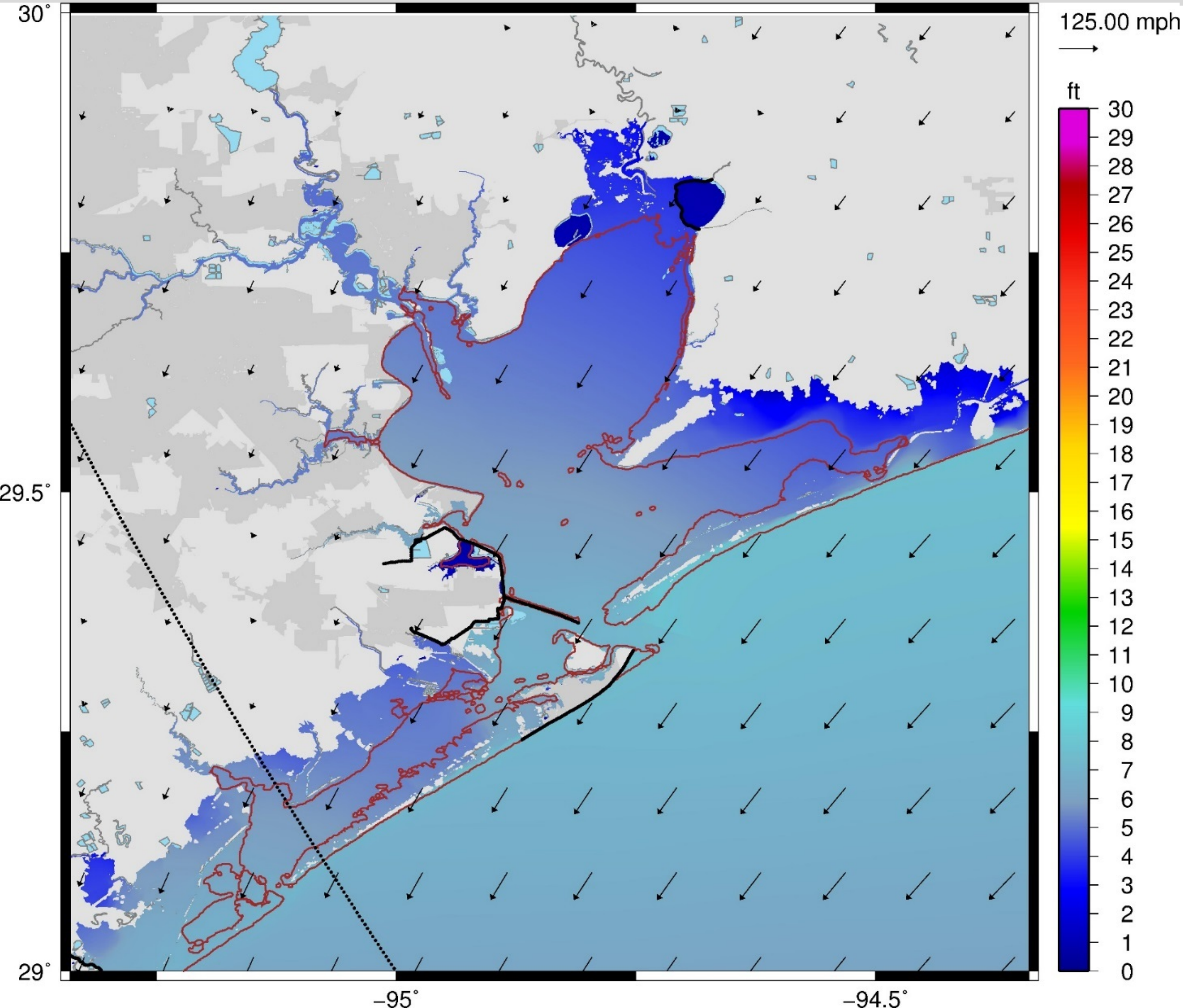
14 hr. prior to landfall



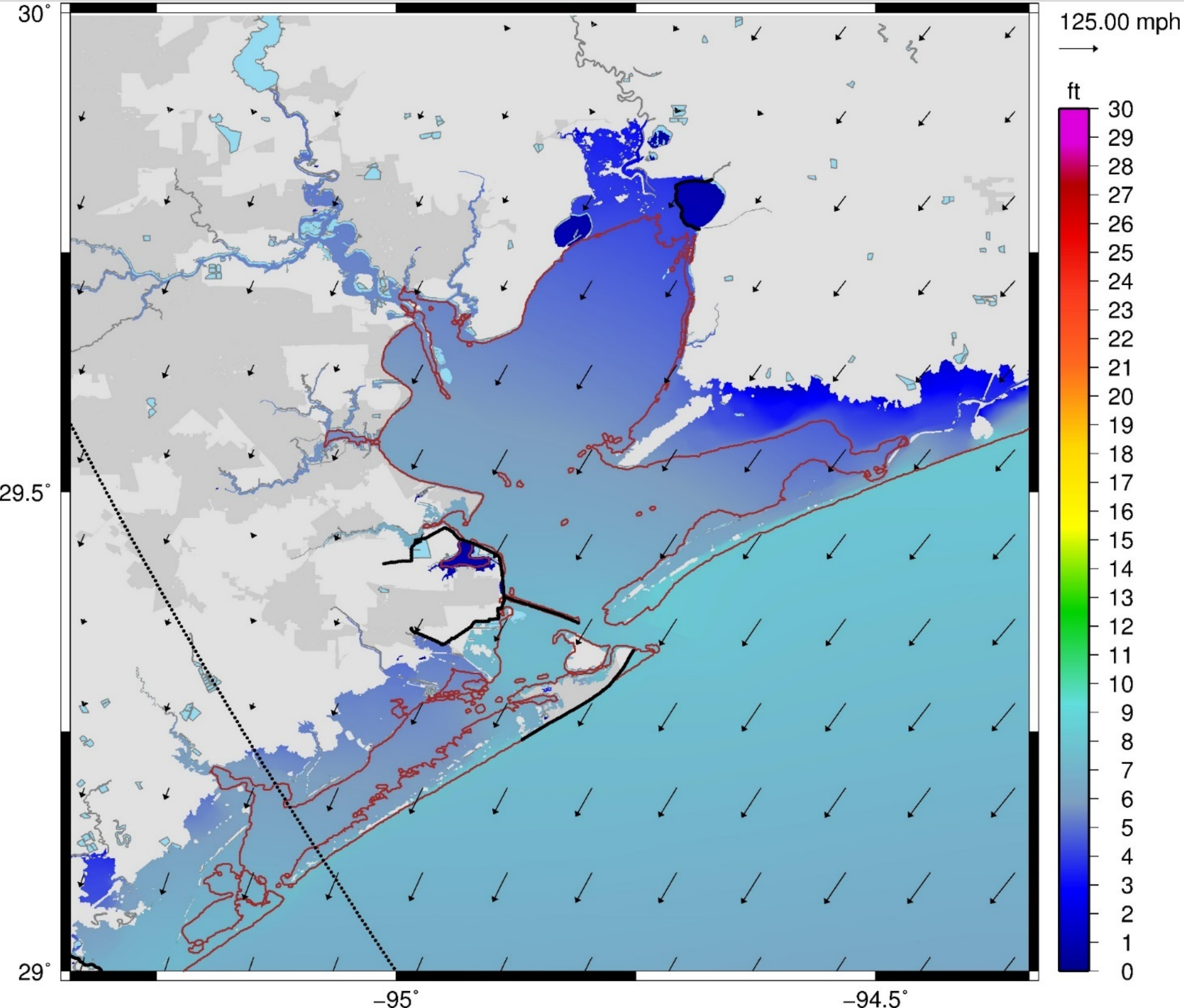
13 hr. prior to landfall



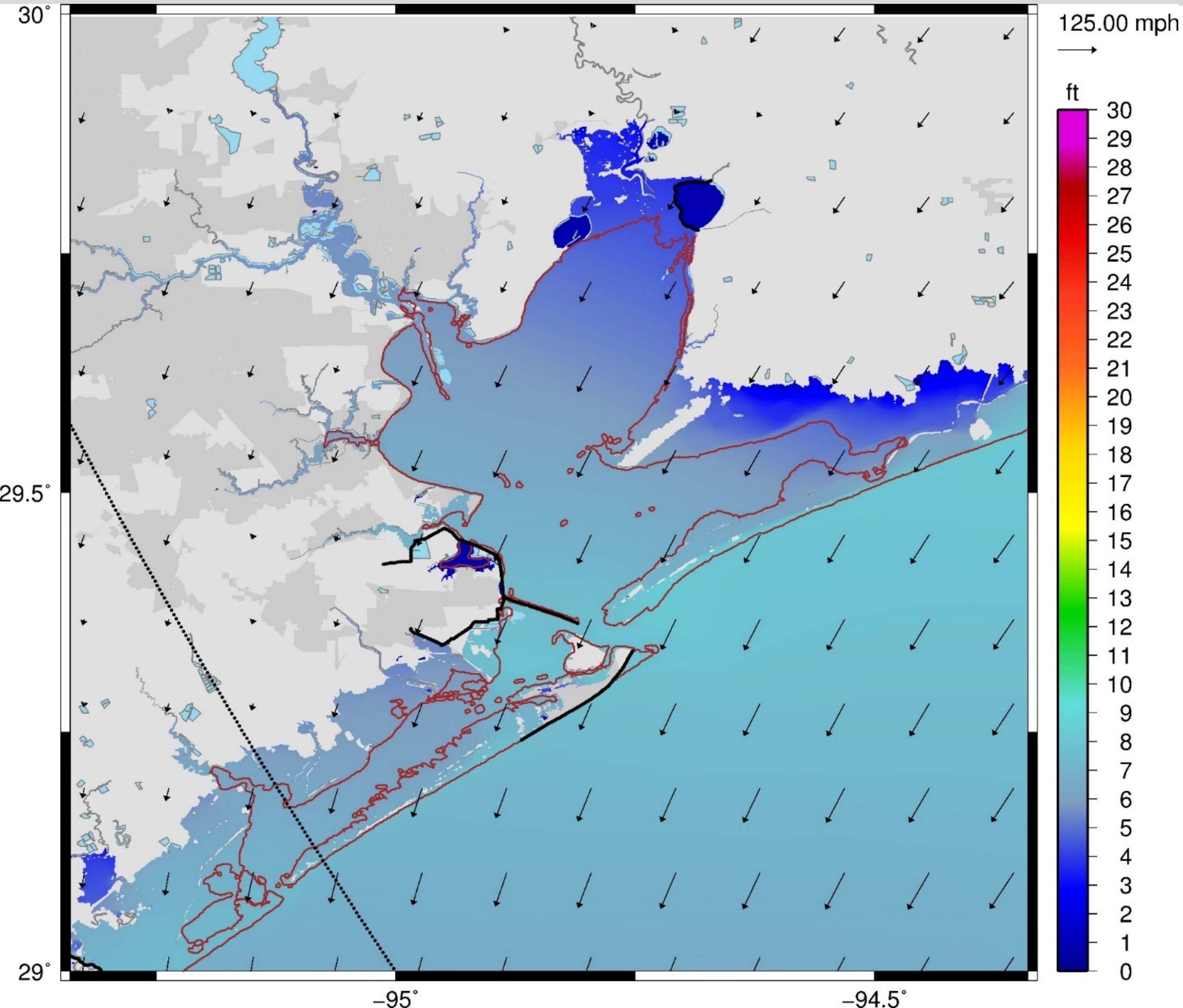
12 hr. prior to landfall



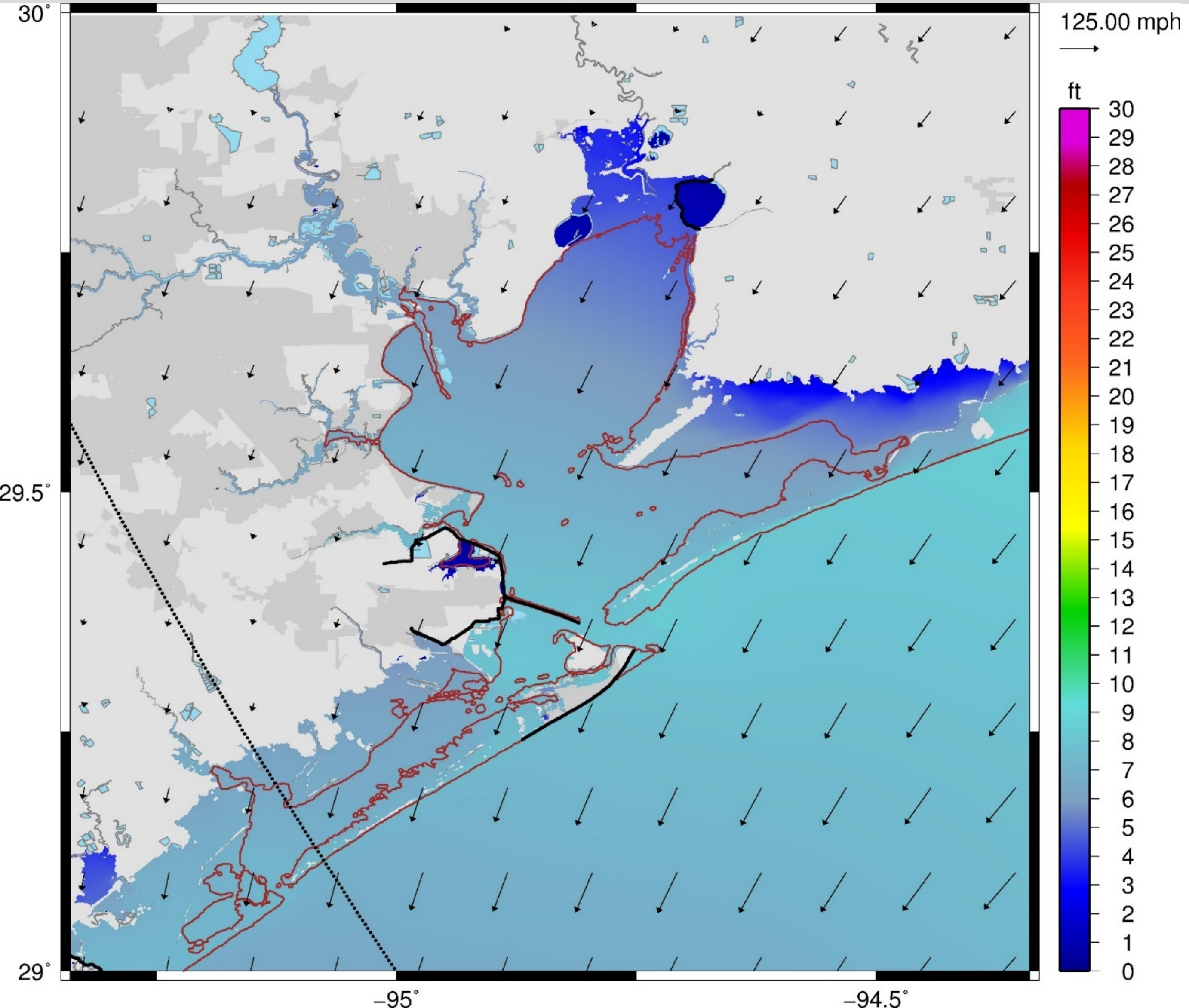
11 hr. prior to landfall



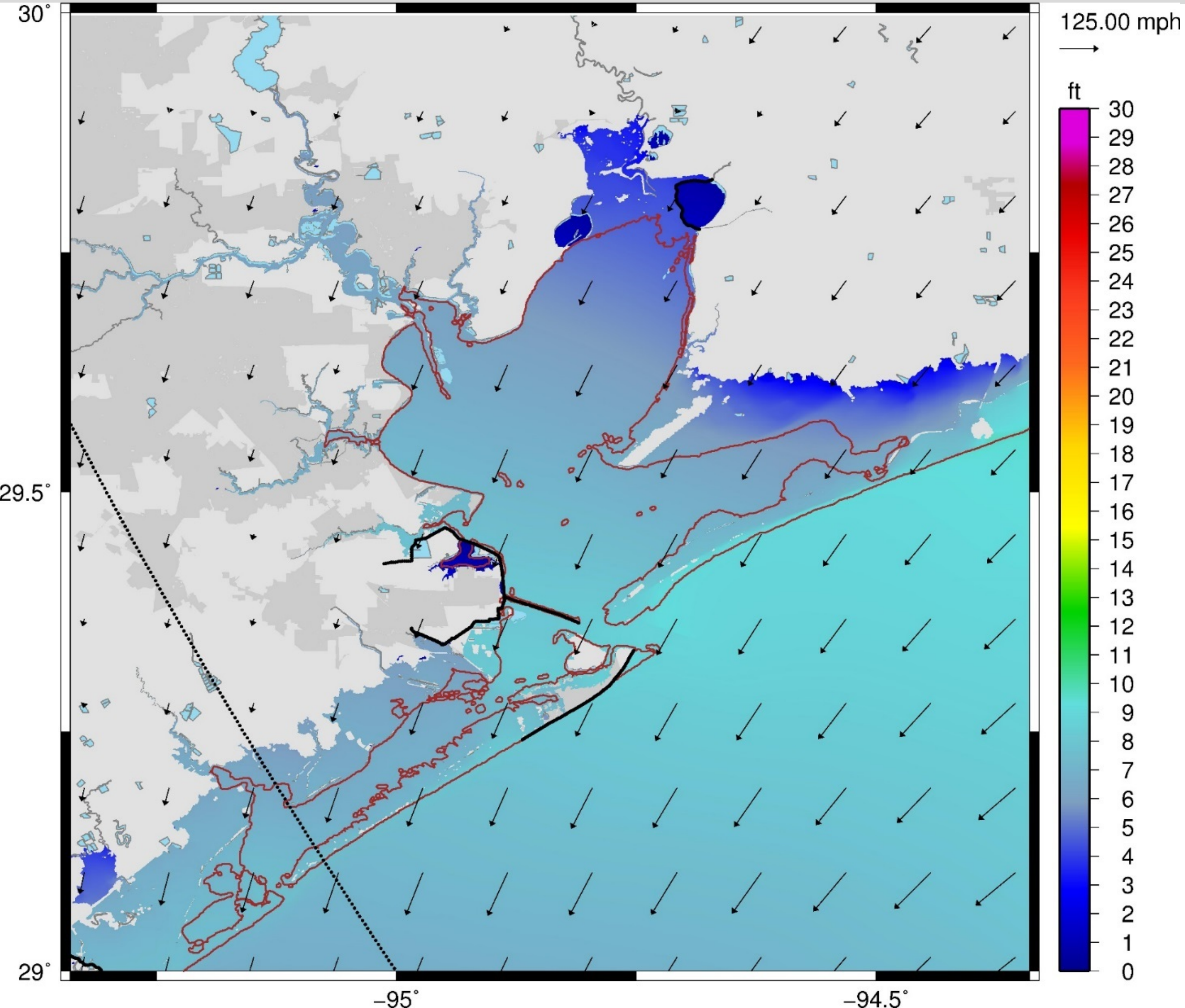
10 hr. prior to landfall



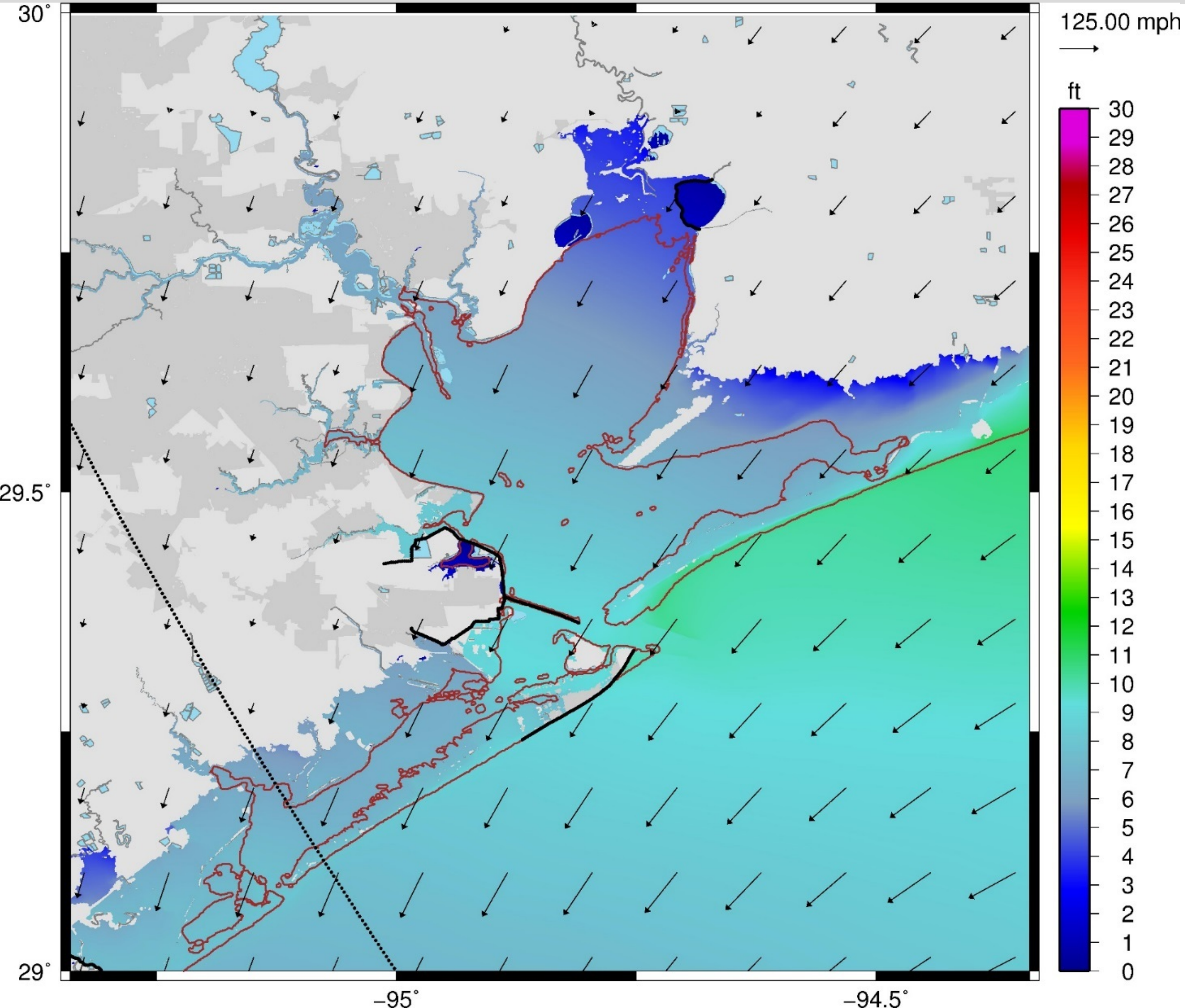
9 hr. prior to landfall



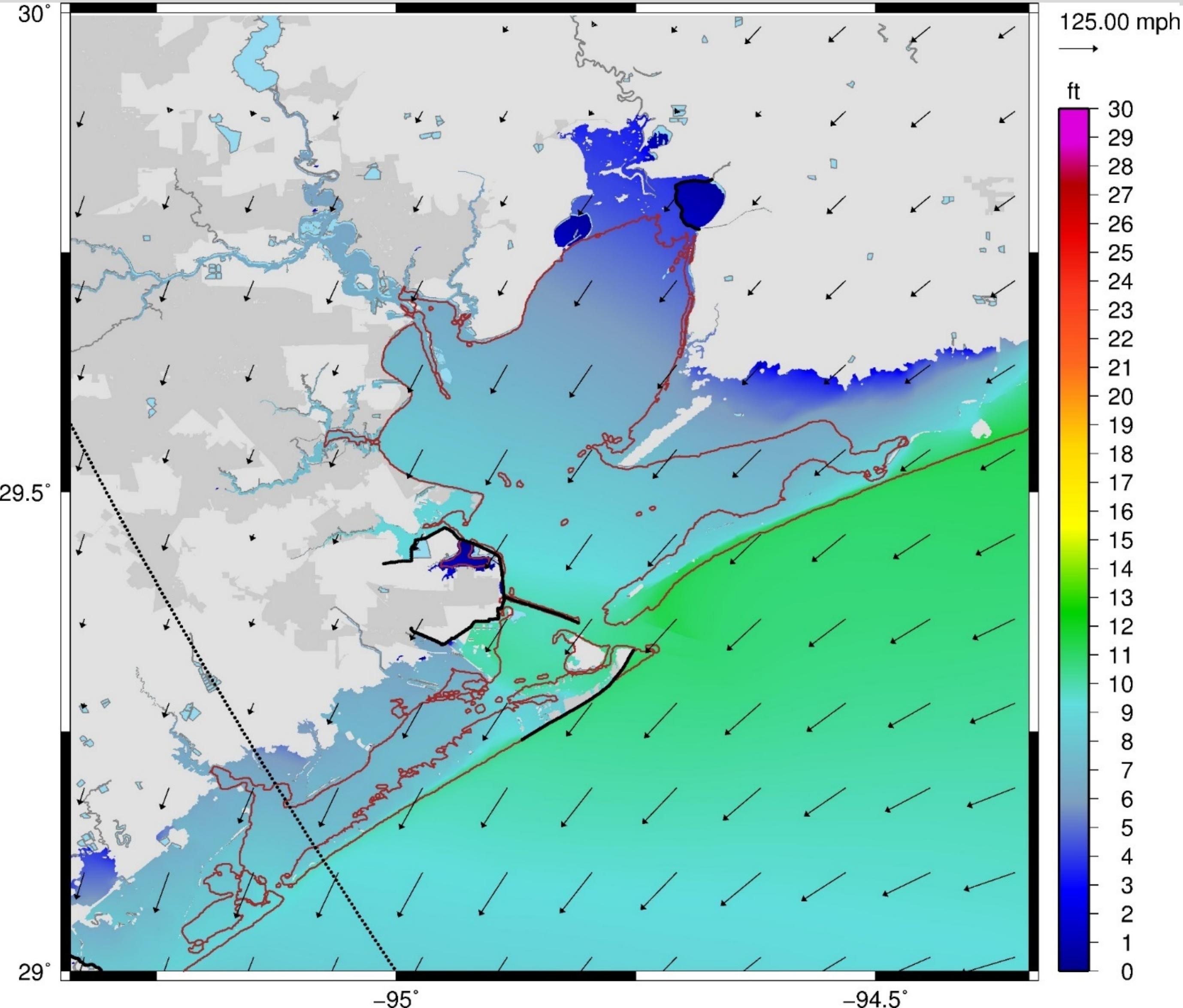
8 hr. prior to landfall



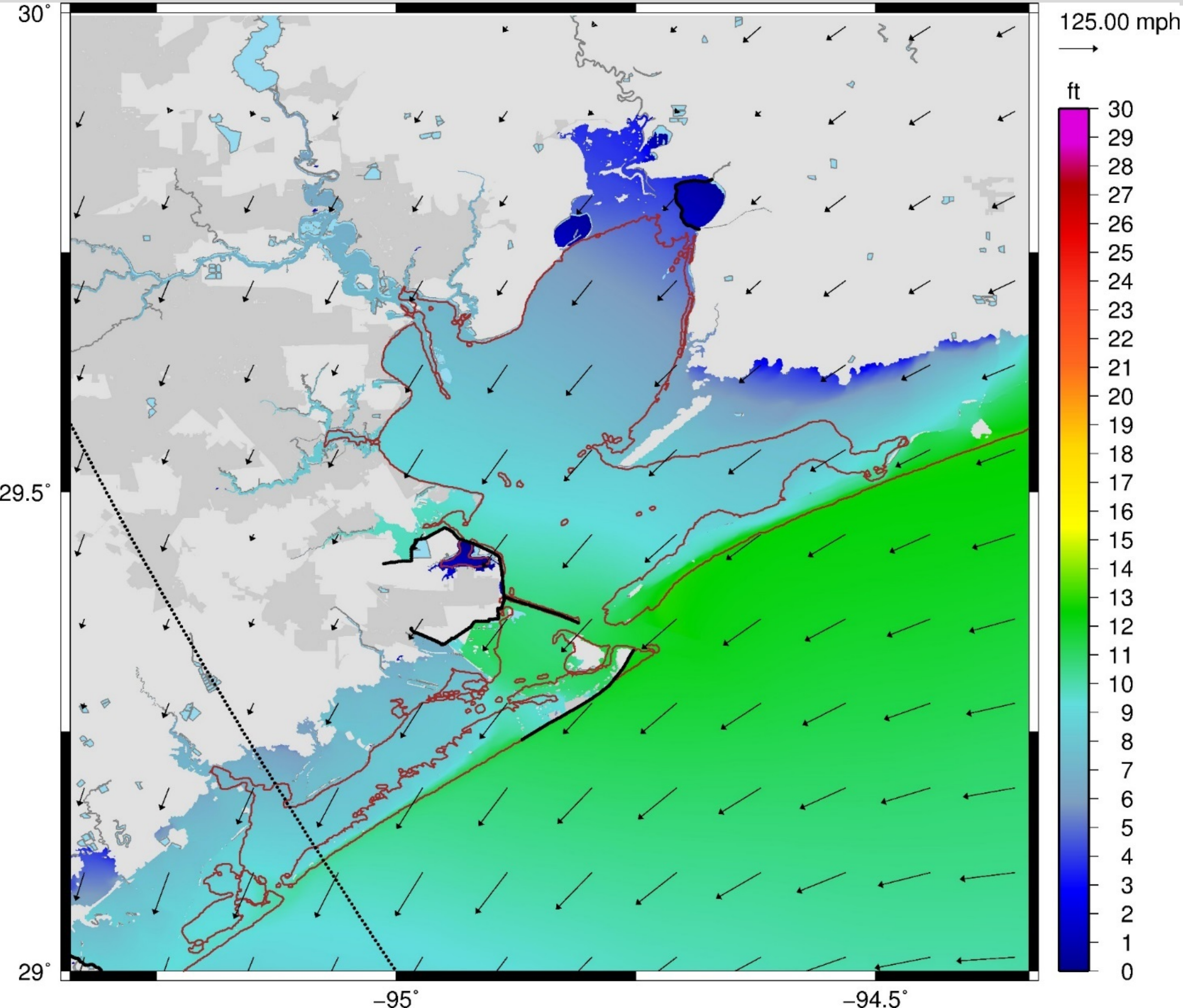
7 hr. prior to landfall



6 hr. prior to landfall



5 hr. prior to landfall



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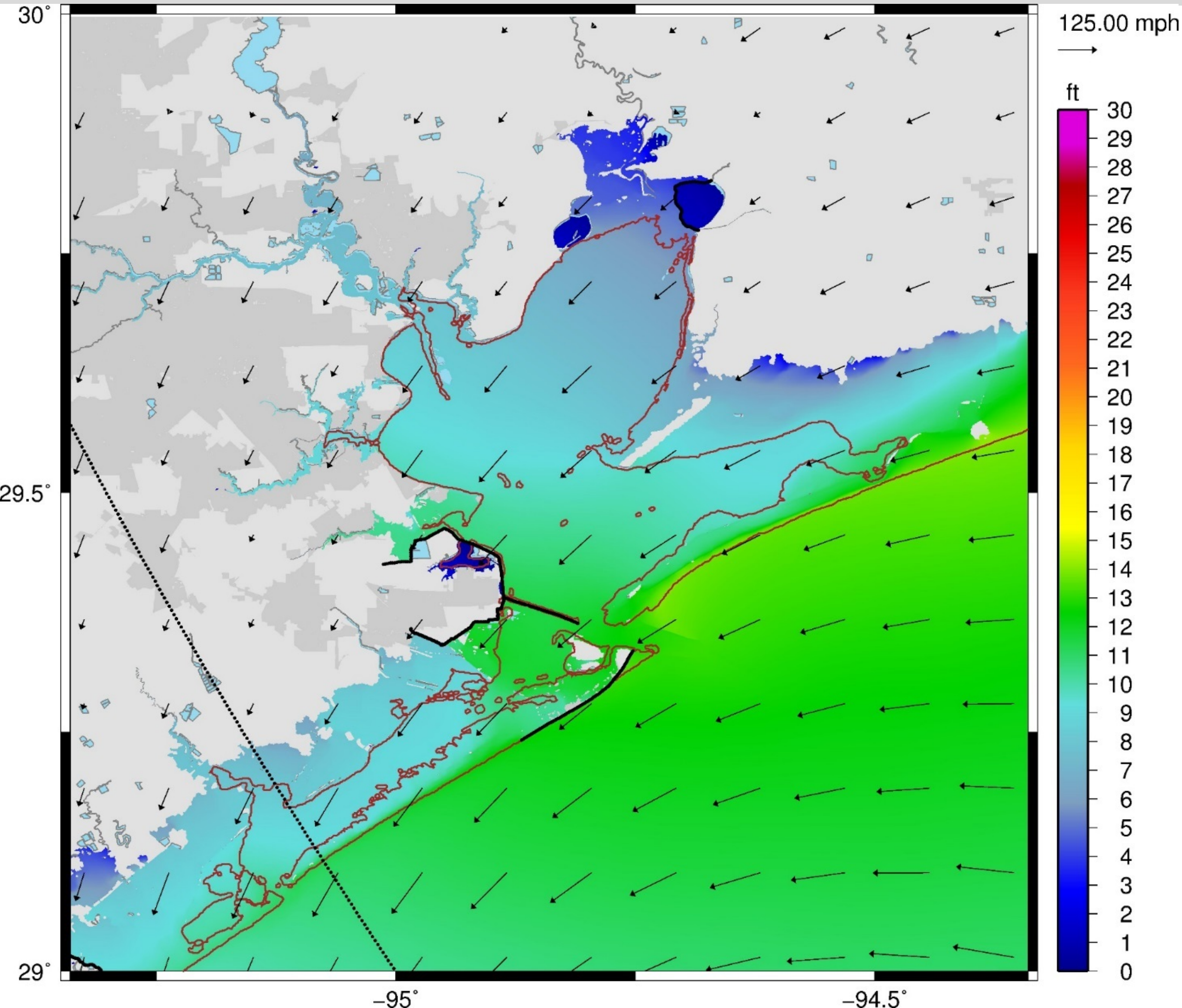
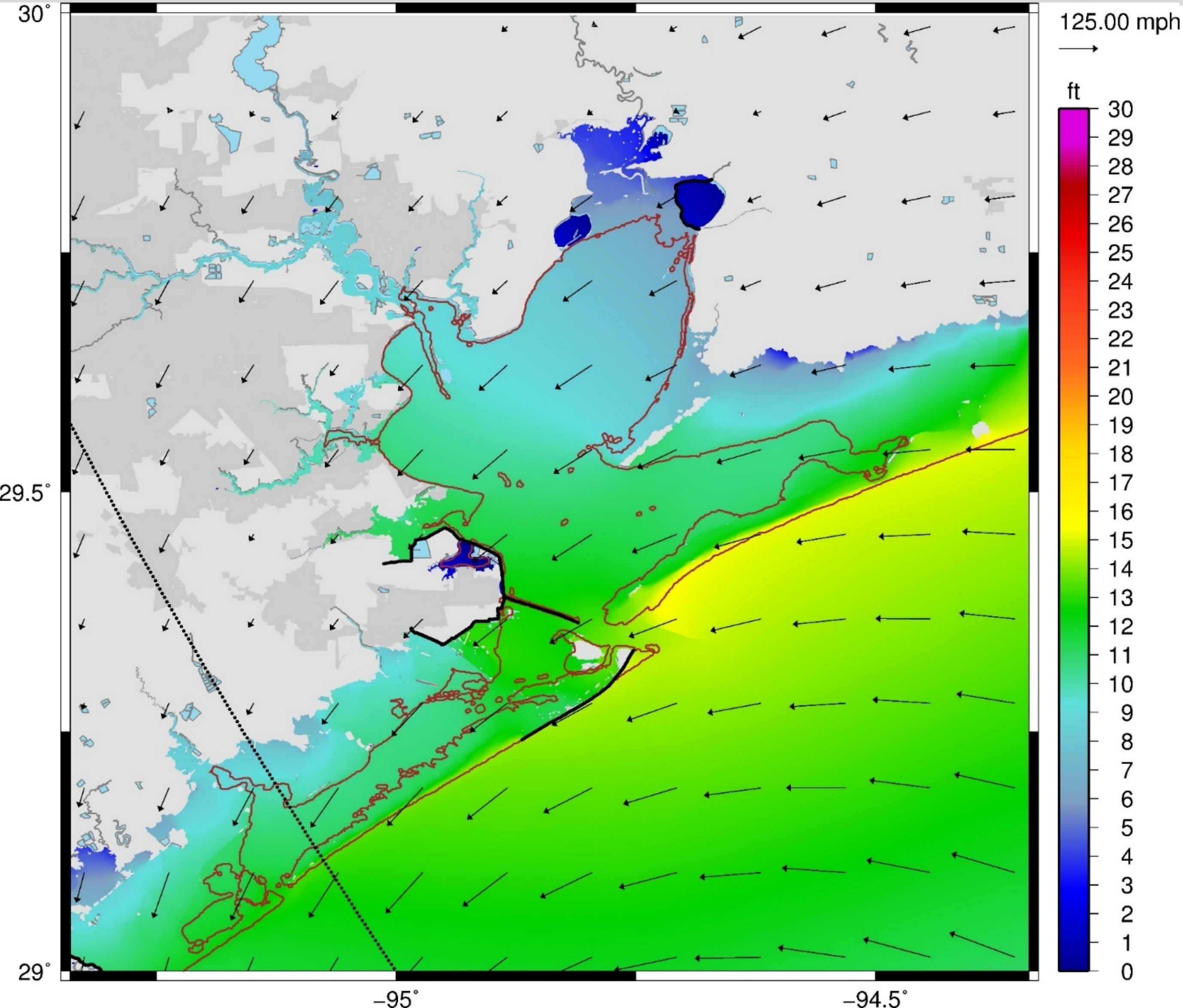
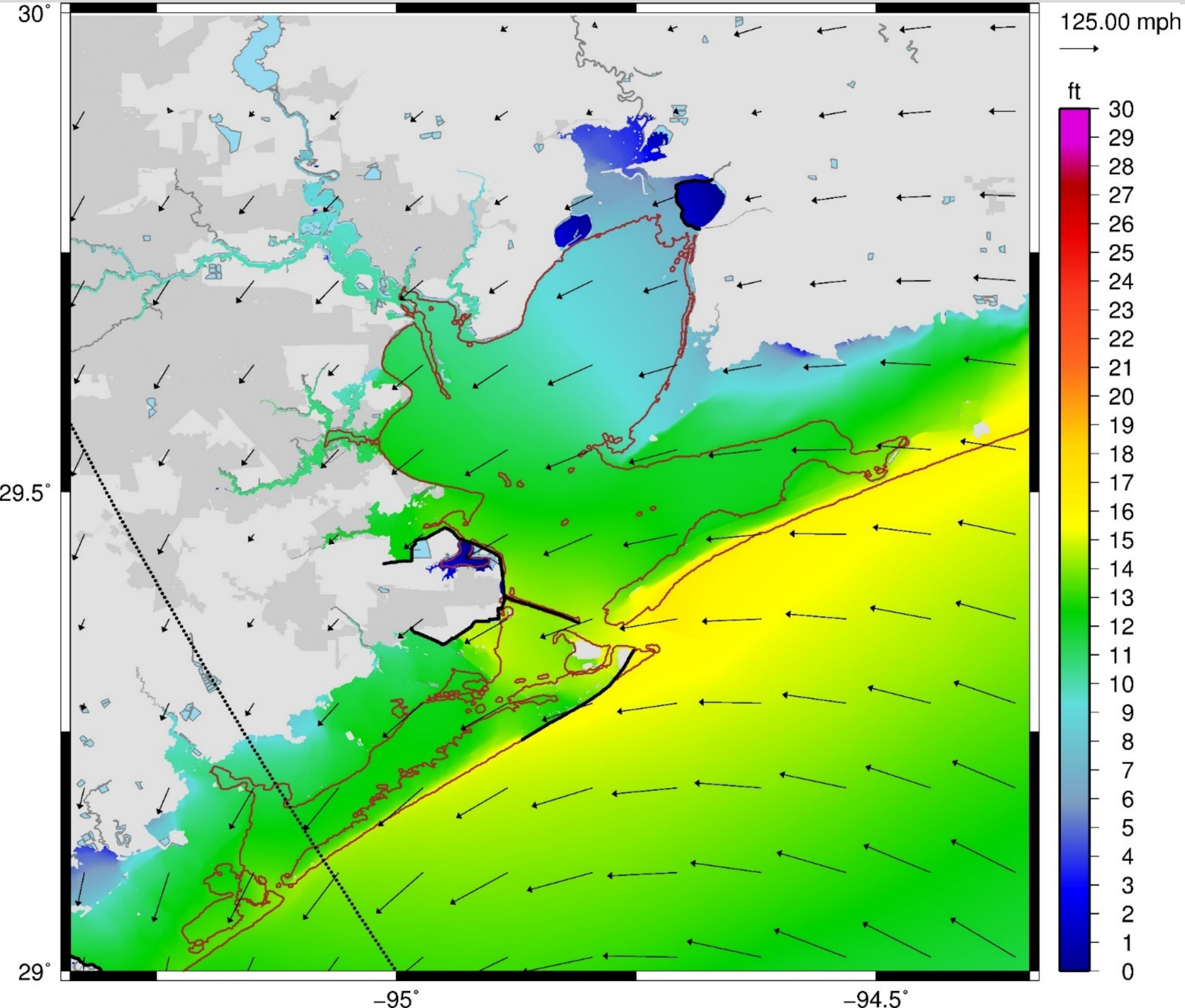


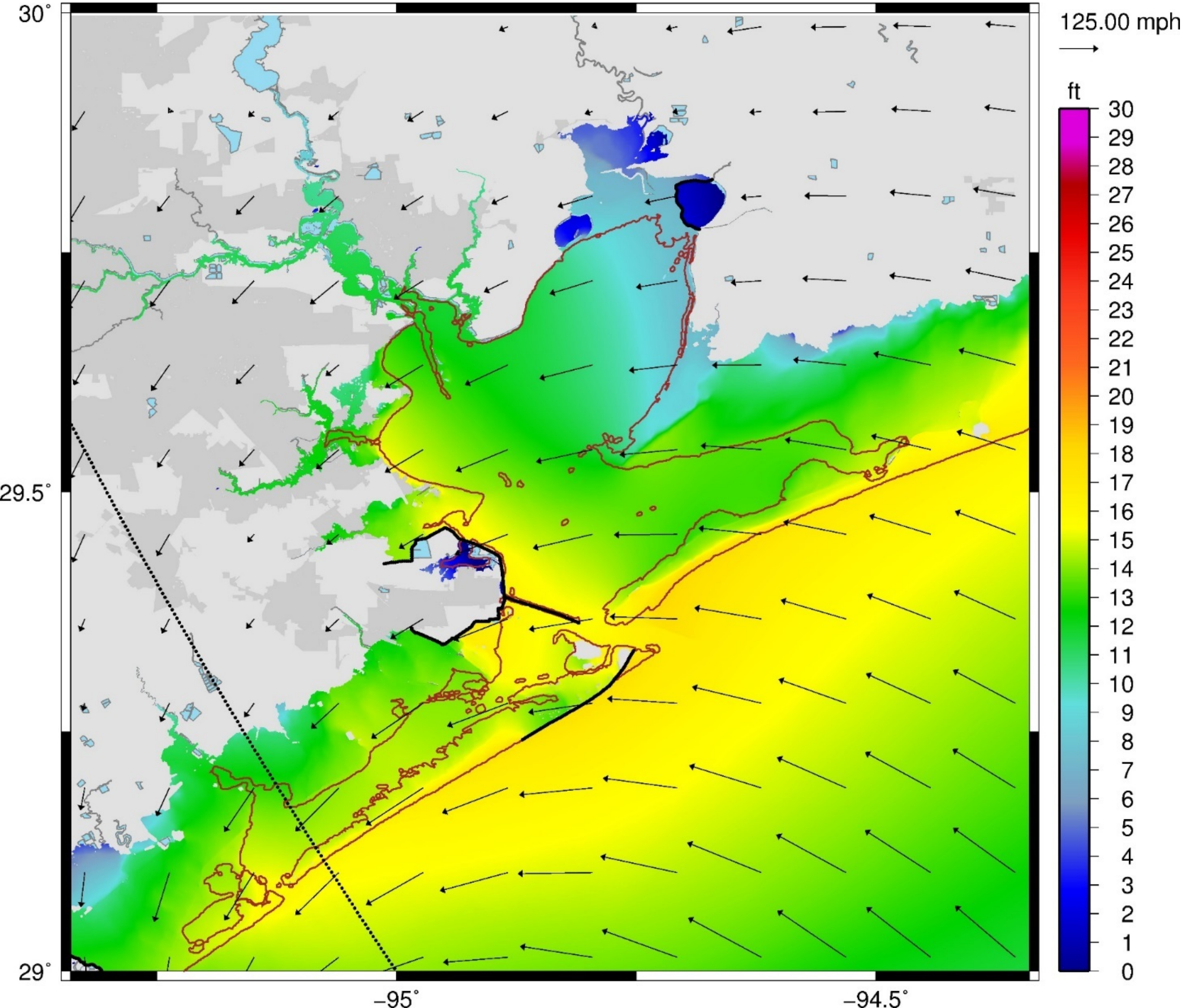
3 hr. prior to landfall



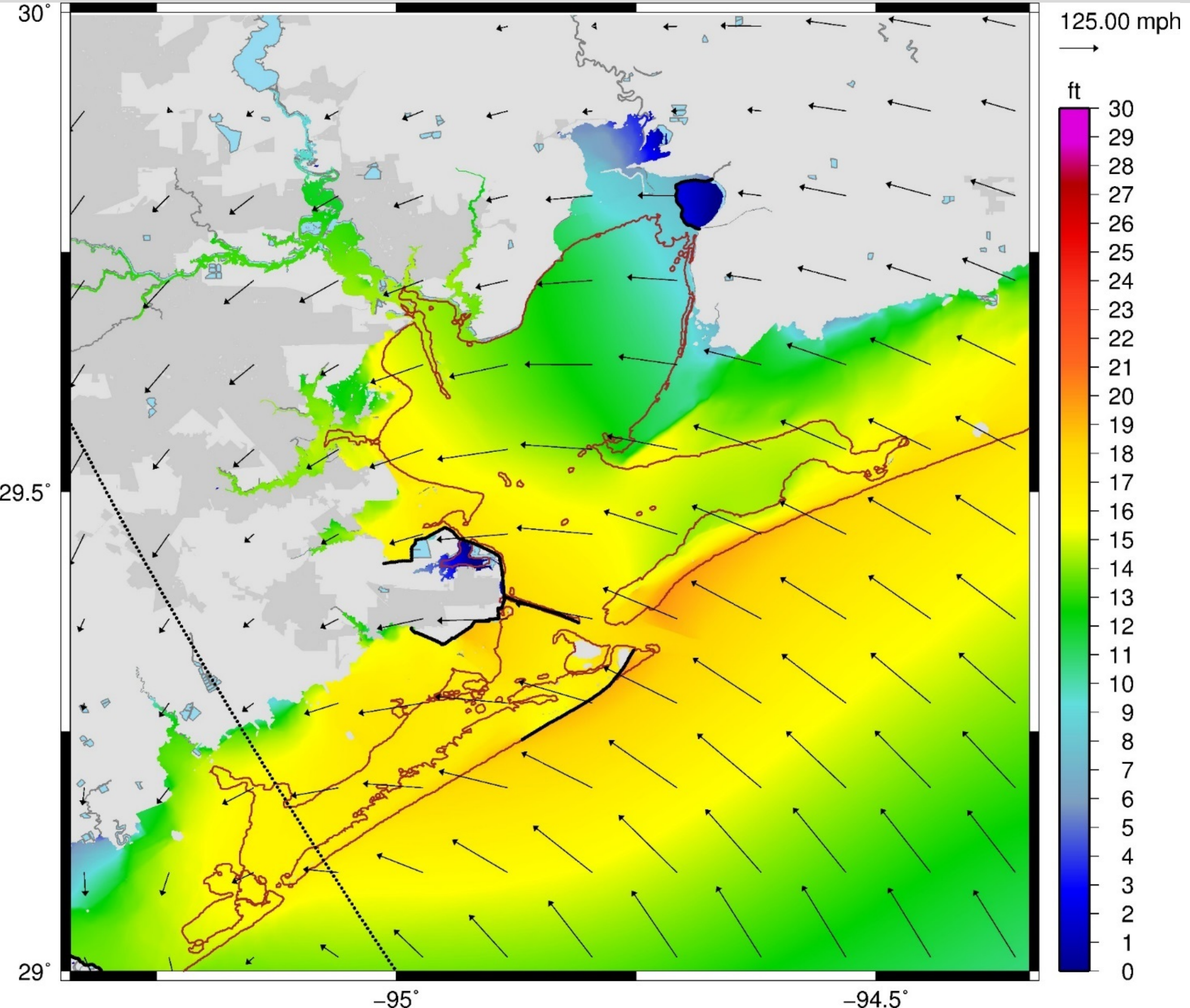
2 hr. prior to landfall



1 hr. prior to landfall



Landfall



30˚
29.5˚
29˚
−95˚
−94.5˚
125.00 mph
ft
30
29
28
27
26
25
24
23
22
21
20
19
18
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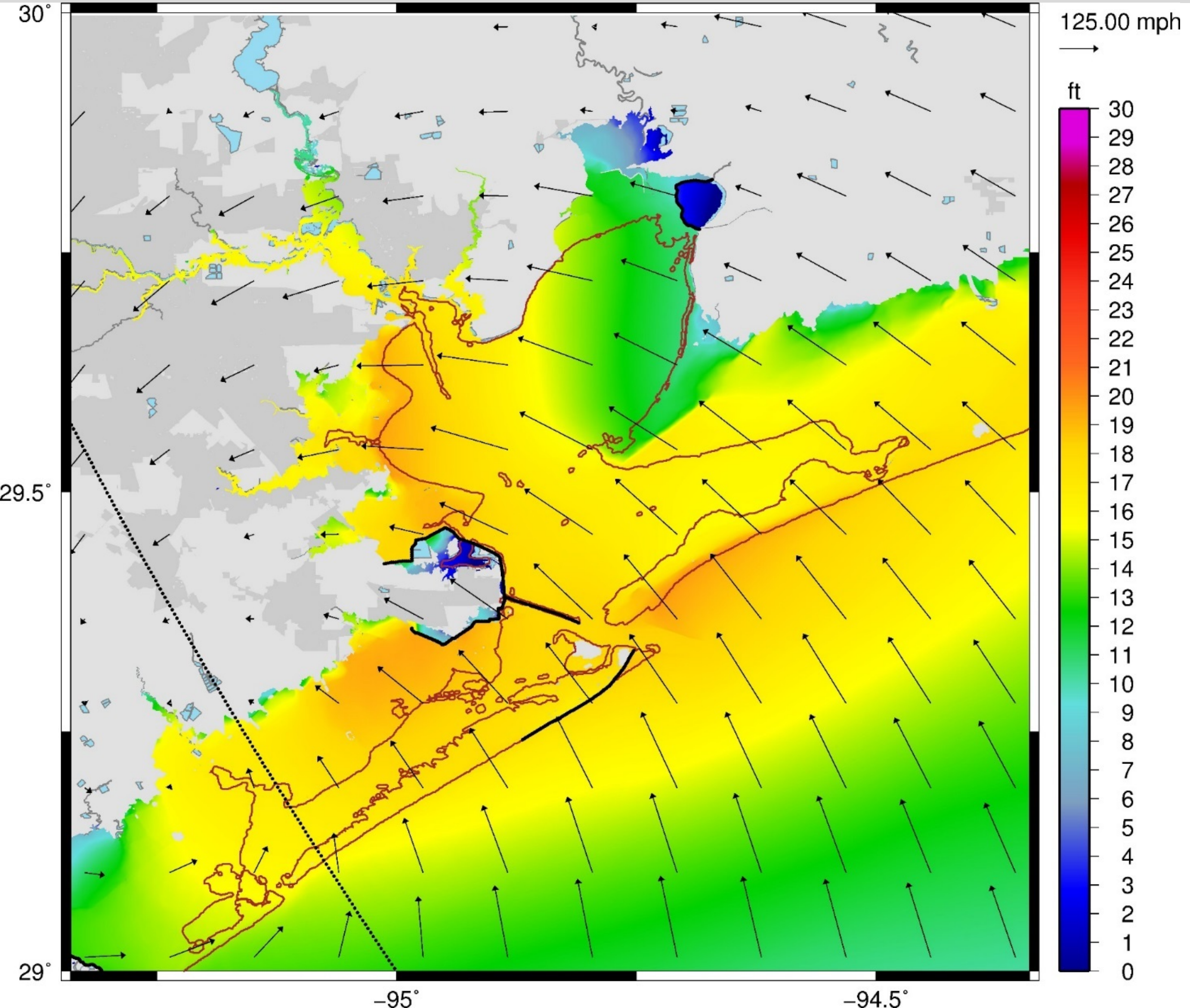
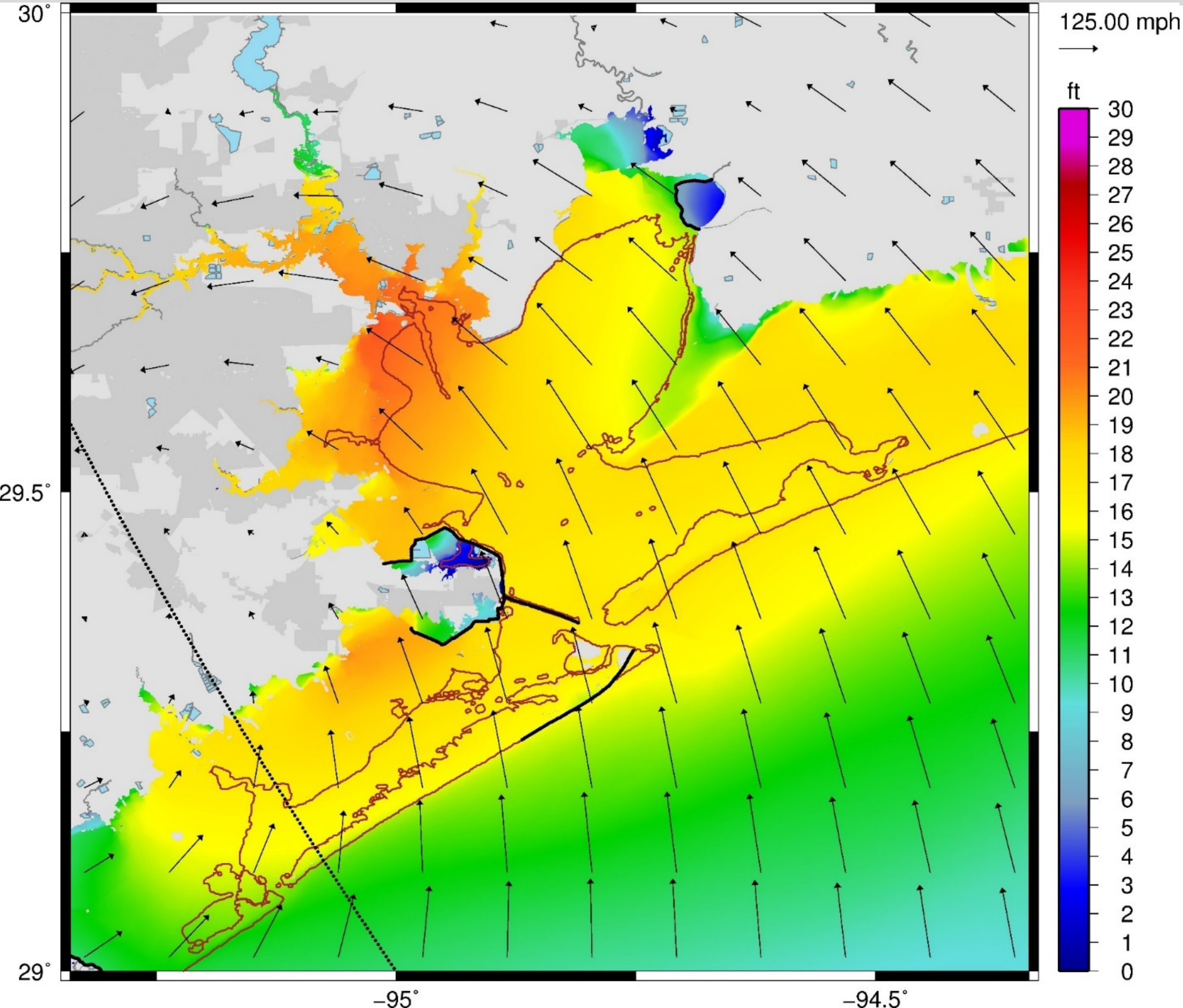
0

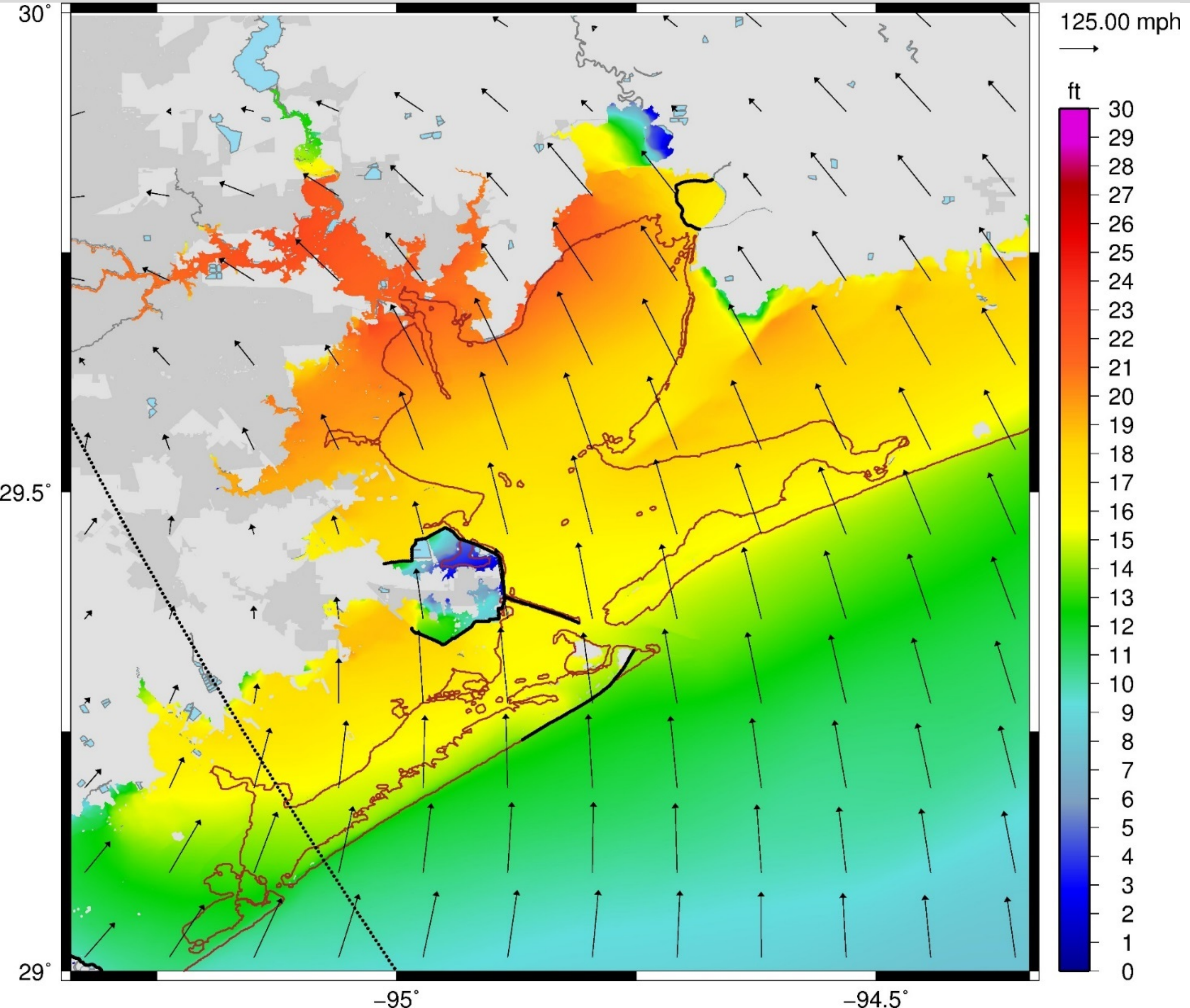
1 hr. after landfall



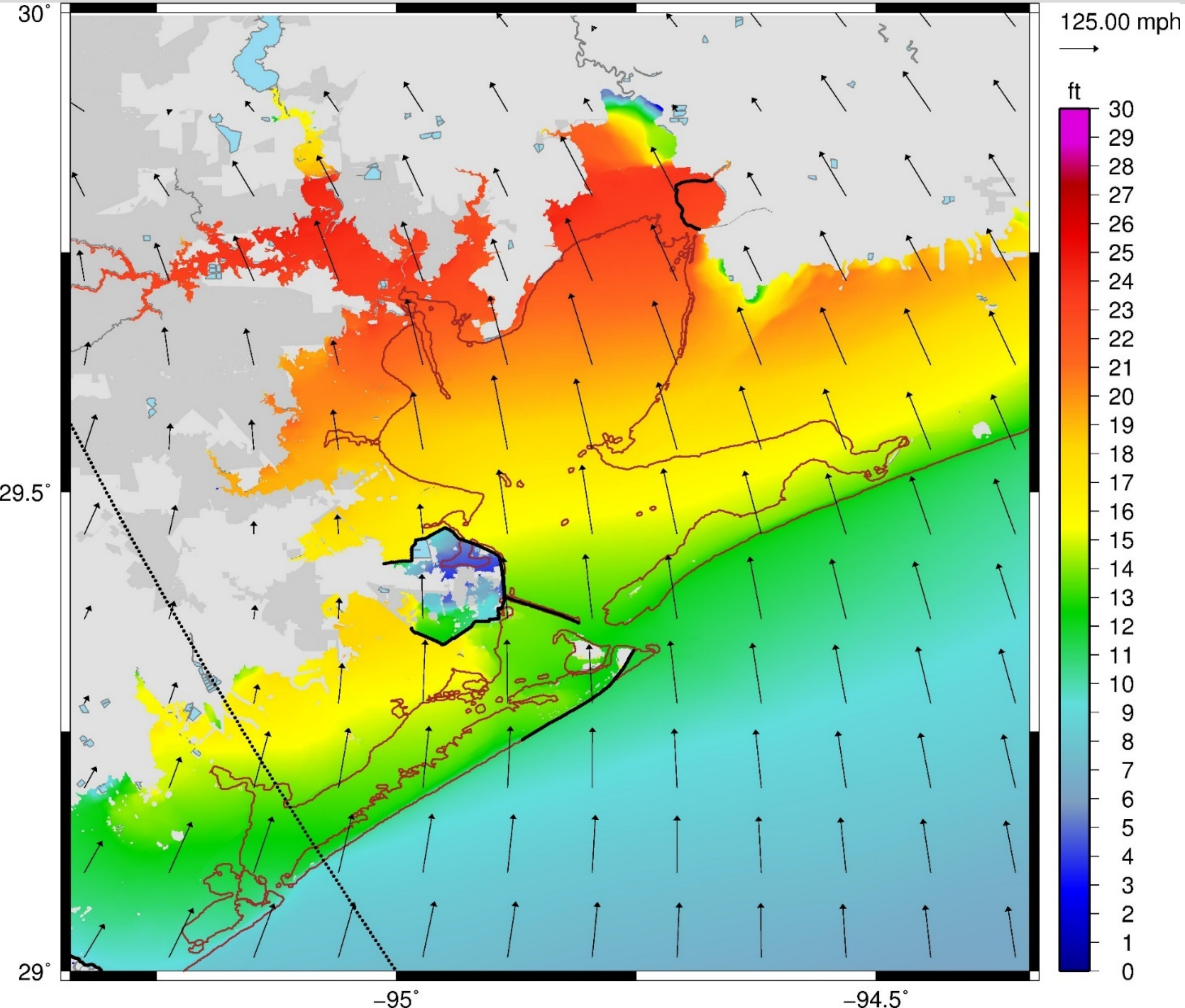
2 hr. after landfall



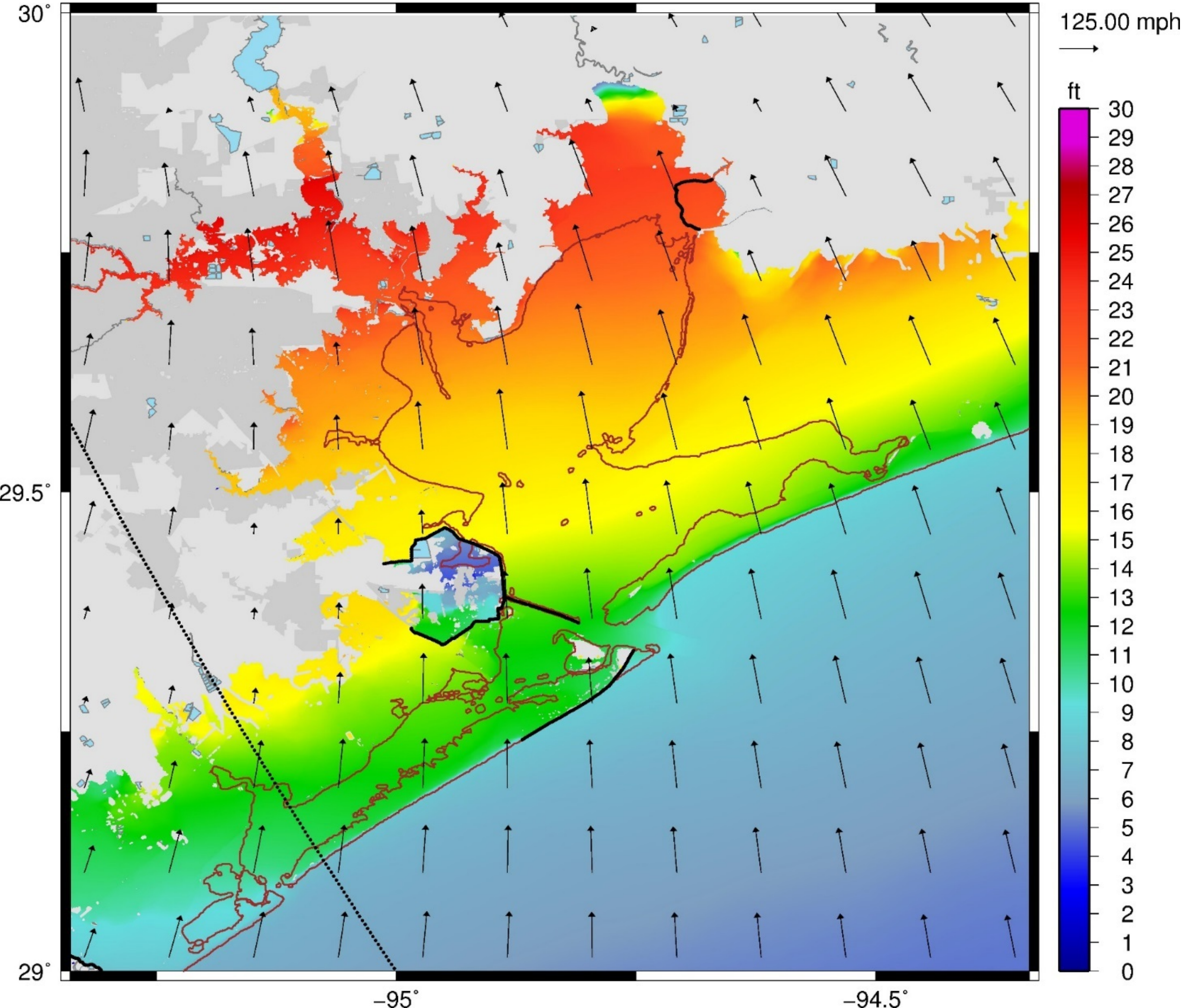
3 hr. after landfall



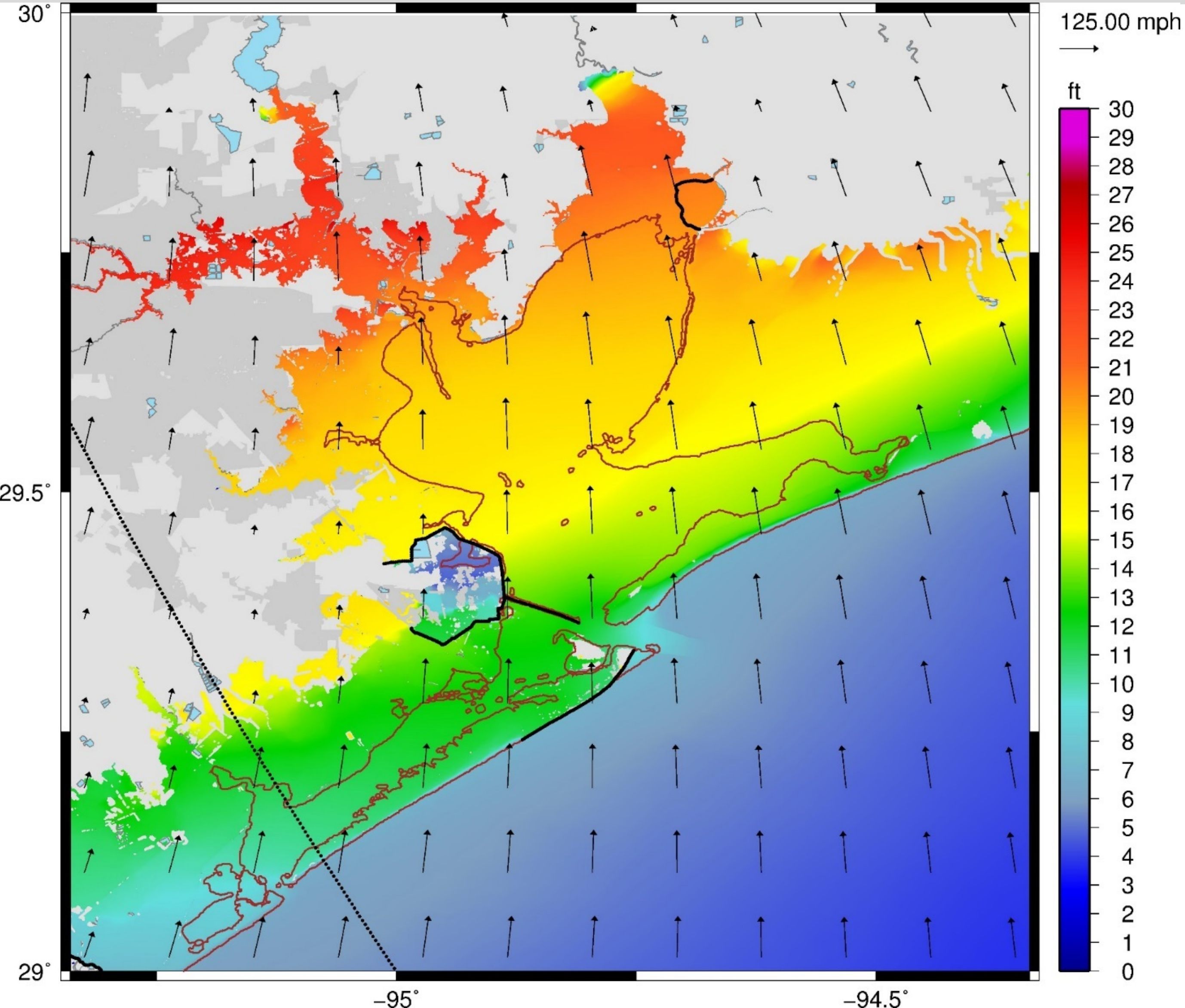
4 hr. after landfall



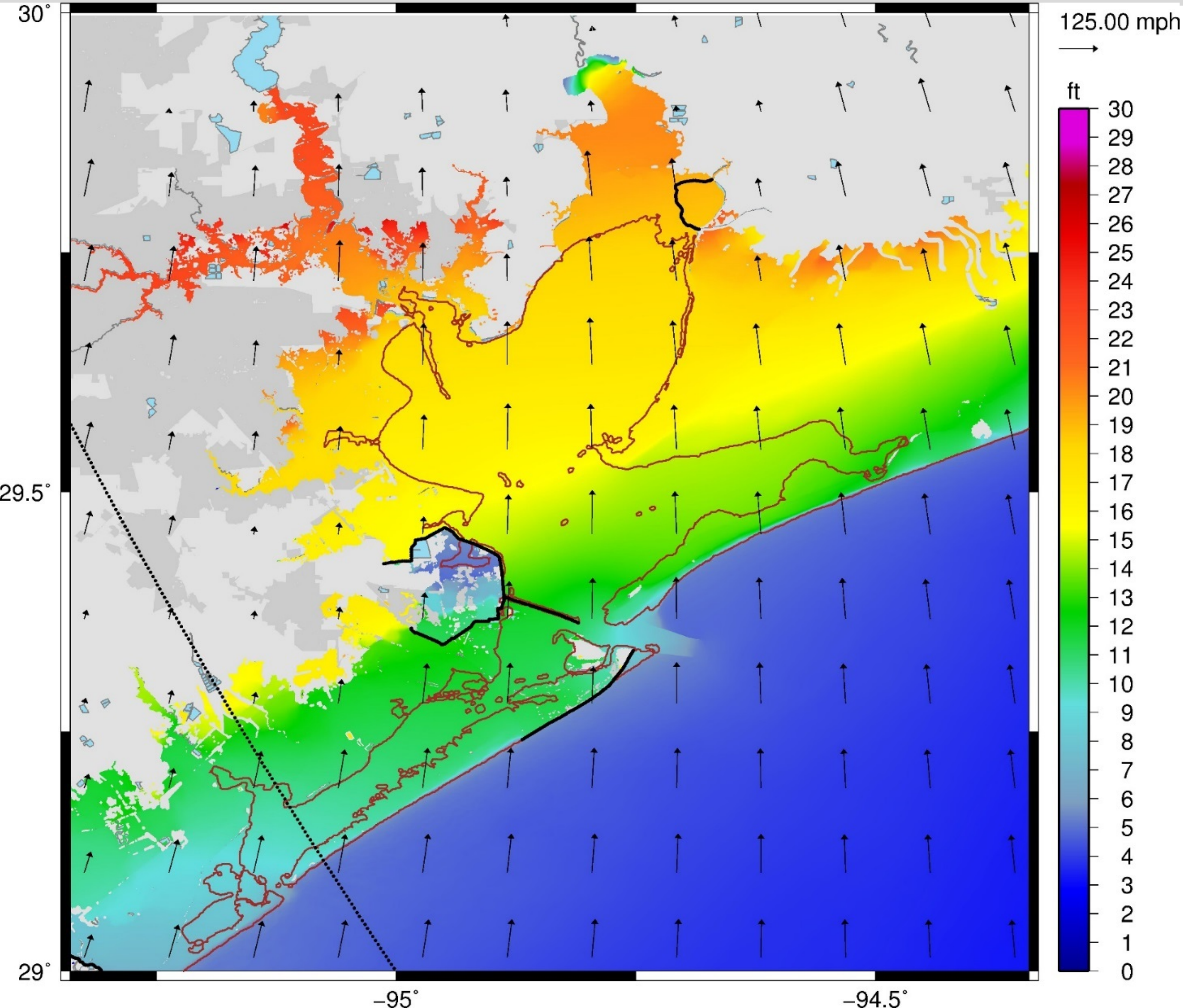
5 hr. after landfall



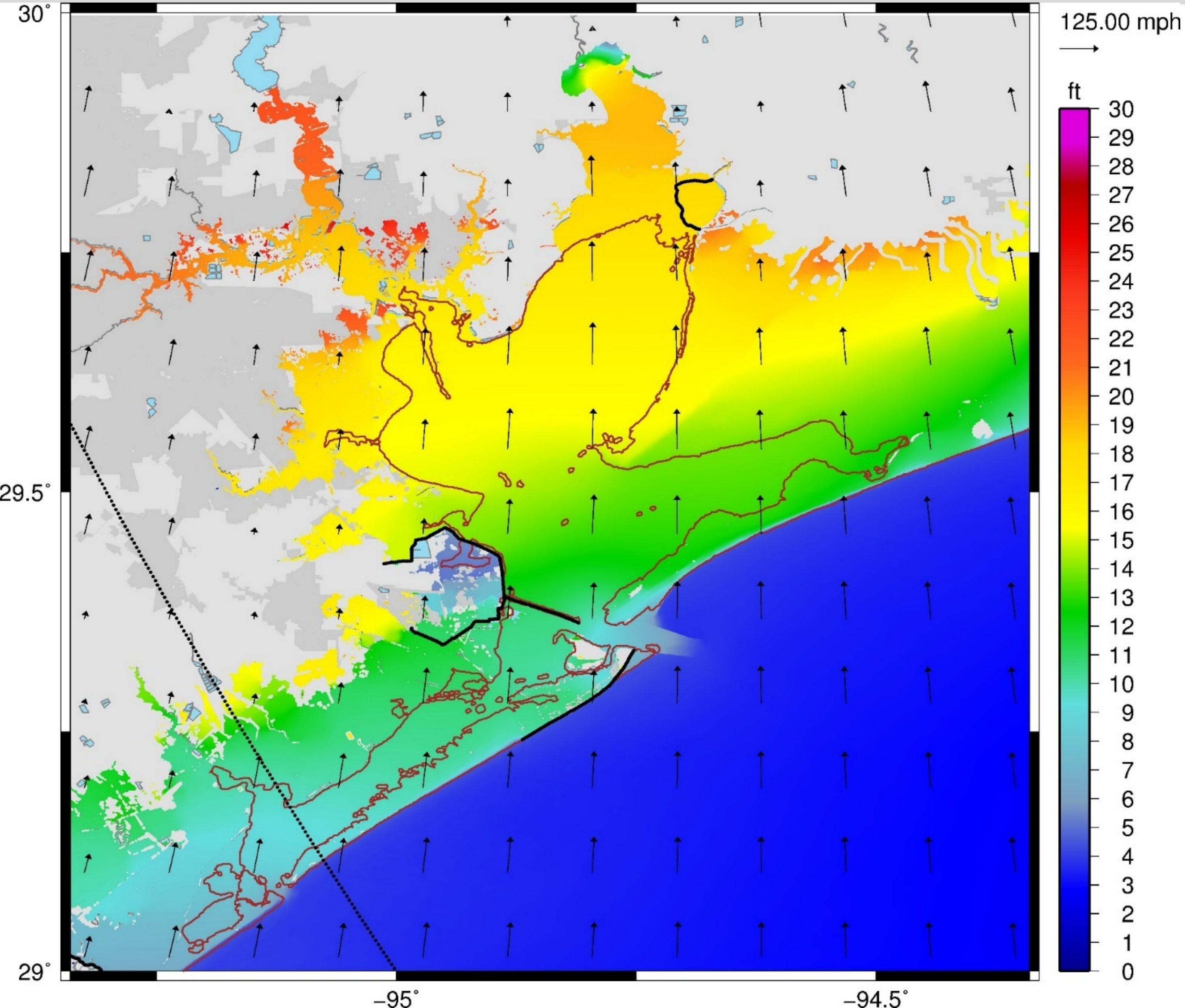
6 hr. after landfall



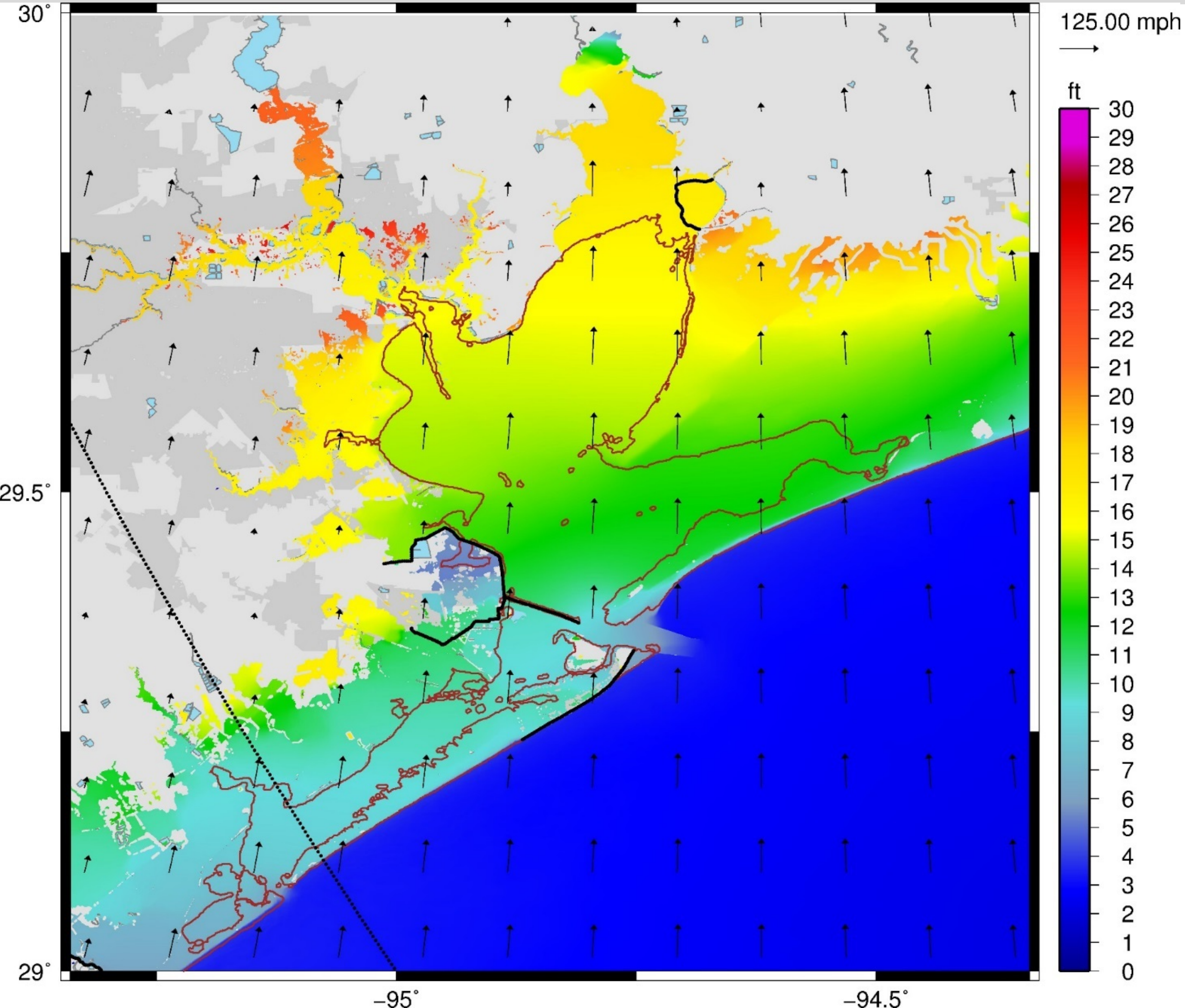
7 hr. after landfall



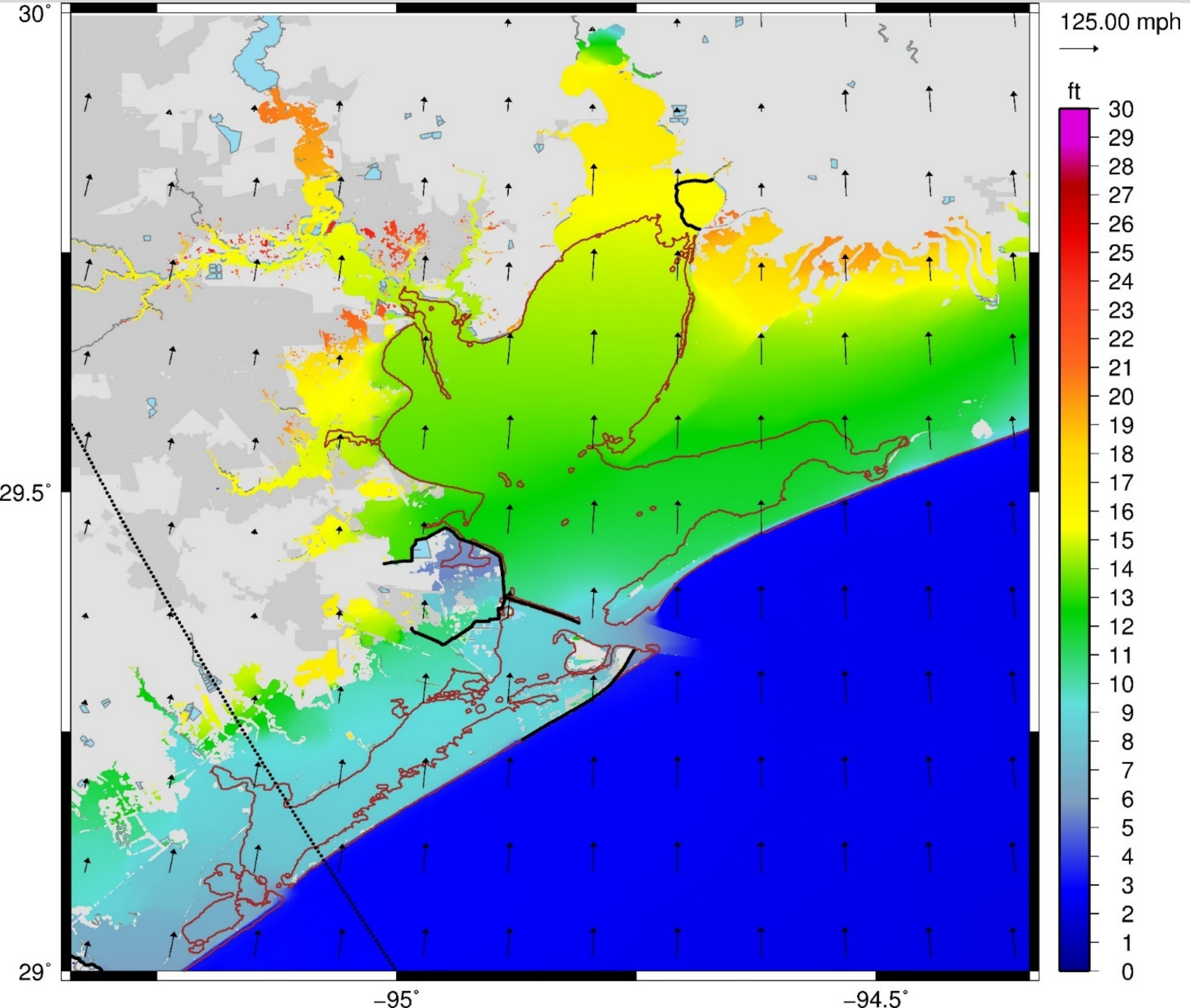
8 hr. after landfall



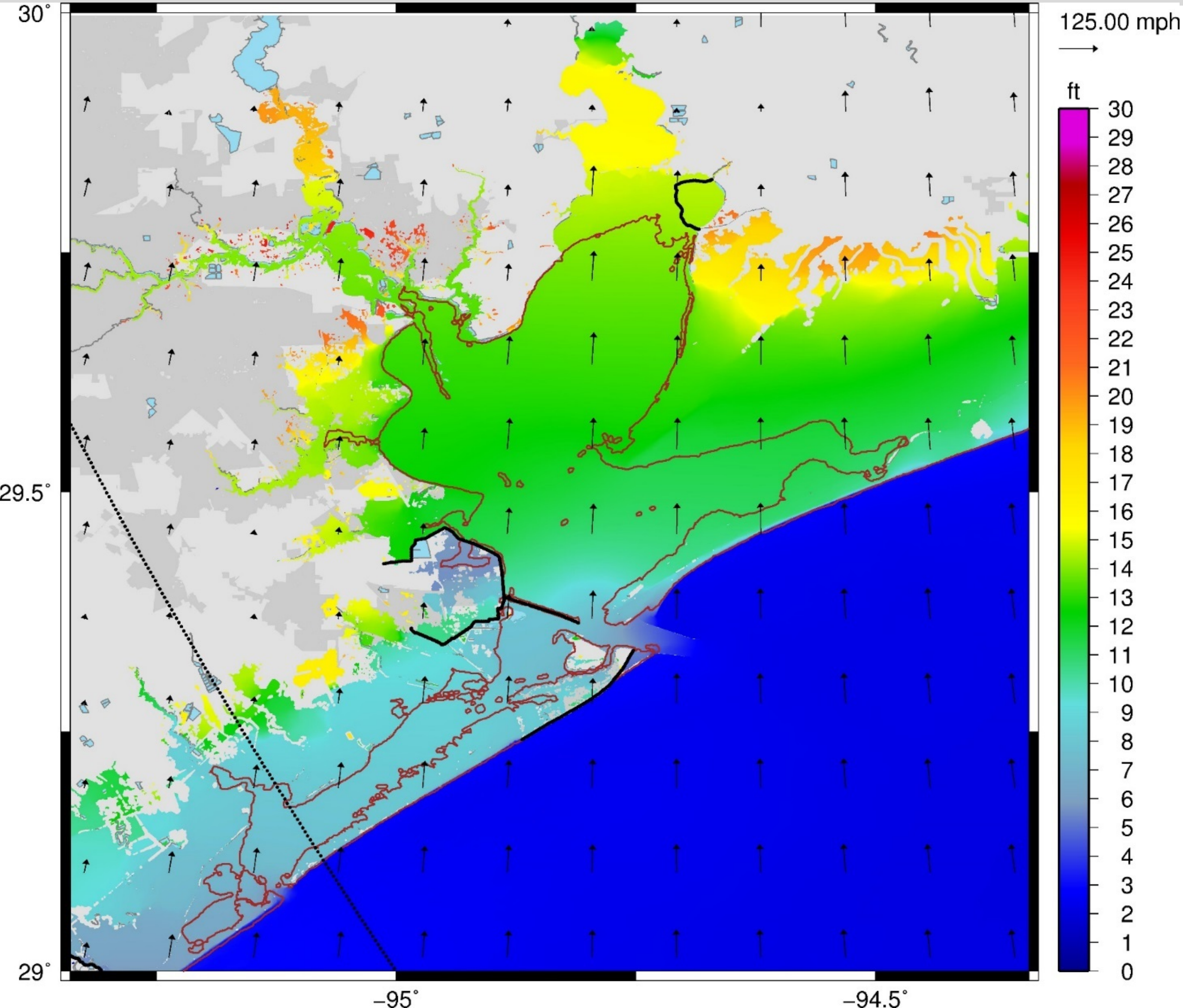
9 hr. after landfall



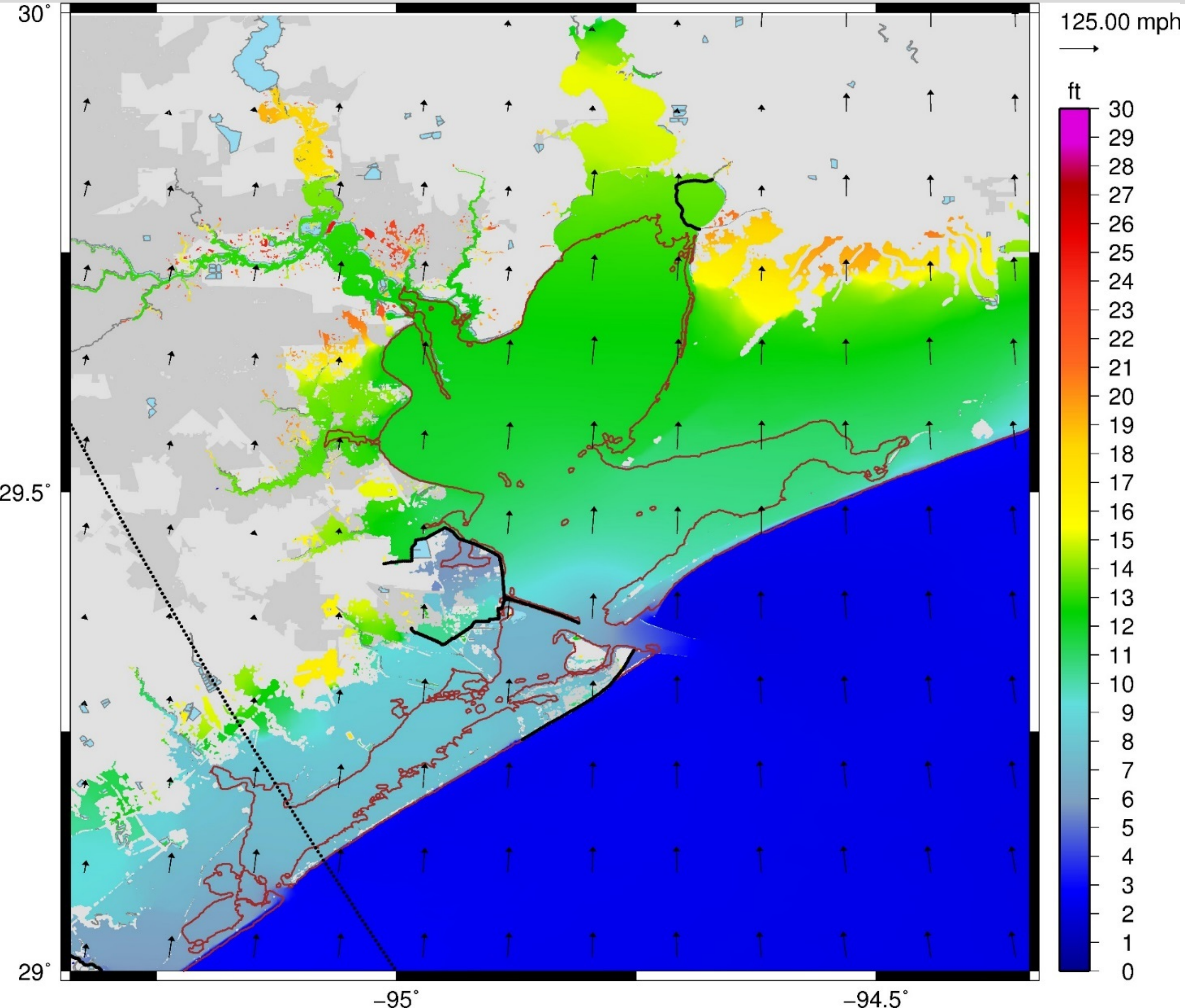
10 hr. after landfall



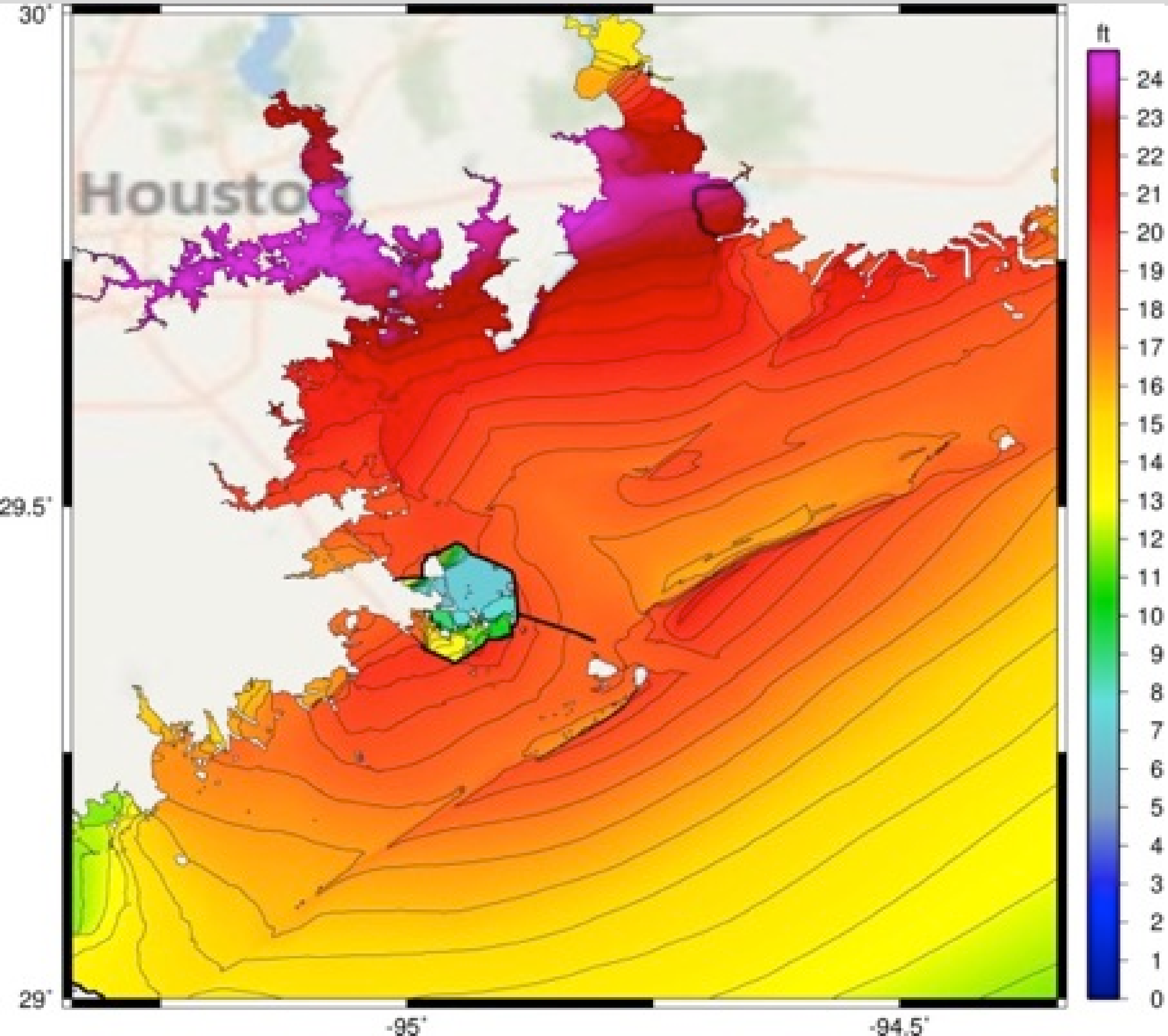
11 hr. after landfall



12 hr. after landfall



Comprehensive Storm Surge Impacts



Ike + 15% Making Landfall Near San Luis Pass

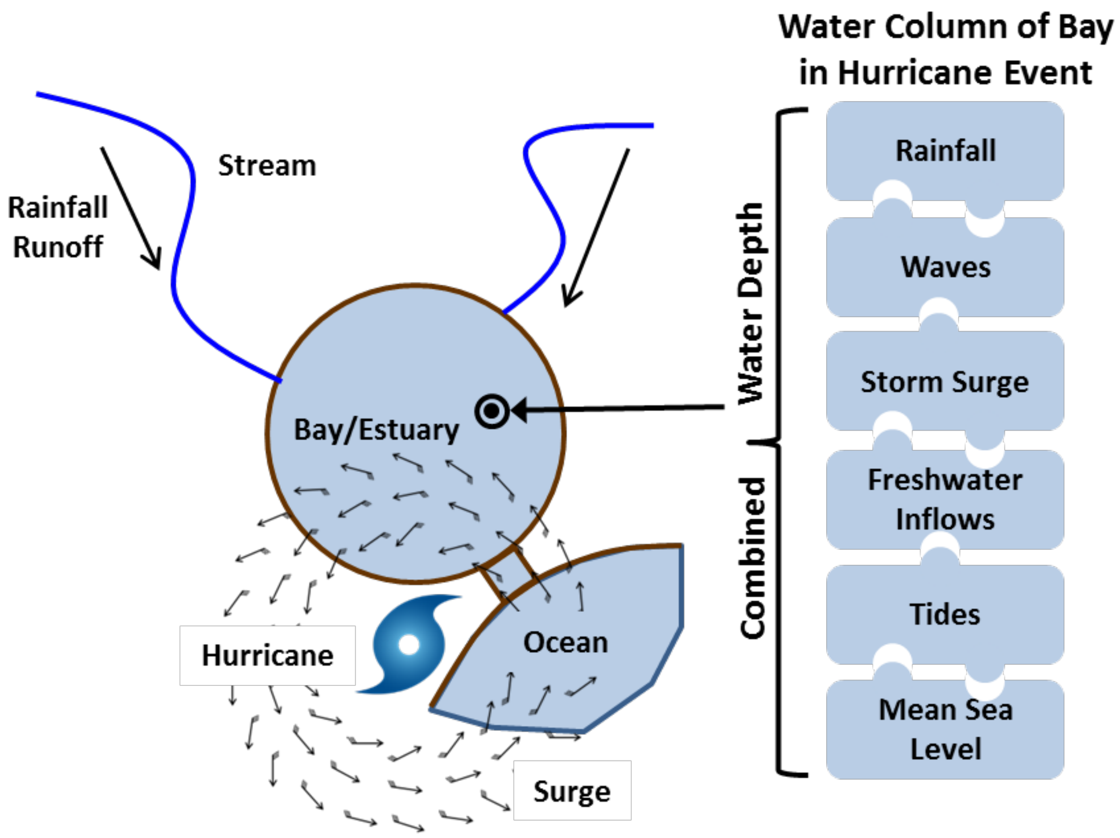
Phase 3: HGAPS (2014-2017)

A regional, comprehensive approach to storm surge risk management:

<u>Multiple lines of defense</u>

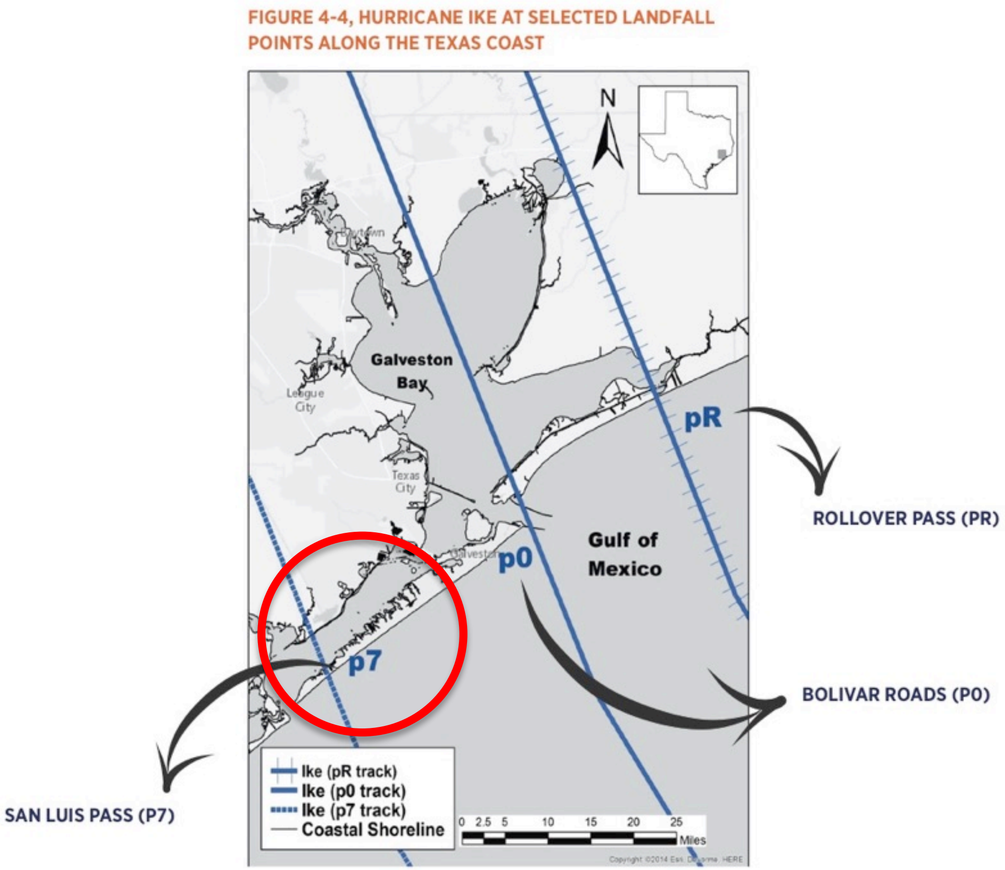
- Building gates and levees
- Raising roadways
- Constructing enclosed dredge containment berms
- Restoring oyster reefs and creating wetlands

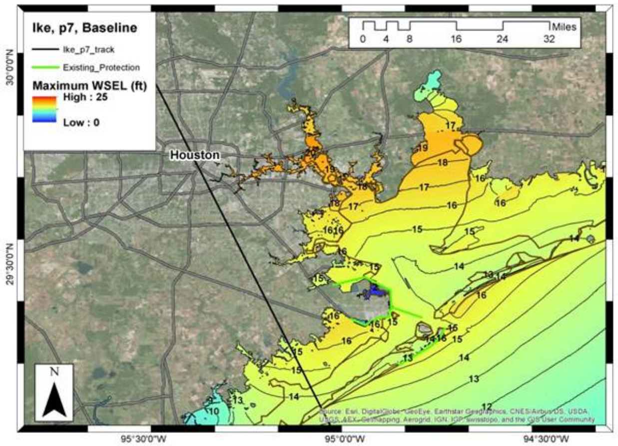
Storm Surge Basics – Residual Surge in Bay

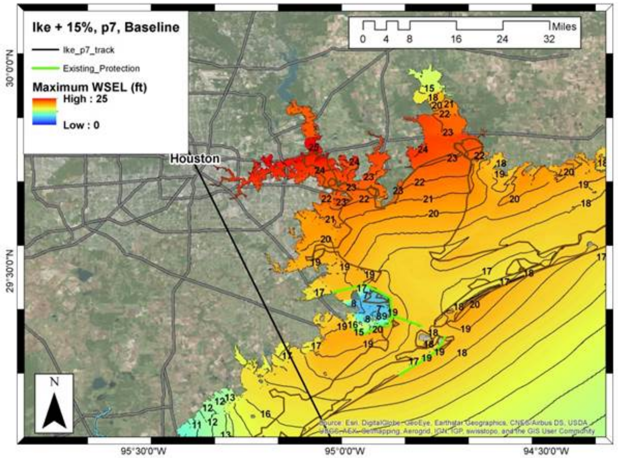


Phase 3: “Hurricane Ike” Simulation

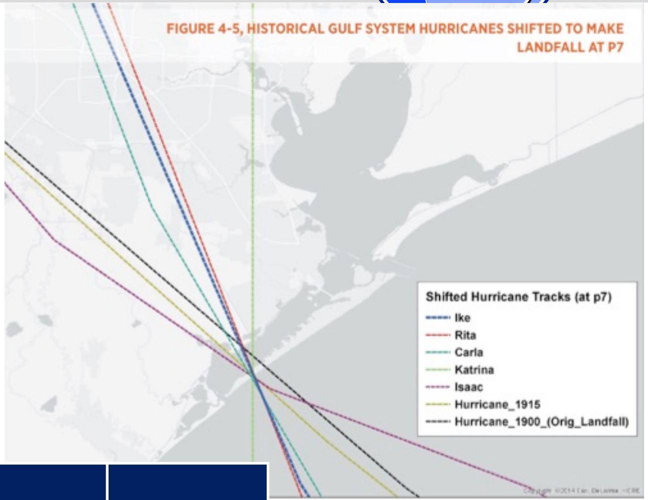
Initial Evaluation of 3 Landfall Locations for Ike







Phase 3: Historic Storm Evaluation



Characteristics of Historic Hurricanes in the Gulf of Mexico

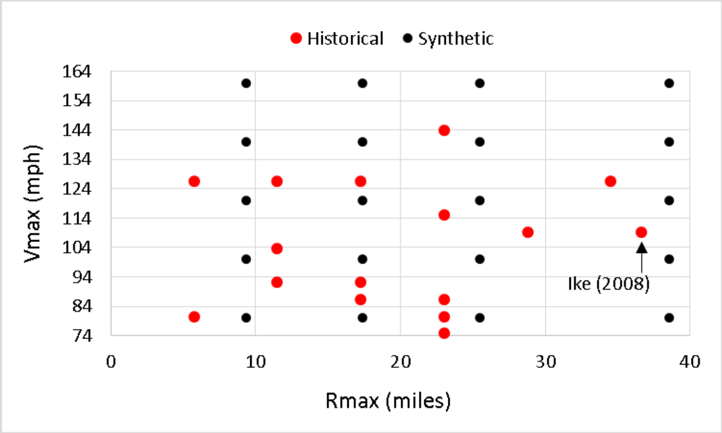
Table 4-1. Historical Gulf System Hurricane Characteristics

Hurricane	Year	Date of Landfall	U.S. Landfall Location	Saffir-Simpson Category	Min. Central Pressure (mb)	Radius to Maximum Winds (mi)	Max. Sustained Winds (mph)	Max. Water Level (ft)
Camille	1969	Aug. 18	MS	5	909	< 15	200	24.6
Katrina	2005	Aug. 29	LA	3	920	29 to 35	127	28
Ivan	2004	Sept. 16	AL/FL	3	943	46 to 58	121	10 to 15
Carla	1961	Sept. 11	TX	3	931	40	115	18.5
Rita	2005	Sept. 24	TX	3	930	35 to 45	115	15
Ike	**2008**	**Sept. 13**	**TX**	**2**	**951**	**46**	**109**	**13**
Gustav	2008	Sept. 1	LA	2	953	-	104	12 to 13
Isaac	2012	Aug. 29	LA	1	965	46 to 52	81	11

Phase 3: Synthetic Storm Simulation

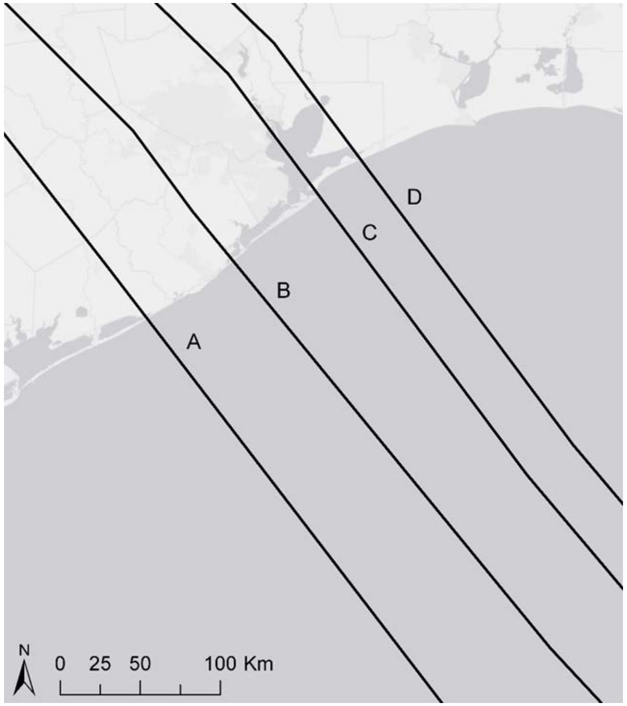
Subsequent Evaluation of 4 Landfall Locations for 20 Different Storms (80 Total)

Storm Intensities and Sizes Simulated for Existing Conditions as compared to Historical Storms



Average Forward Speed (15 mph) and roughly shore-normal angle of approach used for the suite of storms

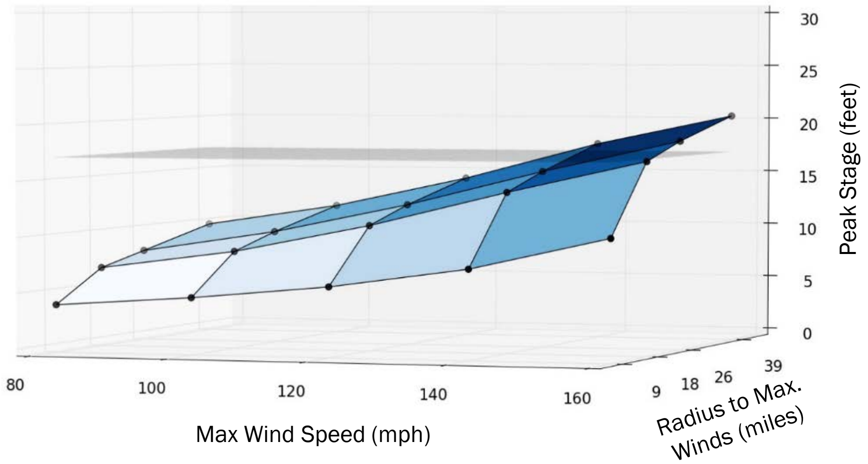
4 landfall locations where synthetic storms were simulated



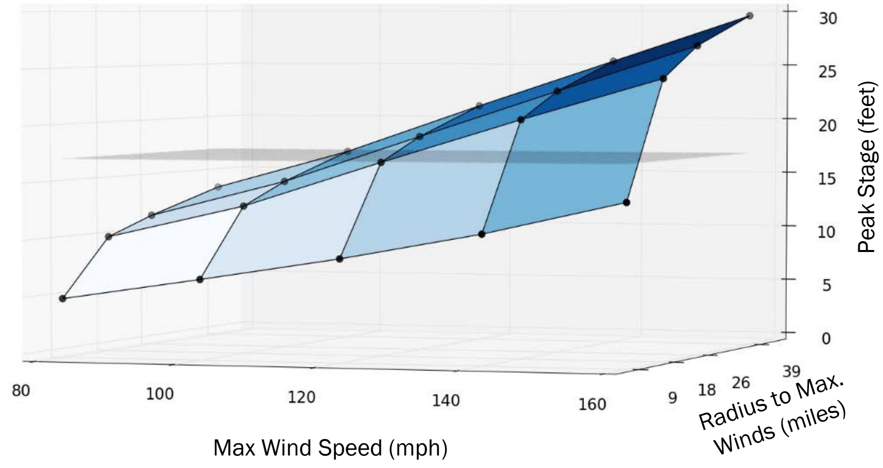
Phase 3: Synthetic Storm Results

Peak Surge Level at Galveston Seawall for Existing Conditions

Direct-hit (Landfall at p0)



Westerly-hit (Landfall just west of p7)



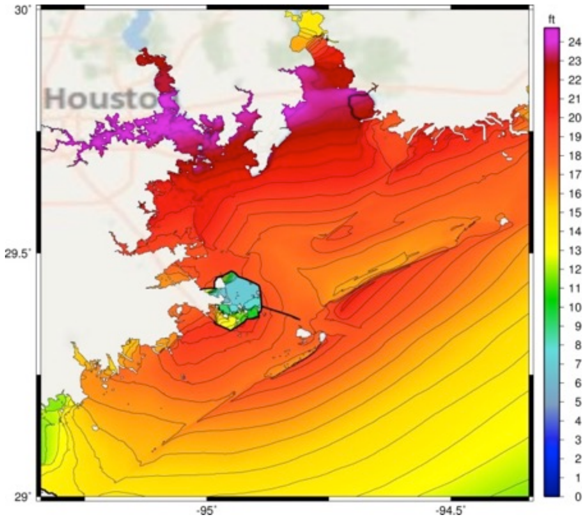
For a **Direct hit**, only the very most intense and largest storms result in over-topping of the Seawall.

For a **Westerly hit**, all 120 mph and greater storms with an Rmax greater than 18 miles result in over-topping of the Seawall.

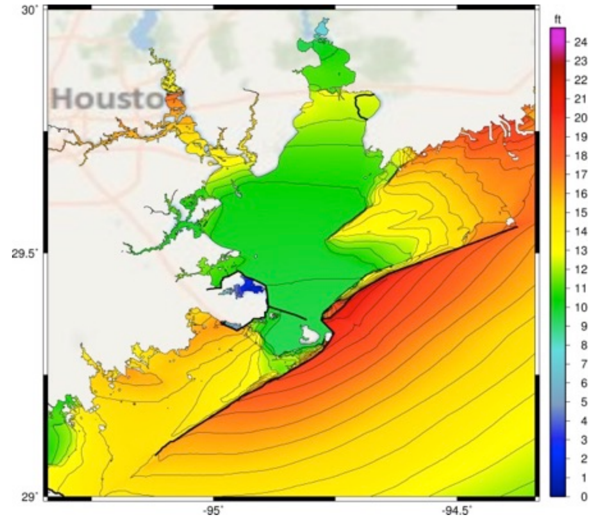
Phase 3: "Ike Dike" Evaluation

Evaluation of the "Ike Dike" Concept

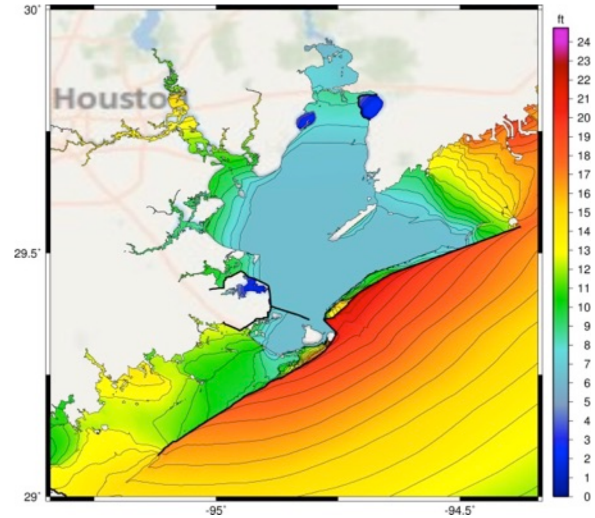
(a) Existing Conditions



(b) **With "Ike Dike"** at 12 ft



(c) **With "Ike Dike"** at 17 ft



ADCIRC analysis for Ike+15%, p7 landfall

Phase 3: Issues with the "Ike Dike"

- Even with a continuous coastal barrier, there will be a **residual surge within the bay** due to the hurricane-force winds pushing the water already in the bay to the west, north and south sides of the bay

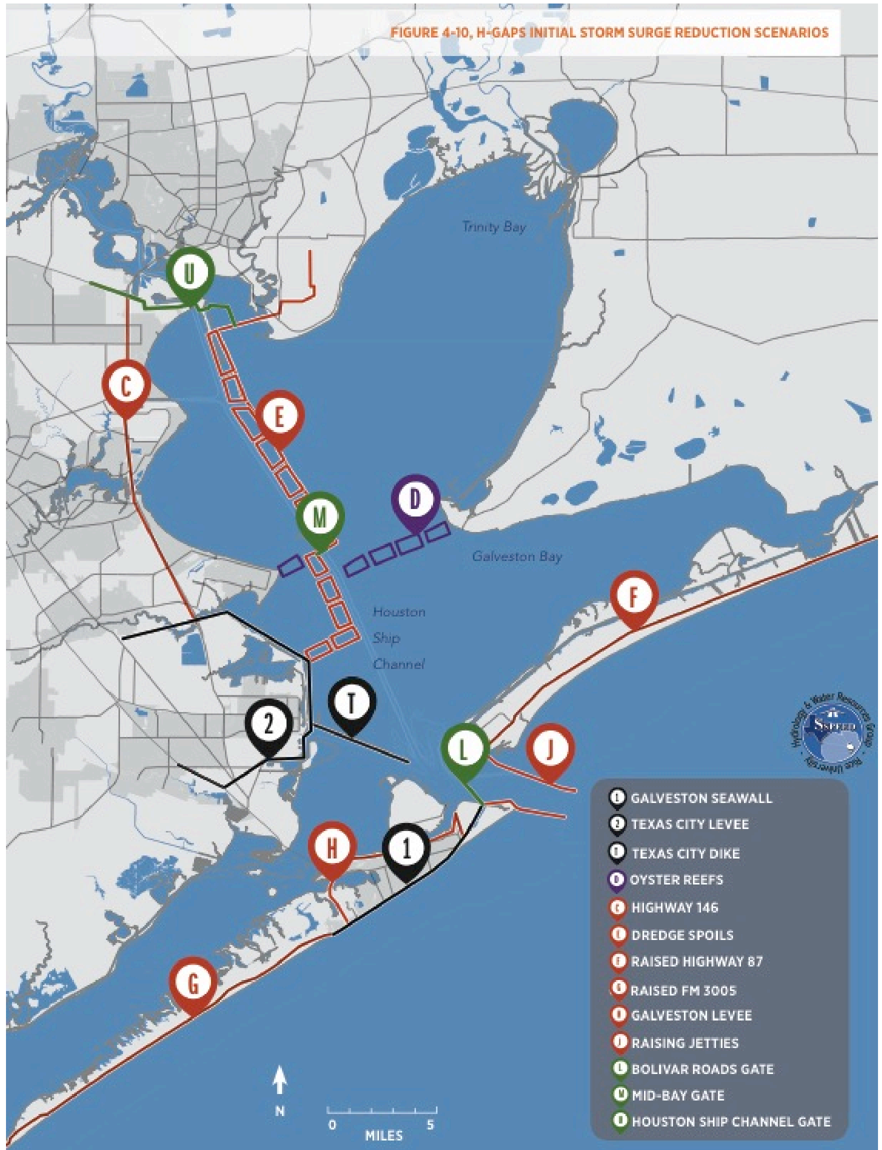
- Any coastal barrier will **eventually be over-topped**, adding to the residual surge in the bay

- Constructing gates across the Bolivar Roads opening will be **difficult, costly and have potential environmental issues**

Phase 3: Multiple Lines of Defense

HGAPS

Initial Evaluation
Of Various Storm
Surge Reduction
Scenarios

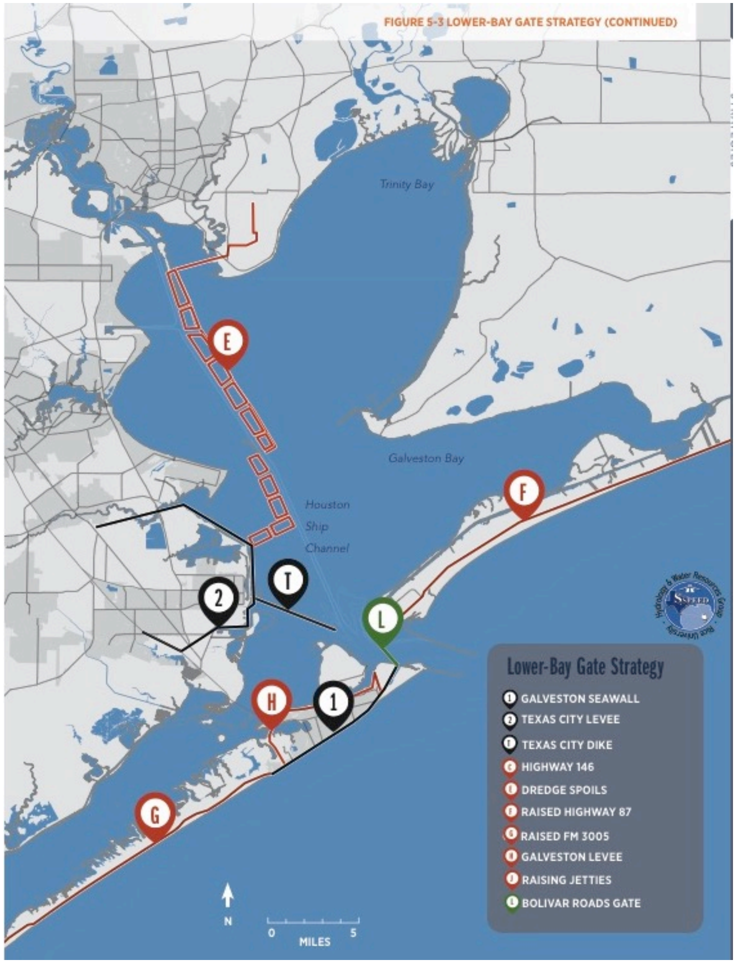


Phase 3: HGAPS Lower-Bay Strategy

Regional Storm Surge Reduction Strategy

<u>“Lower-Bay” Strategy</u>

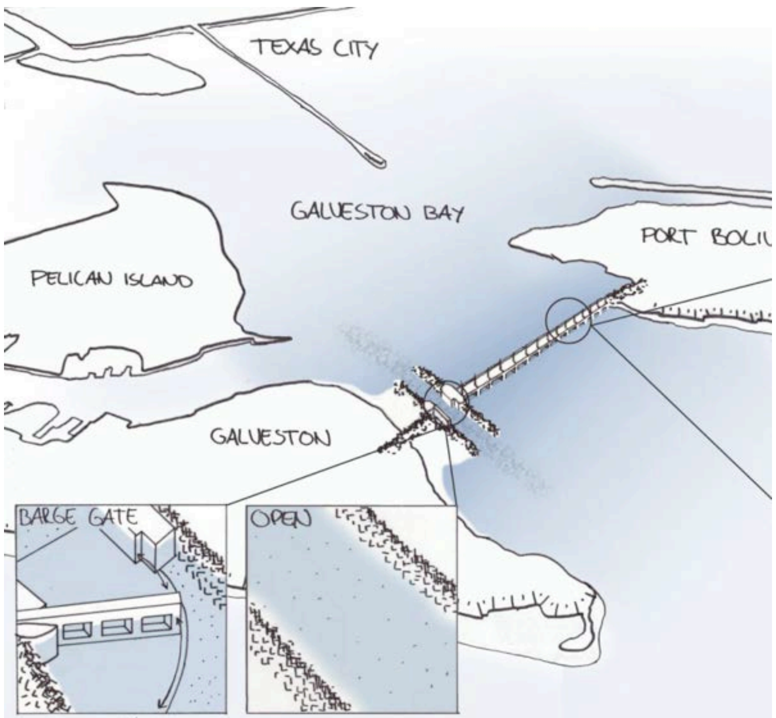
- Coastal Spine (F, 1 and G)
- HSC Gate and Environmental Gate at Bolivar Roads Inlet (L)
- Backside Galveston Levee (H)
- In-bay Berms w/ small gates (E)

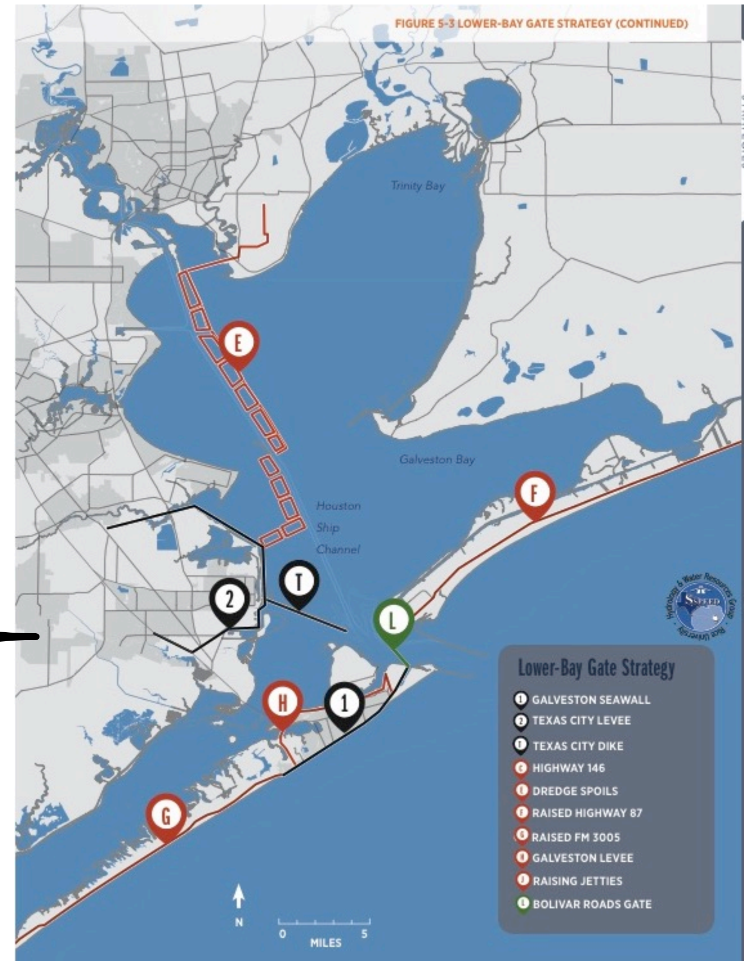


Phase 3: HGAPS Lower-Bay Gates - L

“Lower-Bay” Regional Storm Surge Reduction Strategy

Dutch Schematic prepared for TAMUG





HSC Gate

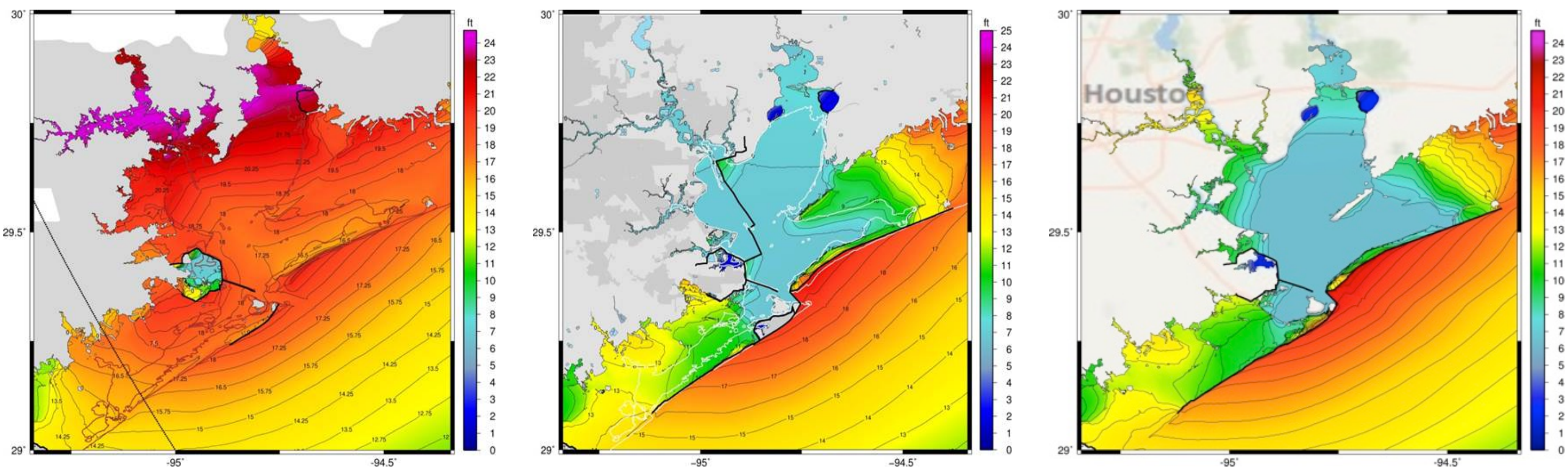
L

Environmental Gate

Phase 3: HGAPS Strategy Evaluation

Evaluation of Strategies: ***Lower-Bay*** *and* ***Ike Dike***

(a) **"Without"** Strategy (b) **"With" Lower-Bay** Strategy (c) **"With" Ike Dike** Strategy

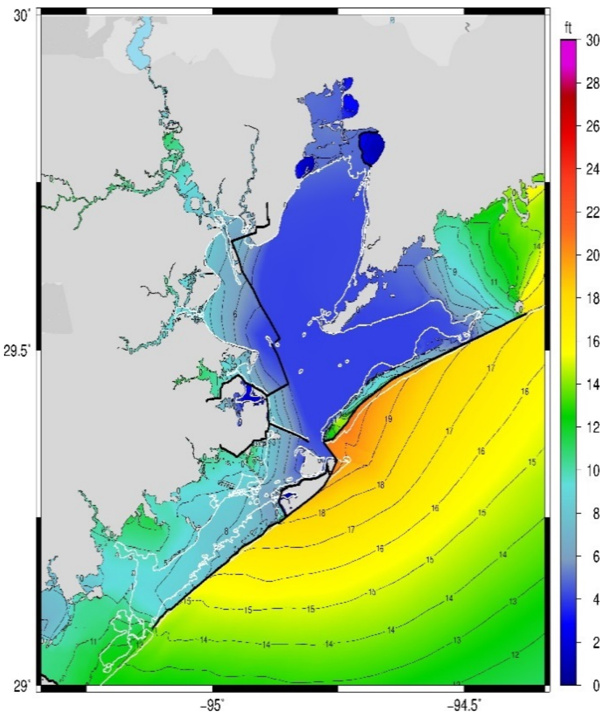


Maximum surge elevations for Ike+15% at p7 landfall for Existing Conditions

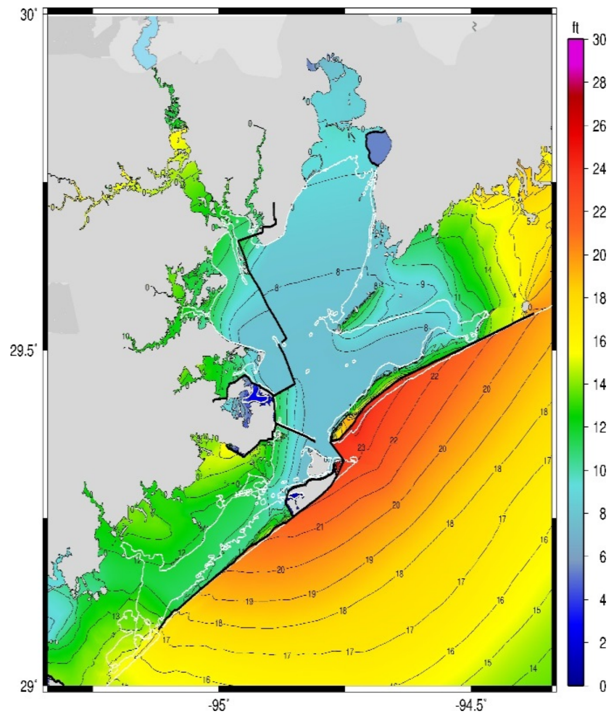
(Note: levee and gate features shown in dark black lines)

Max WSEL: Lower-Bay

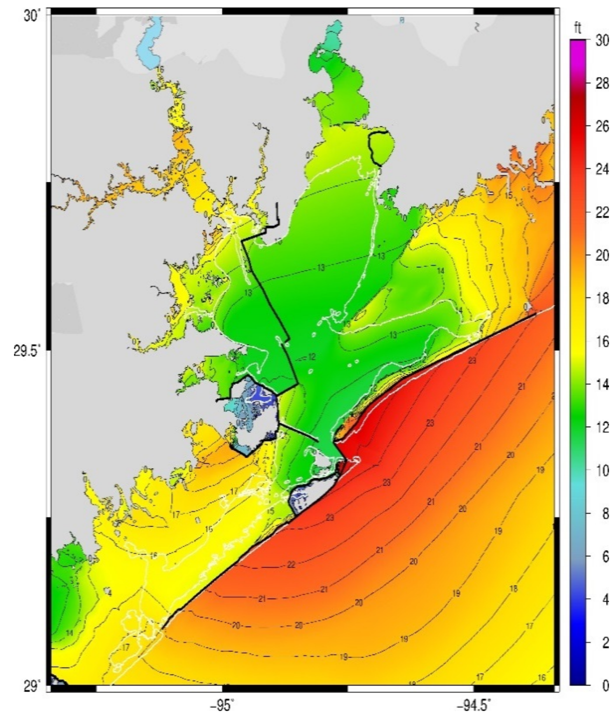
FEMA 33
100-yr



FEMA 36
250-yr



FEMA 36 + SLR
250-yr in 2085



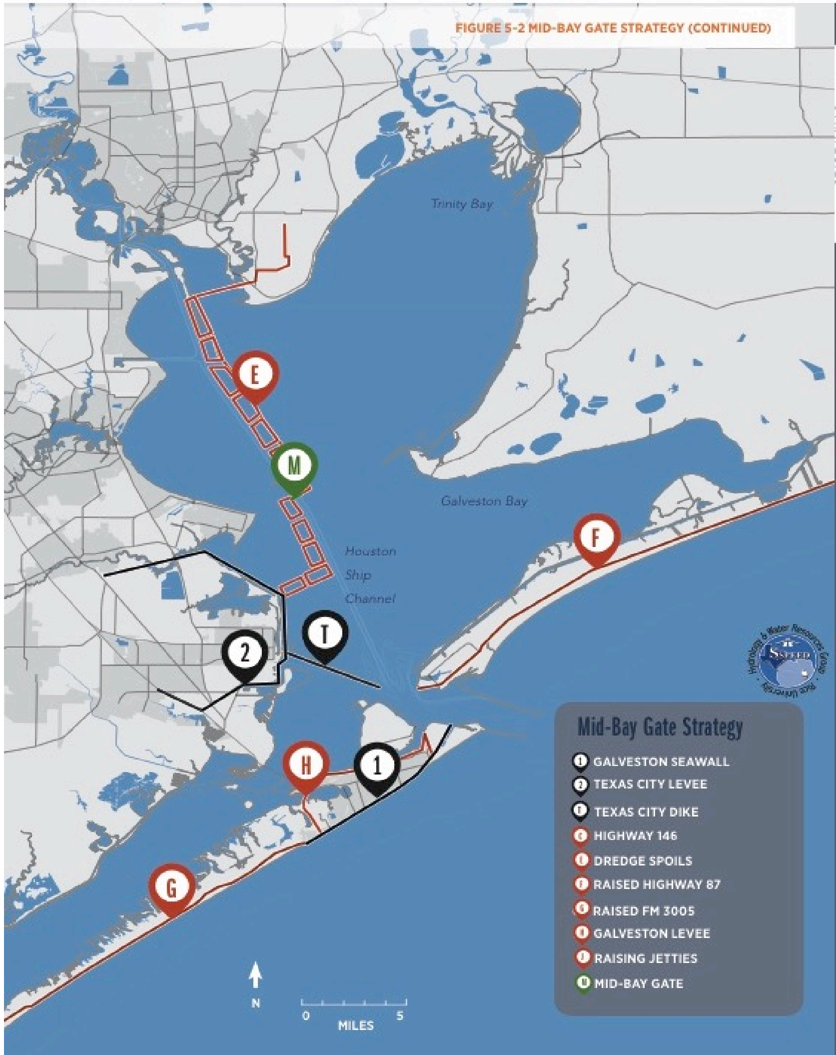
Maximum surge elevations for FEMA Storm 33 and 36 at p7 landfall
(Note: levee and gate features shown in dark black lines)

Phase 3: HGAPS Mid-Bay Strategy

Regional Storm Surge Reduction Strategy

<u>"Mid-Bay" Strategy</u>

- Coastal Spine (**F**, 1 and **G**)
- HSC Gate in middle of Galveston Bay (**M**)
- Backside Galveston Levee (**H**)
- In-bay Berms with small gates (**E**)



Phase 3: HGAPS In-Bay Berms

Phase 3: HGAPS Mid-Bay Gate - M

"Mid-Bay" Regional Storm Surge Reduction Strategy

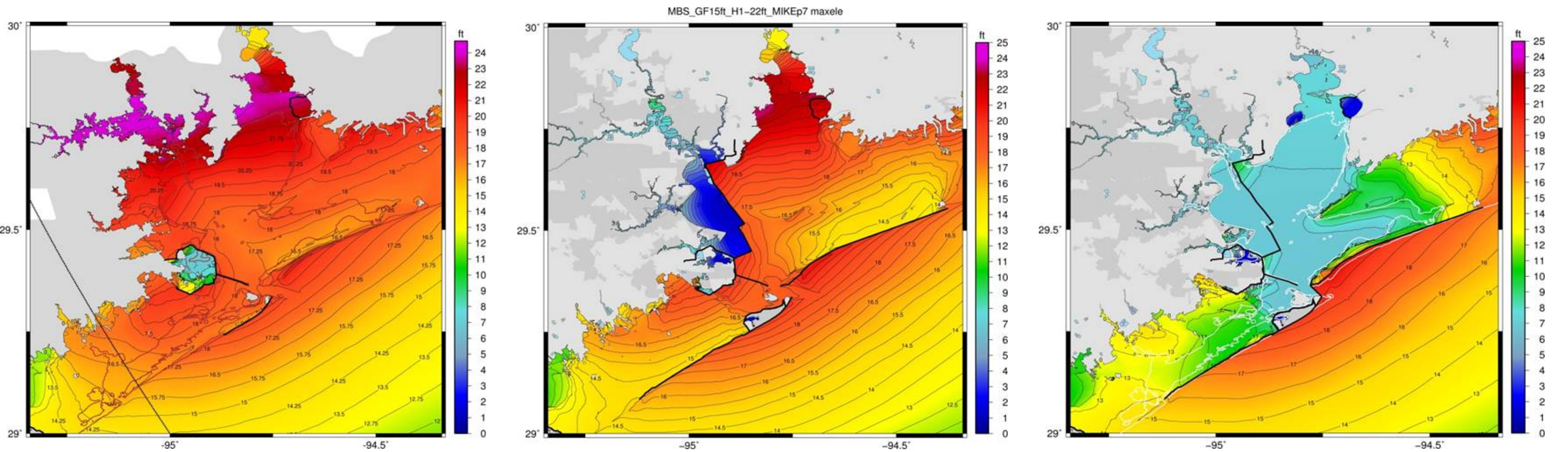
Phase 3: HGAPS Strategy Evaluation

Evaluation of Strategies: <u>Mid-Bay</u> and <u>Lower-Bay</u>

a) **"Without"** Strategy

b) **"With" Mid-Bay** Strategy

(c) **"With" Lower-Bay** Strategy

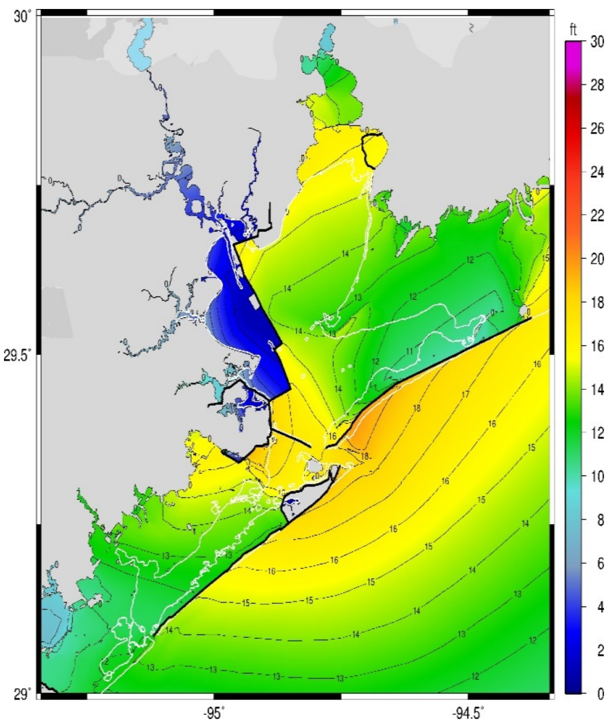


Maximum Surge Elevations for Ike+15% at p7 landfall

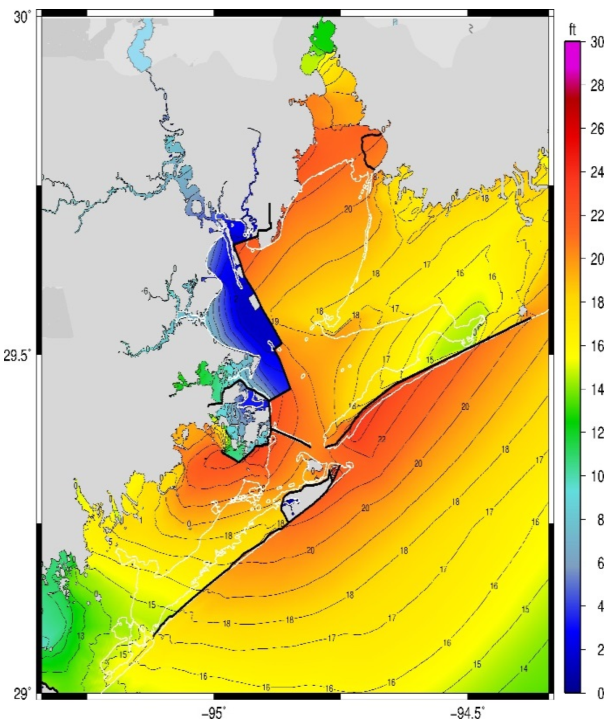
(Note: levee and gate features shown in dark black lines)

Max WSEL: Mid-Bay

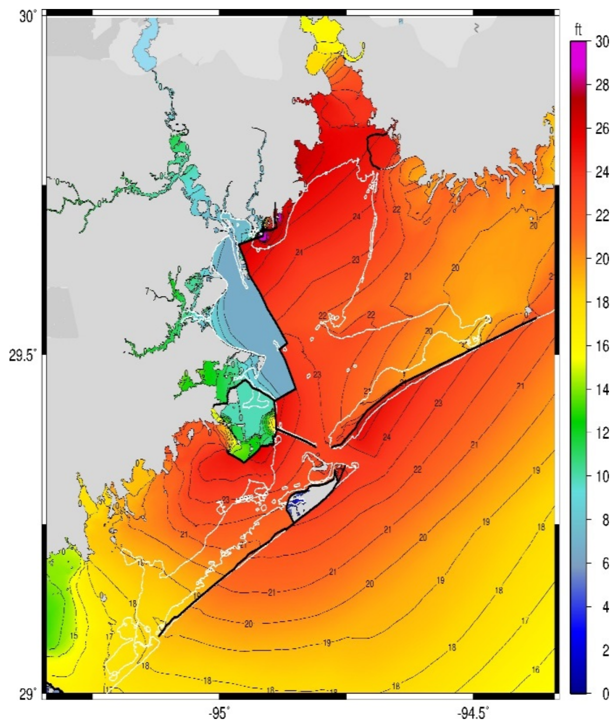
FEMA 33
100-yr



FEMA 36
250-yr



FEMA 36 + SLR
250-yr in 2085



Maximum surge elevations for FEMA Storm 33 and 36 at p7 landfall
(Note: levee and gate features shown in dark black lines)

FEMA Design Storm Analysis

Storm[1]	Stage (ft) at Seawall / Clear Lake / HSC											
	Baseline			Coastal Spine			Lower-Bay			Mid-Bay		
	Seawall	Clear Lake	HSC	Seawall	Clear Lake	HSC	Seawall	Clear Lake	HSC	Seawall	Clear Lake	HSC
FEMA-33	18	16.5	21	19	10	12	19	8	11	18.5	5	4
Ike+15%	19	19	24	19. 5	11	13.5	19.5	9	10	19	5.5	5
FEMA-36	21.5	21	26	22.5	12	16.5	22.5	11	15	21.5	7	6
FEMA-36 + SLR for 2085	23.5	24	29	24	16.5	20.5	24	16	19	23.5	12	12

[1] = Landfall at P7
[2] = Observed at Pier 21

Approximate Return Period[2]	Storm[2]
100-yr	FEMA-33
150-yr	Ike+15%
250-yr	FEMA-36
250-yr in 2085	FEMA-36 + SLR for 2085

Example from the Dutch

Zuiderzee

- 26 km long
- Provides protection to Amsterdam area
- Road between Flevoland and North Holland
- Planned to be part of a polder (not completed)

Phase 3: Preliminary Cost Estimates

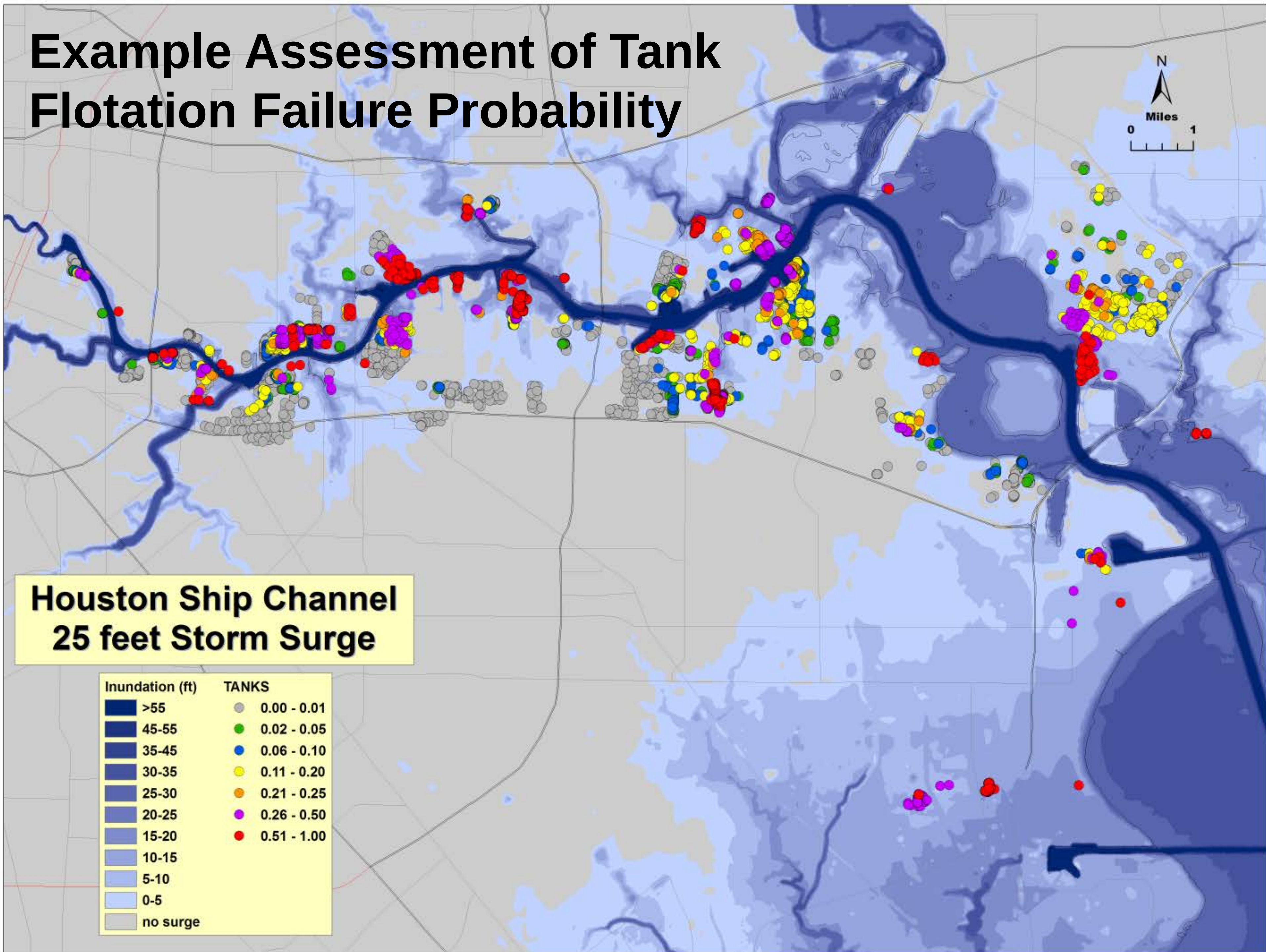
H-GAPS Strategy	Description	Cost Estimate
Mid-Bay **Gate at M**	Navigation gate across the HSC ("**M**"), with levees and dredged containment berms along the HSC within the Bay connecting it to high ground ("E"), Backside Galveston Levee ("H"), and raising the roadways of Hwy 87 ("F") and FM-3005 ("G")	**$2.76 B**
Lower-Bay **Gate at L**	Navigation gate across the HSC, along with an environmental gate across the rest of Bolivar Roads, with levees connecting the gates into high ground ("**L**"), with levees and dredged containment berms along the HSC within the Bay ("E"), Backside Galveston Levee ("H"), and raising the roadways of Hwy 87 ("F") and FM-3005 ("G")	**$7.62 B**

Residential Damages

Table 6-1. Residential Flood Damage Estimates (using Ike15-p7)

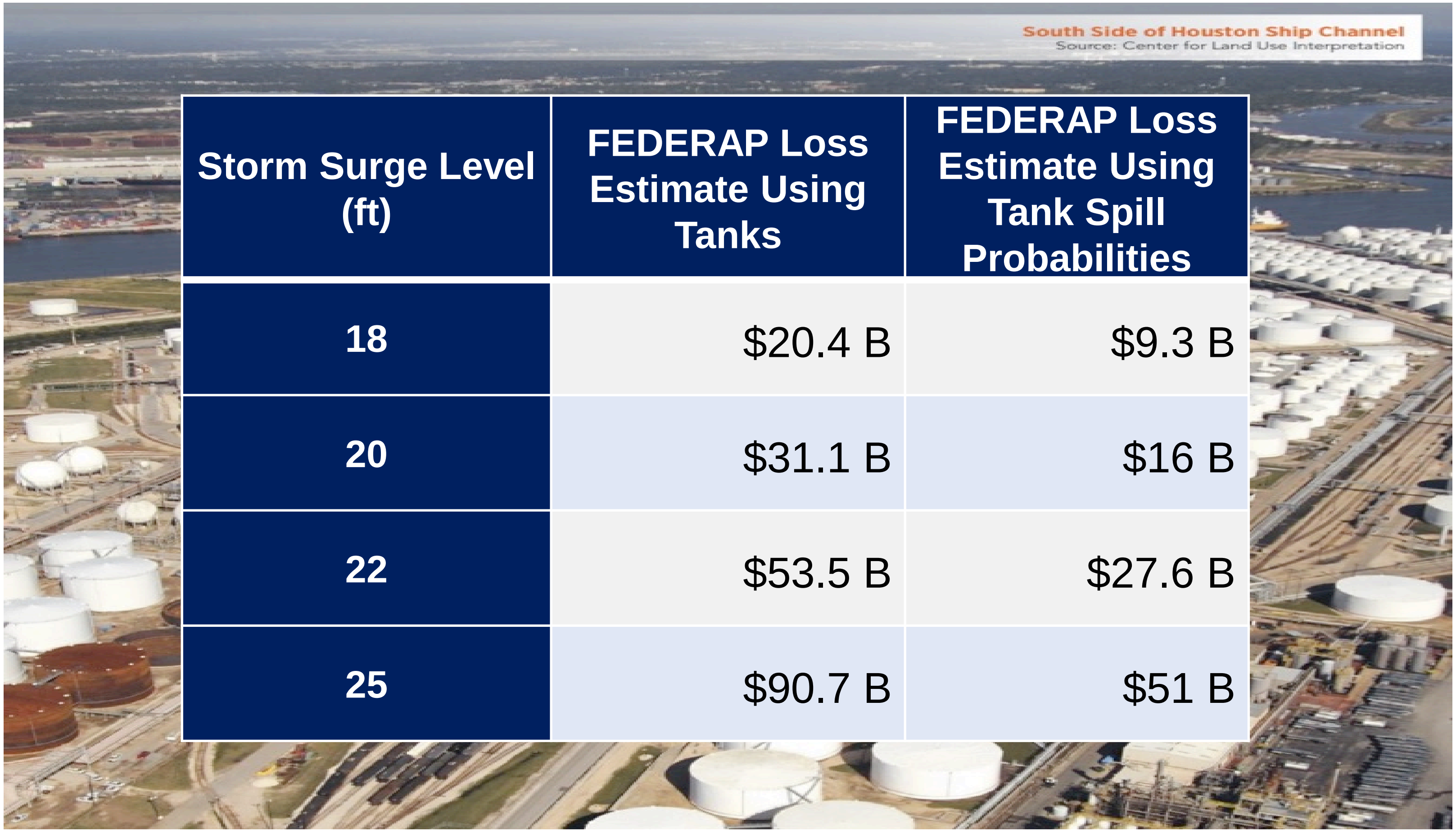
County	Baseline Conditions	Lower Bay	Mid Bay
Galveston	$7,157 M	$1,469 M	$2,316 M
Harris	$1,510 M	$3 M	$1 M
Chambers	$229 M	$2 M	$153 M
TOTAL	**$8,896 M**	**$1,474 M**	**$2,470 M**

Example Assessment of Tank Flotation Failure Probability



Phase 3: Flood Damage Risk Assessment

Industrial Damages



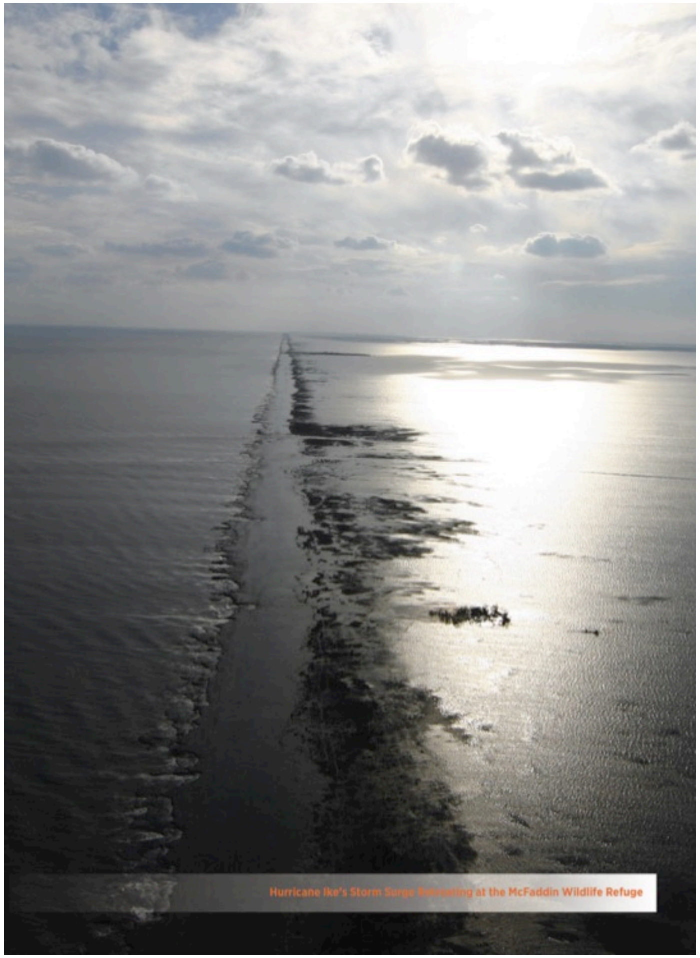
Storm Surge Level (ft)	FEDERAP Loss Estimate Using Tanks	FEDERAP Loss Estimate Using Tank Spill Probabilities
18	$20.4 B	$9.3 B
20	$31.1 B	$16 B
22	$53.5 B	$27.6 B
25	$90.7 B	$51 B

Phase 3: Benefit – Cost Summary

Economic Performance Estimates for HGAPS Strategies

Table 7-5. H-GAPS Benefit-Cost Summary (using Ike15-p7)

	Baseline Conditions	Lower Bay	Mid Bay
Industrial Damages	$37.0 B	$0	$0
Residential Damages	$8.9 B	$1.5 B	$2.5 B
Total Damages	**$45.9 B**	**$1.5 B**	**$2.5 B**
Reduced Damages (Benefit)	-	**$44.4 B**	**$43.4 B**
Cost	-	**$7.6 B**	**$2.8 B**


Hurricane Ike's Storm Surge Retreating at the McFaddin Wildlife Refuge

Phase 3: Conclusions and Future Work

- Developed a **regional surge protection system** for
  - the **population** in the Galveston Bay area,
  - the **industrial complex** along the HSC, and
  - the **preservation of the barrier islands** (Galveston Island and Bolivar Peninsula)

- The **ultimate plan** includes a regional storm surge reduction strategy with "**multiple lines of defense**"
  e.g. a coastal barrier and in-bay surge controls

- The regional strategy **includes components** that can be implemented quickly to **provide interim protection**

- The regional strategy must be **economically, environmentally and socially acceptable**

Digging Deeper

- Alternatives
  - No Action Alternative
  - SSPEED
  - TAMUG
  - GCCPRD
- Cost Estimates
  - Coastal Spine element
- Environmental Issues with Alternatives
- Legal Issues

Legal Issues

- With federal action (permit or funding)
  - National Environmental Policy Act and EIS
  - Endangered Species Act
  - Section 404 Clean Water Act
  - Executive Orders
    - Climate change and sea level rise
    - Ecosystem Services

Legal Issues

- With federal action (permit or funding)
  - National Environmental Policy Act and EIS
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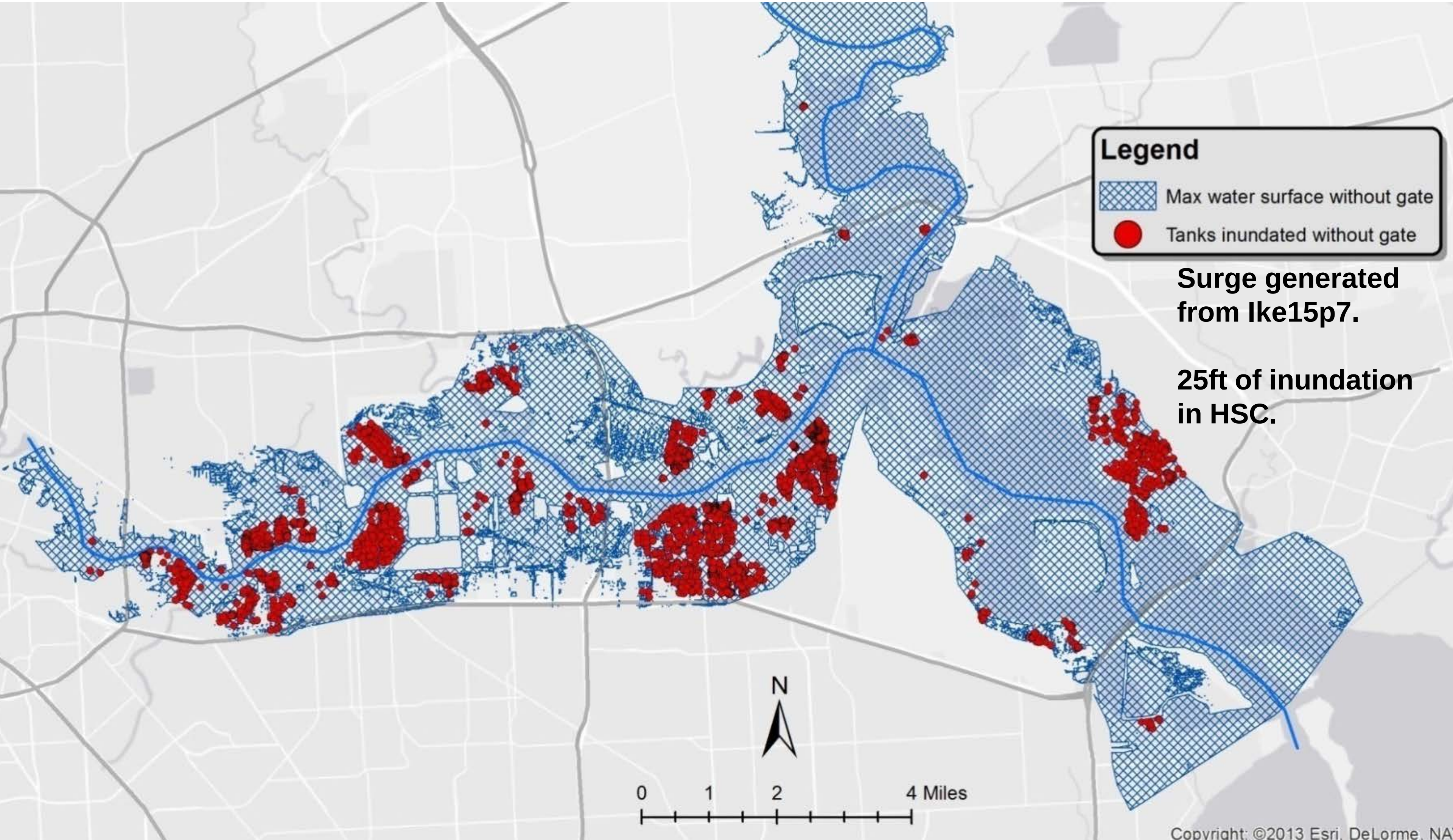
  - Section 404 Clean Water Act
  - Executive Orders
    - Climate change and sea level rise
    - Ecosystem Services
- Additional requirements with federal funding
  - Corps of Engineers funding requirements
  - Certain benefits may not be included in calculations

Alternatives

No Action Alternative

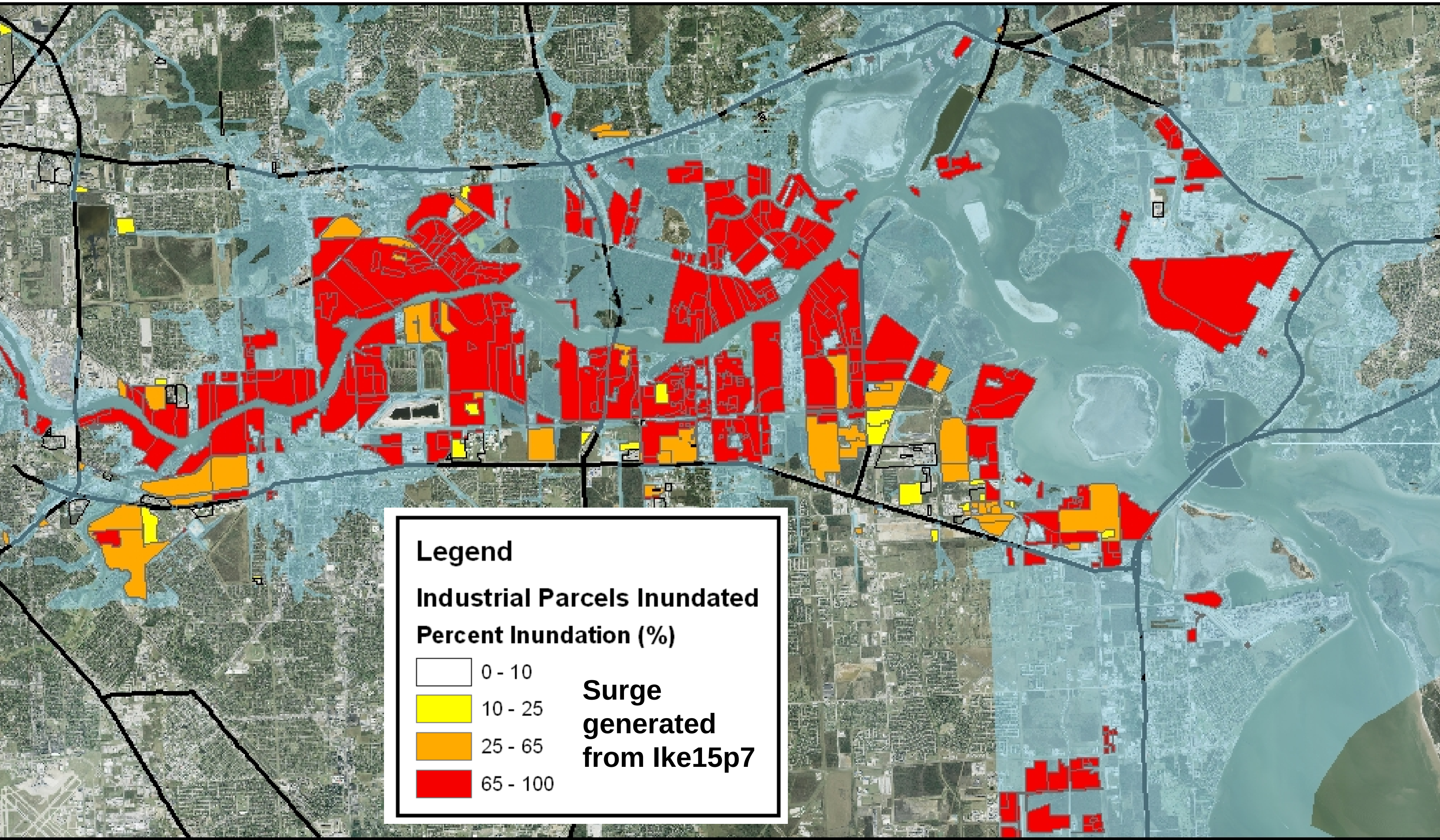
No Action Alternative



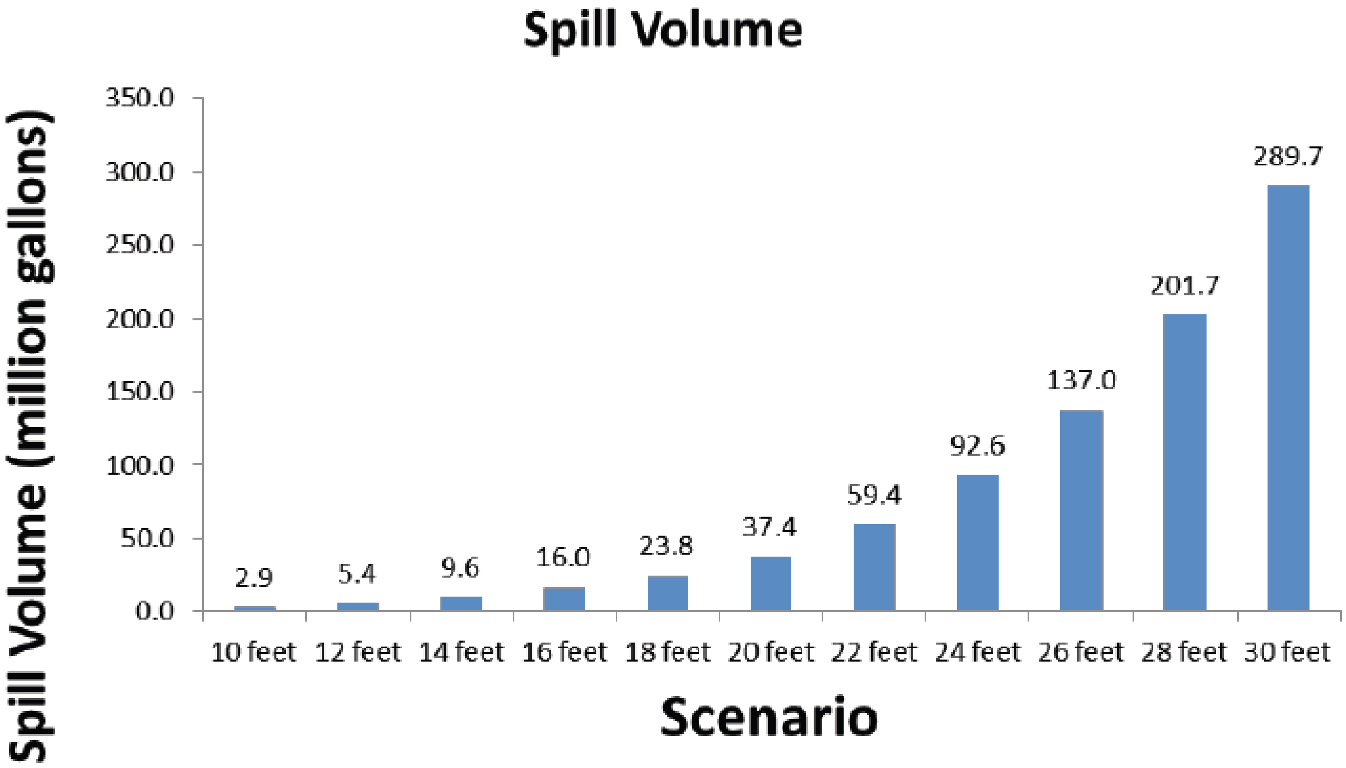
Surge generated from Ike15p7.

25ft of inundation in HSC.

No Action Alternative



Spill Volumes for Different Scenarios



Comparison of Spill Volumes

- **Deepwater Horizon Spill – 210 million gal**
- **24 foot surge HSC – 92 million gallons**
- **22 foot surge HSC - 59 million gallons**
- **Exxon Valdez - 11 million gallons**
- **Murphy Oil – 1 million gallons after Katrina**

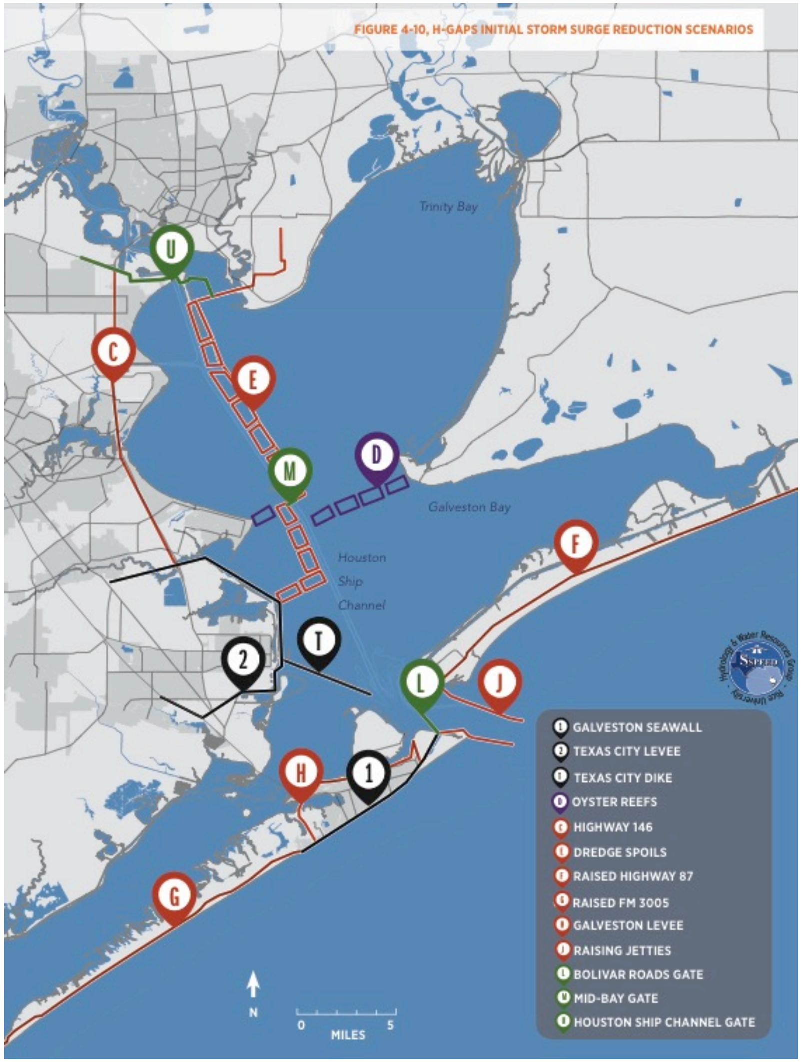
SSPEED Center Alternatives

3 Gate Strategies

- Upper-Bay
- Mid-Bay
- Lower-Bay

SSPEED's proposed plan:

- **Mid-Bay** + **Lower Bay** Gate Strategies

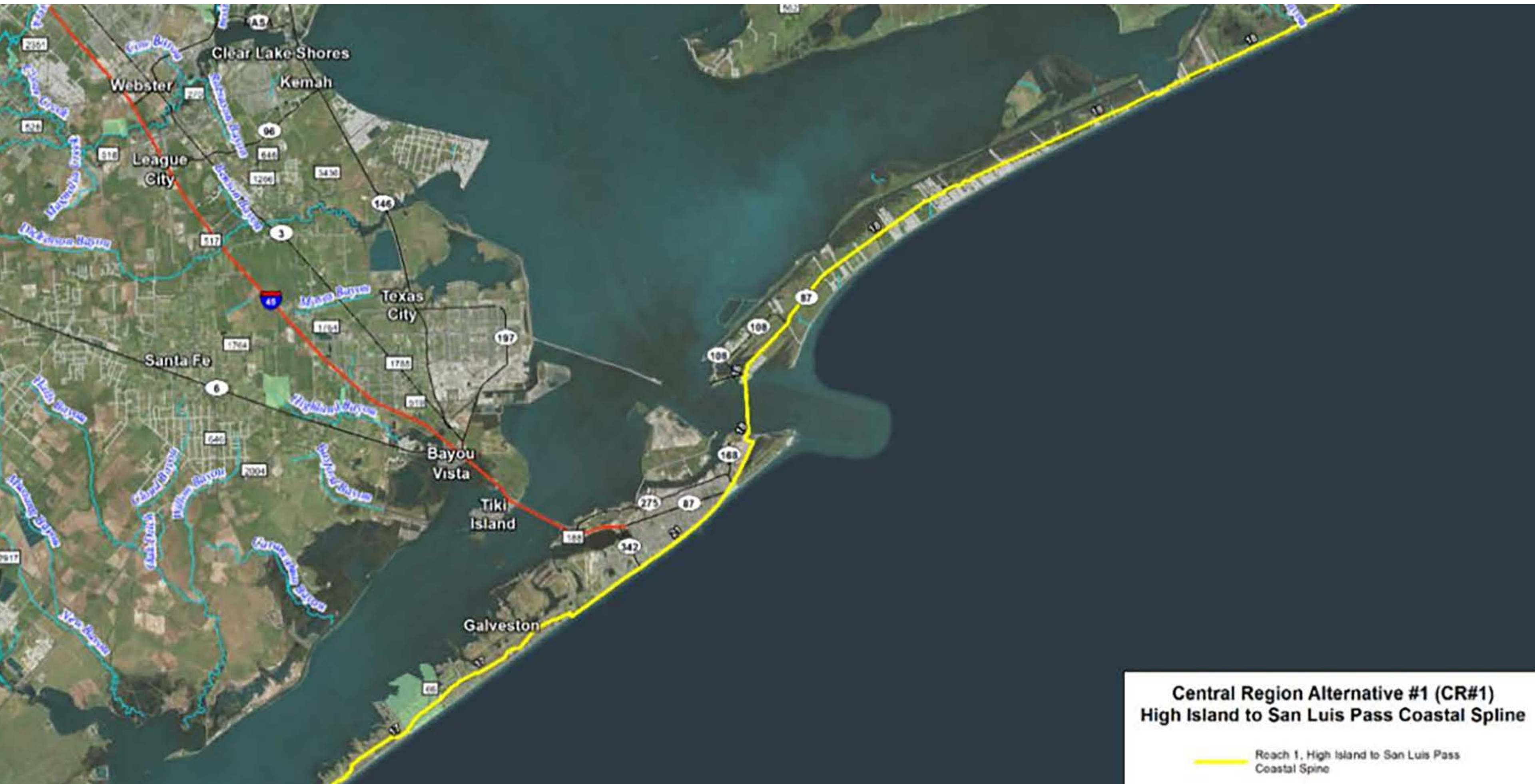


TAMUG Alternative

Ike Dike

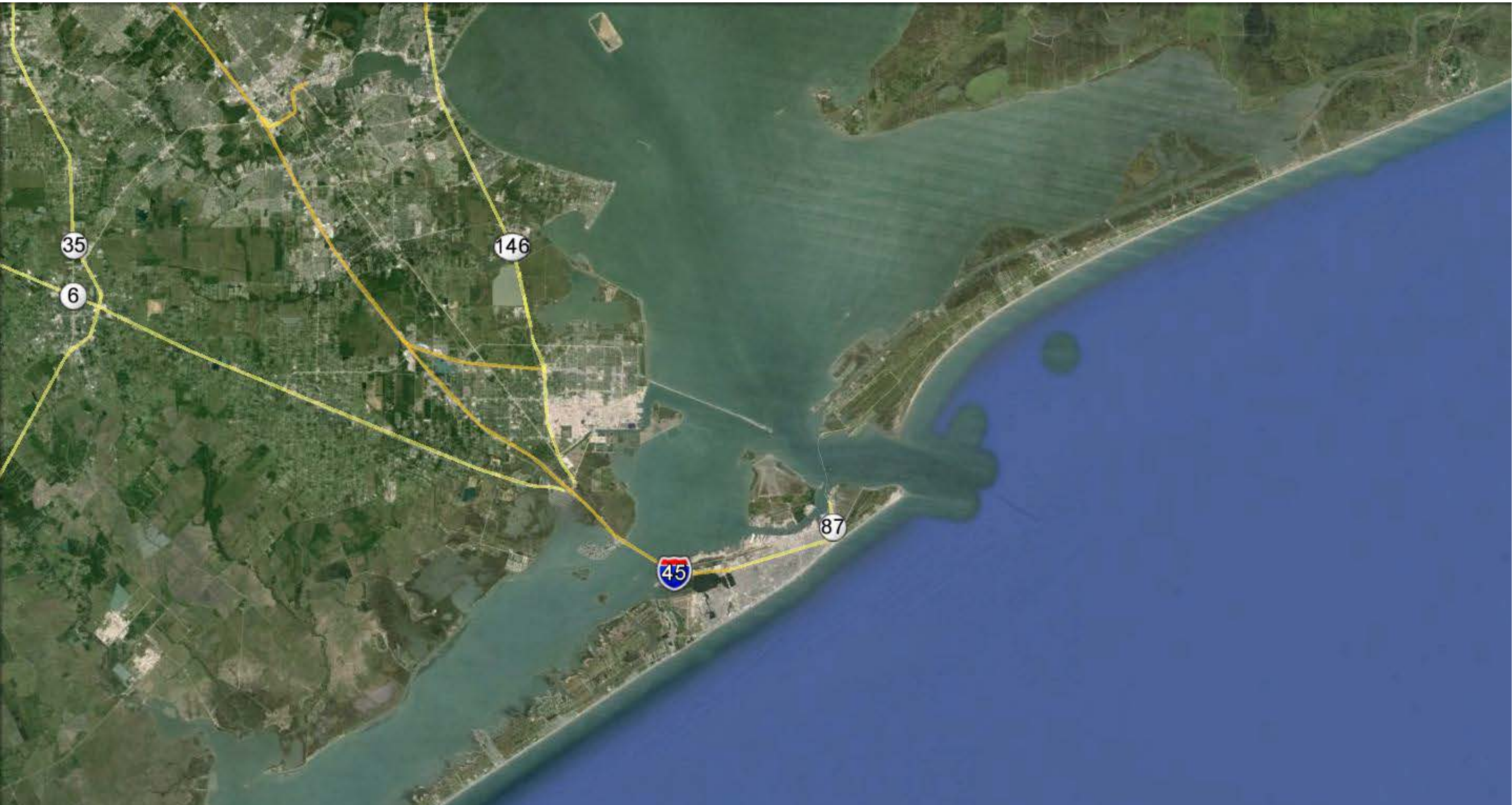
GCCPRD Alternative

Central Region Alt #1: High Island t San Luis Pass Coastal Spine



Coastal Spine Alignment

What does it look like? Where will it be located?



Dike Location

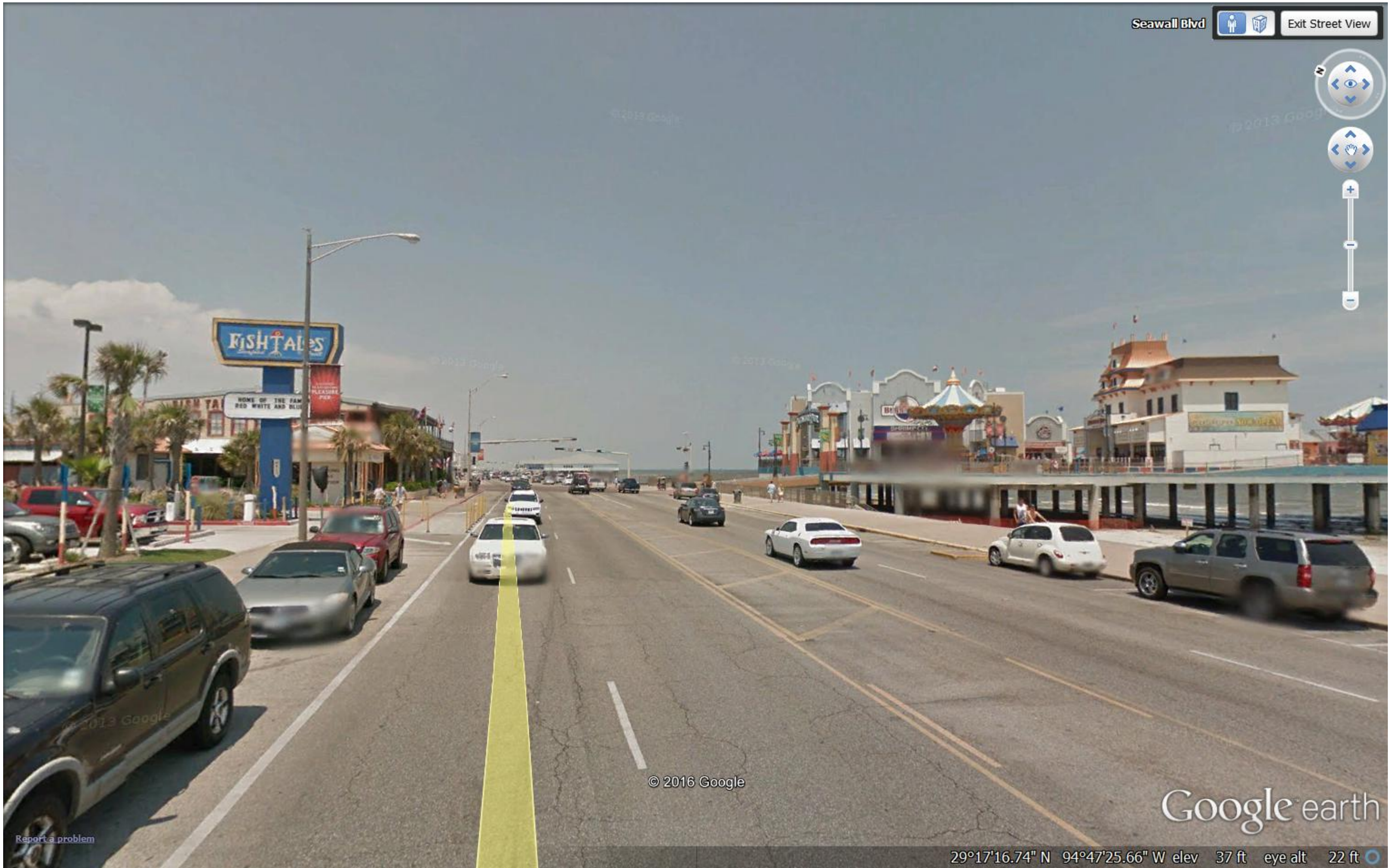
What does it look like? Where will it be located?


21328


21328

Rendering of Sand Dune Construction

Seawall



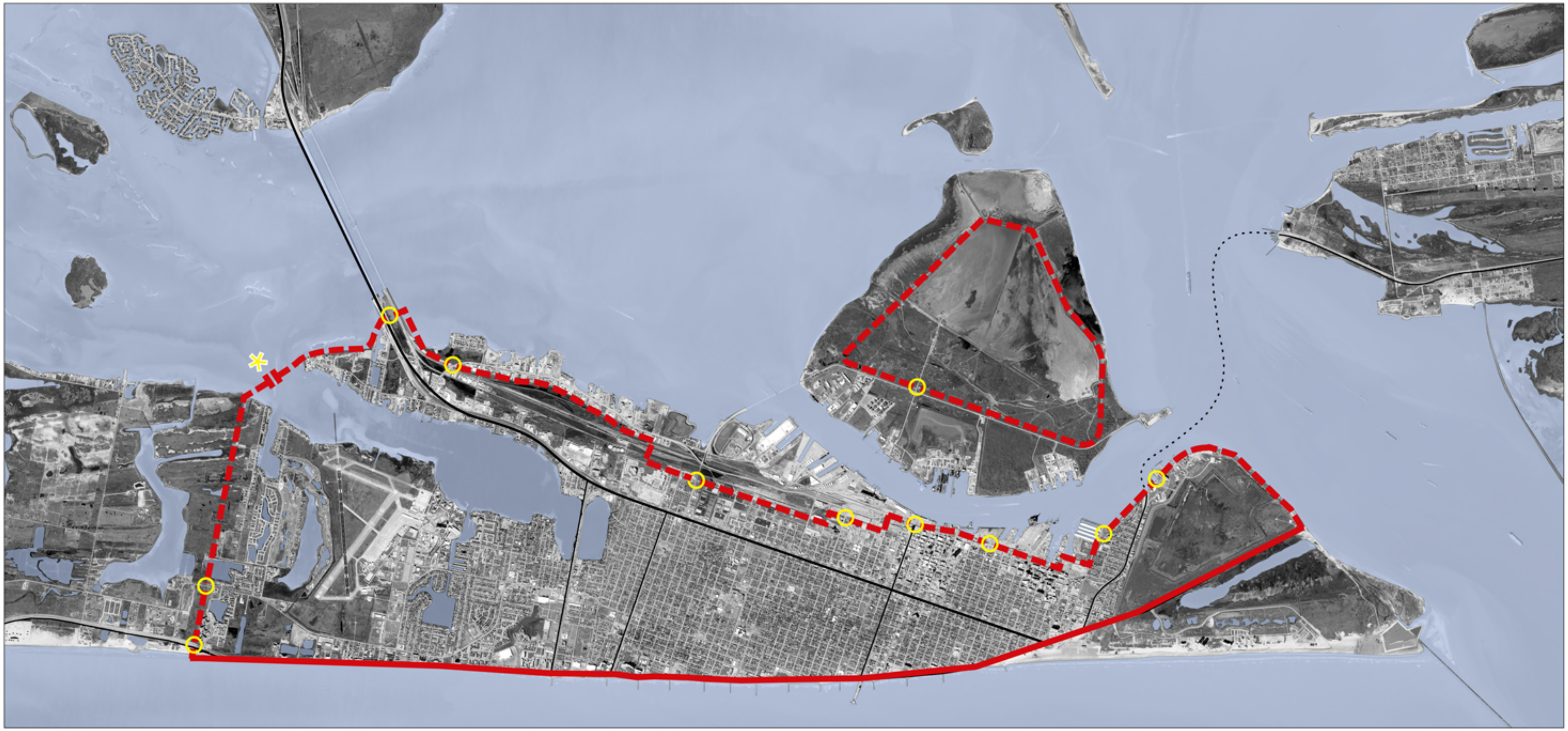
Seawall Blvd
Exit Street View
FISHTALES
© 2016 Google
Google earth
Report a problem
29°17'16.74" N 94°47'25.66" W elev 37 ft eye alt 22 ft

Galveston Island Levee
Concept 1

Galveston Island Levee - Option A, Population Alignment

0 0.25 0.5 1 1.5 2
Miles

Galveston Island Levee Concept 2



Galveston Island Levee - Option B, Pelican Island Alignment

Galveston Island Levee
Concept 3

Galveston Island Levee - Option C, Protected Port Alignment

Cost Estimates of Coastal Spine

Cost Estimates

	Cost Estimates						
	Navigation Gates	Environmental Gates	Levee / Sand Dunes	Seawall Elevation	City of Galveston Back-side Levee	Contingency	TOTAL
SSPEED	$0.55 B	$4.0* B	$0.125 B	-	$.3 B	20%	$6B
TAMUG	$0.55 B	$4.0 B	$3.4 B	-	-	-	$8.9B
GCCPRD	$1.7 B	$2.2 B	$1.9B		$1.1B	25% (land) 40% (water)	$5.8B

* This gate cost could cost as high as $10 billion based on recent storm surge barrier construction costs.

Environmental Issues with the Alternatives

Environmental Flows

- GCCPRD
  - Proposed 25 environmental gates; **50%** of flows allowed

How much flow is allowed through the barriers?

How does this impact estuarine health?

Barrier Across the Eastern Scheldt

Eastern Scheldt Barrier

Eastern Scheldt Barrier

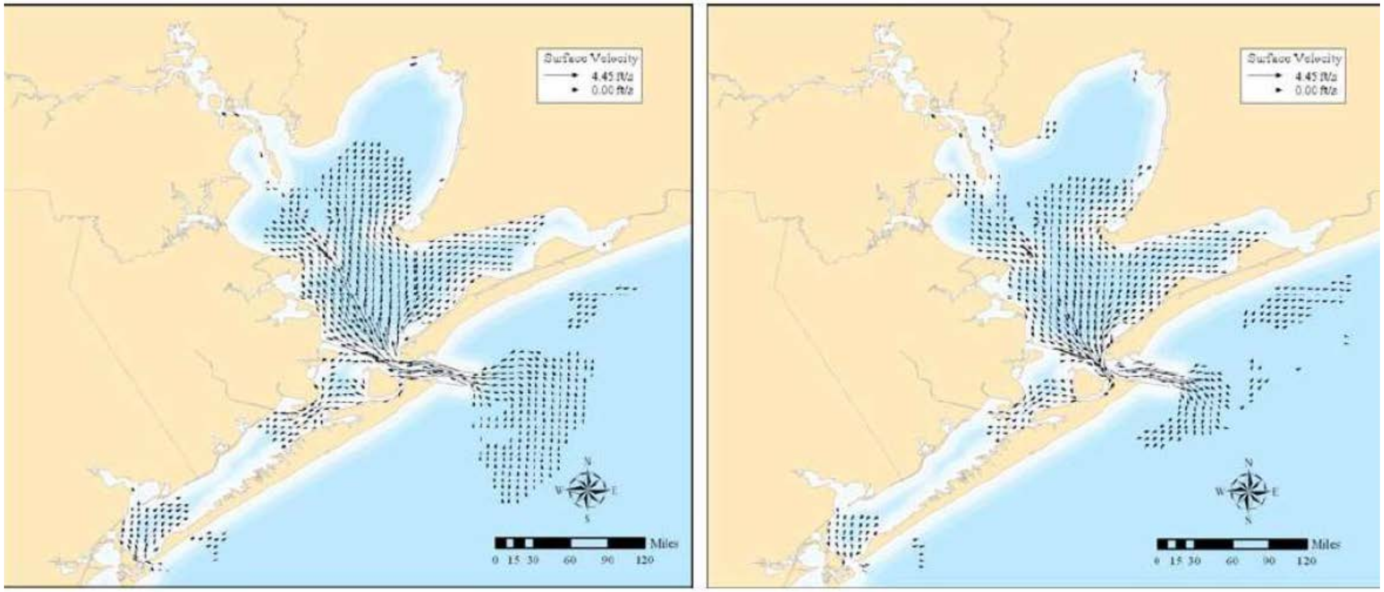
Environmental Gate System

Bolivar Roads

Role of Bolivar Roads

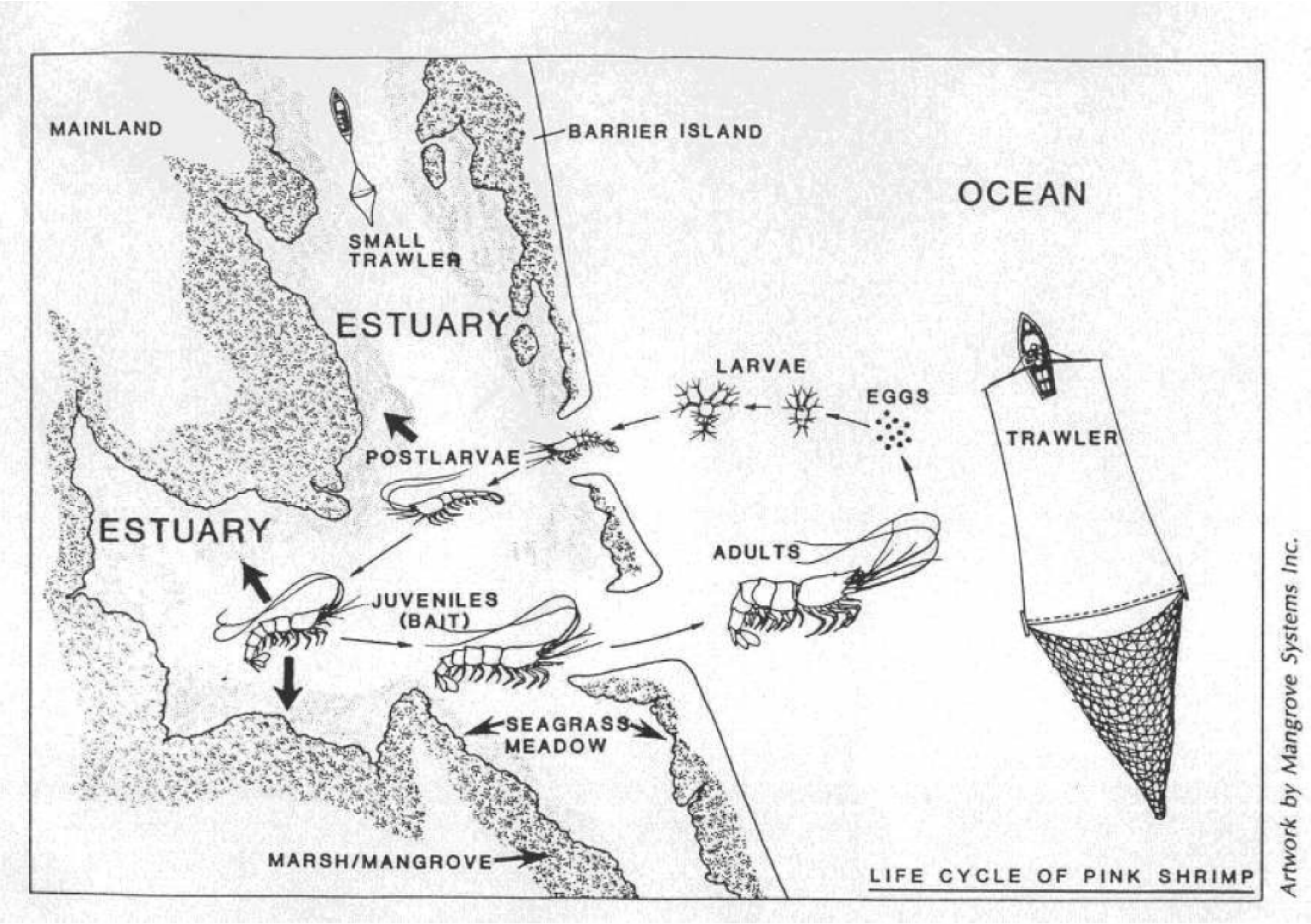
Surface Velocity Vectors vs. Tidal Stage

Incoming (L) Outgoing (R)

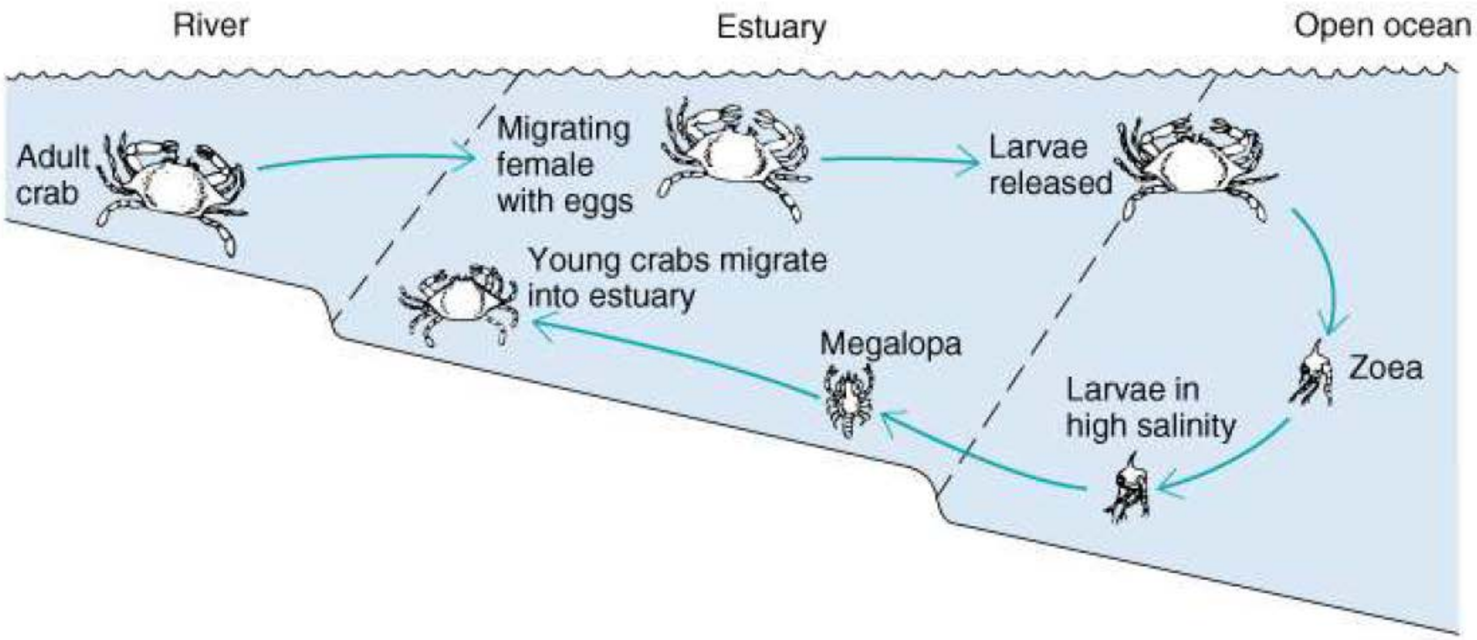


Carillo and Berger (2001).

Life Cycle of a Shrimp

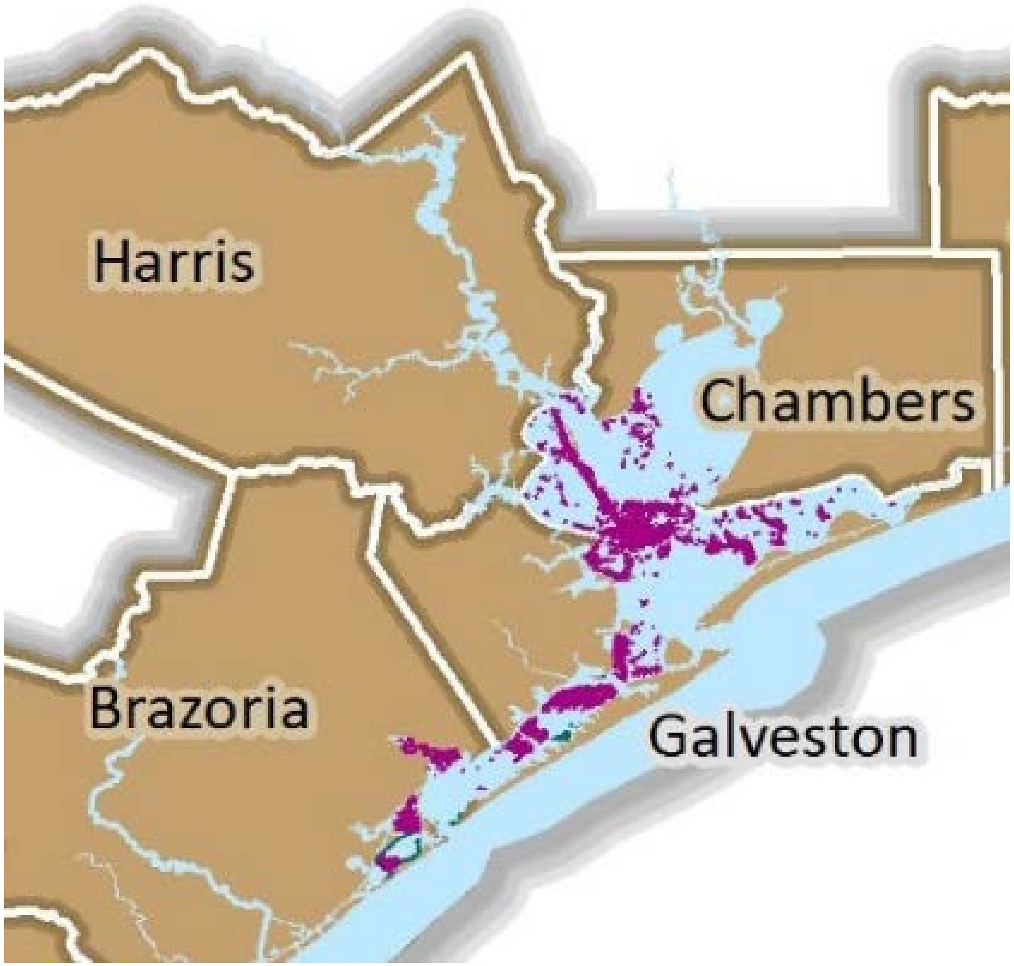


Life Cycle of a Blue Crab



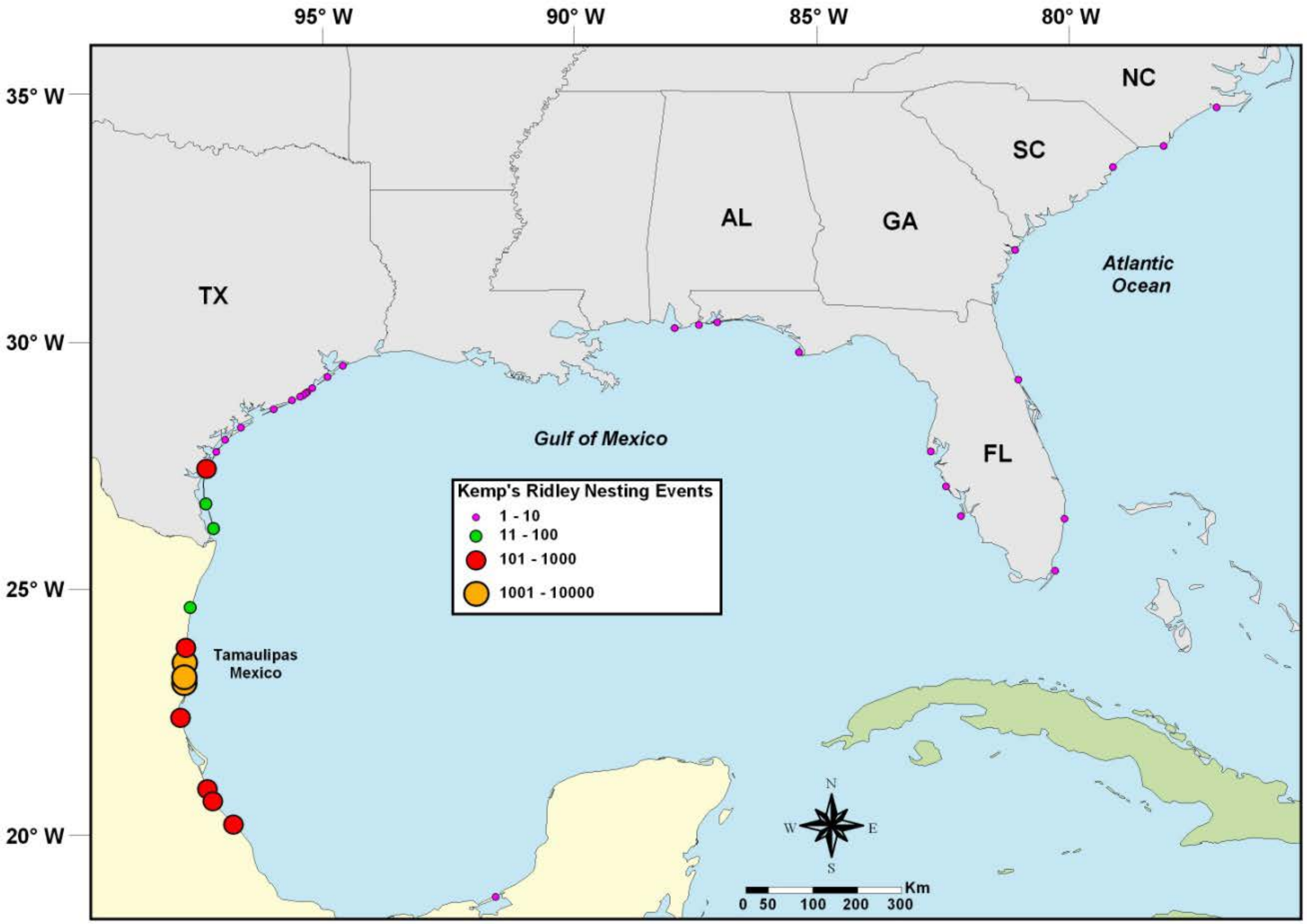
Protection of Mammals

Galveston Bay Oyster Reefs



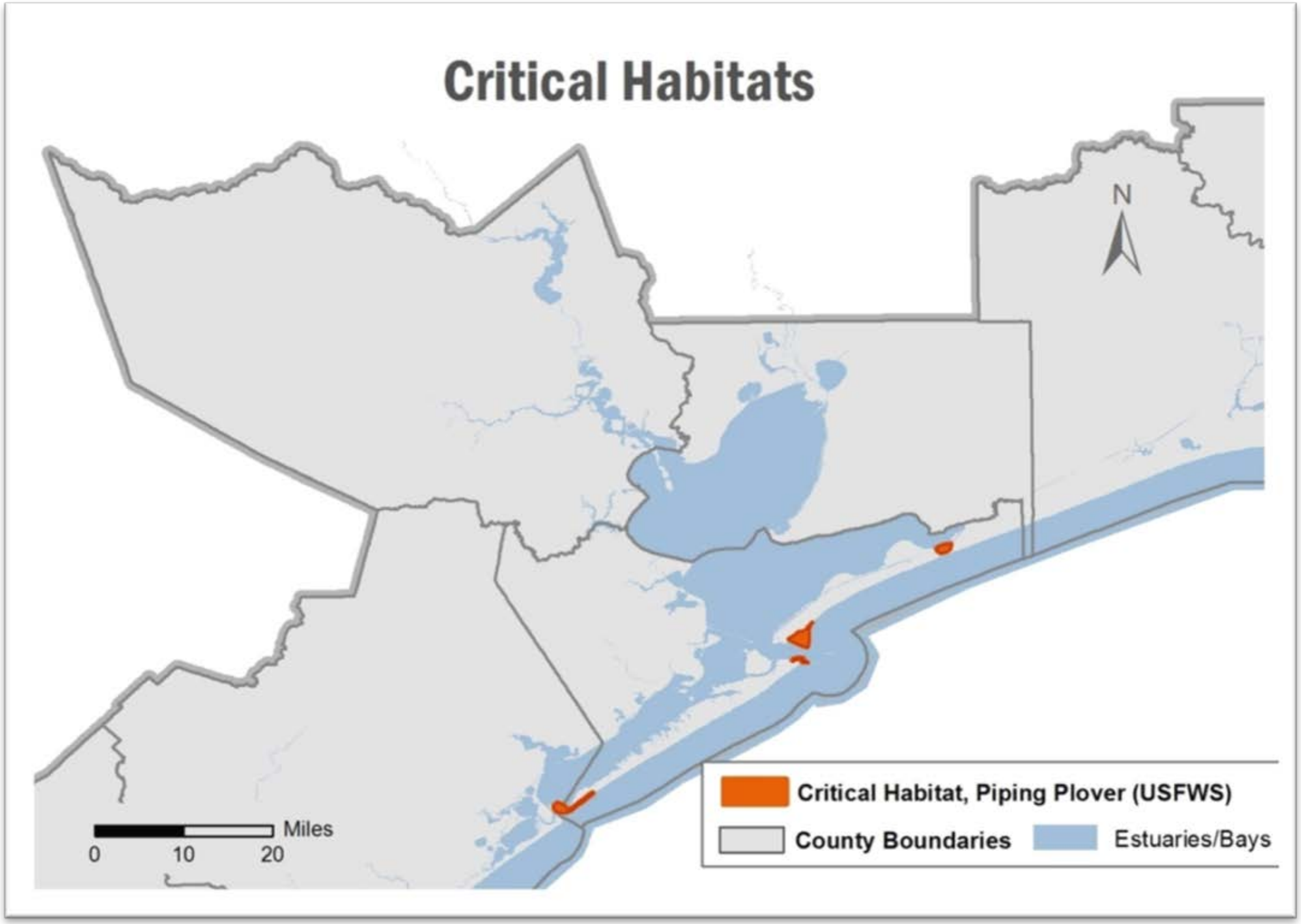
The Beach and Nesting Kemp’s Ridley Sea Turtles

Sea Turtles



Source: Kemp's Ridley Bi-National Recovery Plan 2nd Rev 2011

Piping Plover



Legal Issues

Legal Issues

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    - Ecosystem Services
- Additional requirements with federal funding
  - Corps of Engineers funding requirements
  - Certain benefits may not be included in calculations
- Federal Circumvention