Hurricanes, Barriers and Climate Change: Galveston Bay Case Study

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Texas Envirothon Teacher Workshop
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1900 Galveston Hurricane Sept 8, 1900.

- Deadliest natural disaster in US history.
- Estimates of the death toll range from 6,000 to 12,000
- Category four hurricane; >135 mph winds.

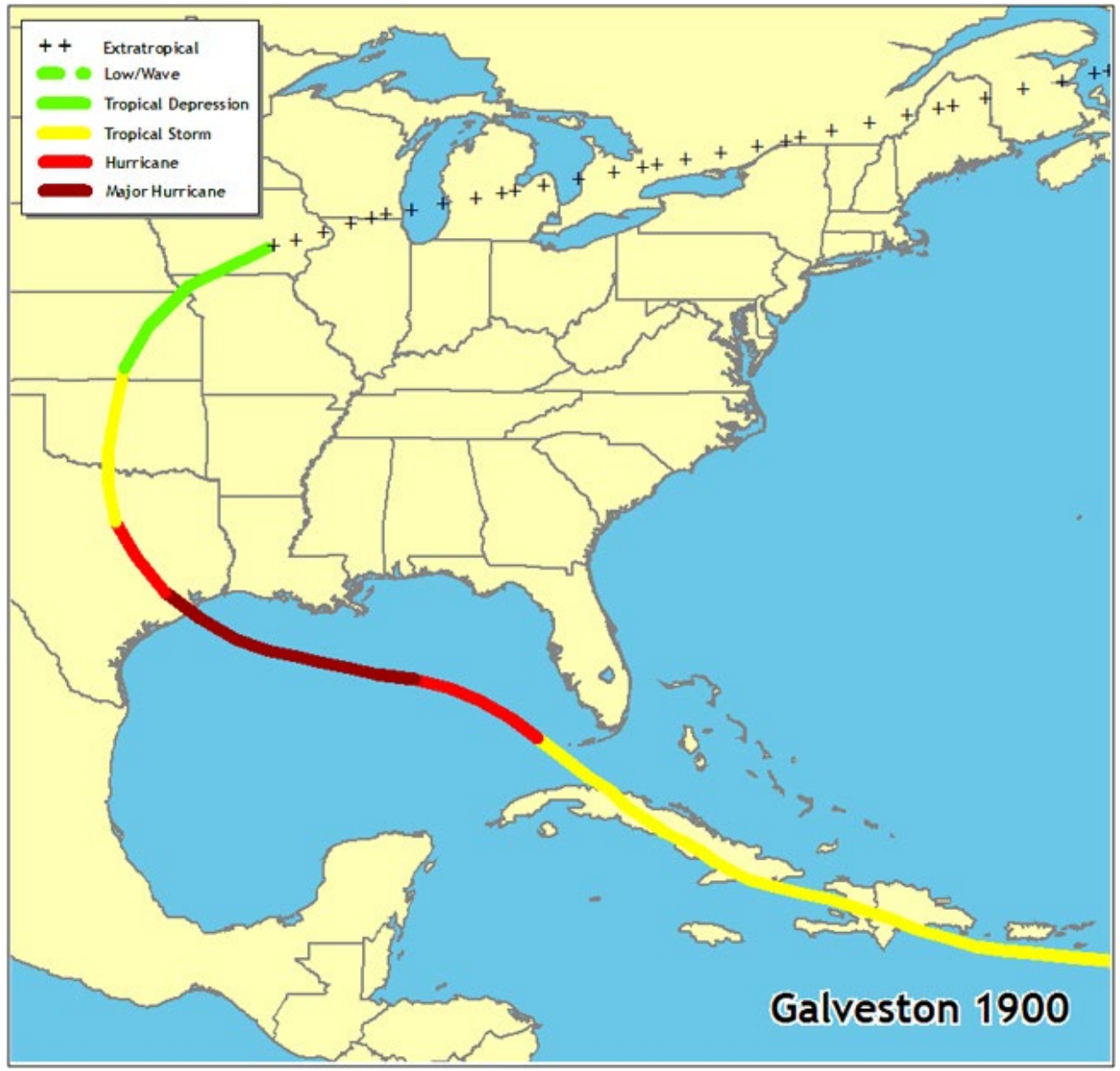
- Massive flooding and storm surge, Gulf covered the island.

- Destroyed > 3,600 buildings

1900 Hurricane Sept 8, 1900.

- First detected over the tropical Atlantic on August 27.
- Limited use of non-USA warnings and science (Cuba; ships at sea): Barometric pressure readings.
- The U.S. Weather Bureau got the forecast completely wrong
- Tragically, the magnitude of the disaster could've been lessened if the U.S. Weather Bureau hadn't implemented such poor communication policies.
- The bureau's director, Willis Moore, "was so jealous of the Cubans that he shut off the flow of data from Cuba to the U.S".
- Popular account: Larson, E. 2000. "*Isaac's Storm*"
- Isaac Monroe – Chief meteorologist Galveston, TX 1889-1901. Lost his wife in the storm.

https://www.history.com/news/how-the-galveston-hurricane-of-1900-became-the-deadliest-u-s-natural-disaster



https://celebrating200years.noaa.gov/magazine/galv_hurricane/galveston_1900_map.html


29.90
30.00
Omaha
Kansas City
St Louis
Springfield
Cairo
Oklahoma City
Amarillo
Little Rock
Memphis
Nashville
Chattanooga
Meridian
Mobile
Vicksburg
Palestine
San Antonio
Fort Eagle
29.80
29.70
29.60

1900 Hurricane Sept 8, 1900.

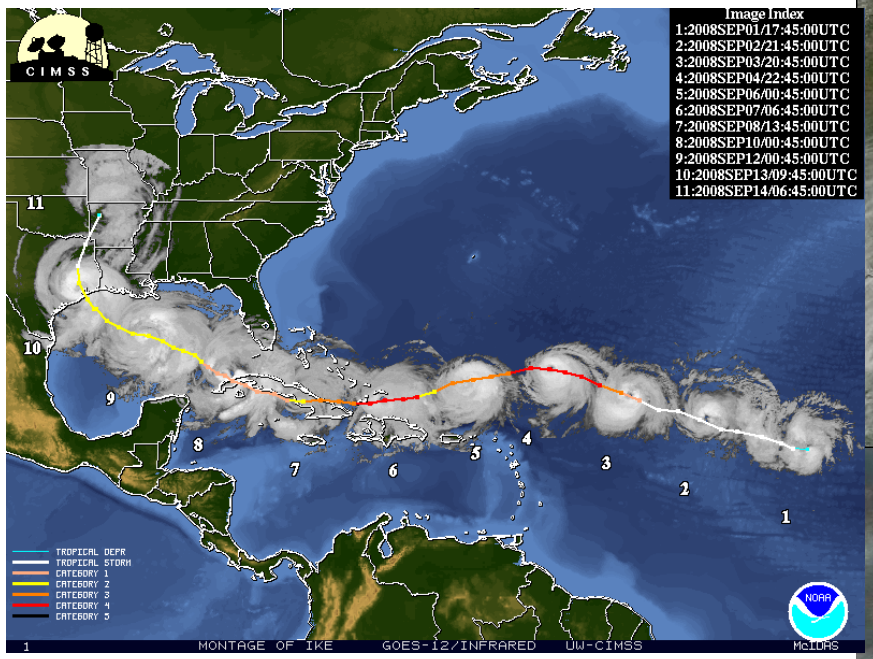
- At the turn of the century, Galveston was booming. It was the nation's biggest cotton port, its third-busiest port overall, and the second-most-heavily-traversed entry for immigrants arriving from Europe, nicknamed the "Western Ellis Island."
- The city had more millionaires, street for street, than any other in America.
- The storm caused such complete destruction and killed so many residents the survivors decided to abandon the town Galveston declined in stature and commerce.
- This hurricane along with the further dredging of the Houston Ship Channel to Houston, and the development of major rail lines to Houston changed the economic landscape of Texas.

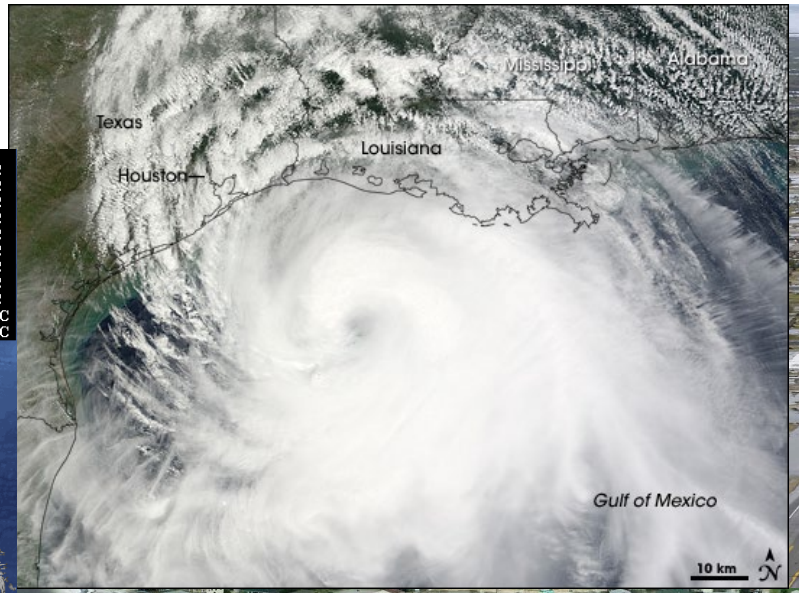
https://www.1900storm.com/isaaccline/isaacsstorm.html

Galveston Seawall built – (1904-1963).

Recent Major Hurricanes in Texas

Ike 9/13/2008



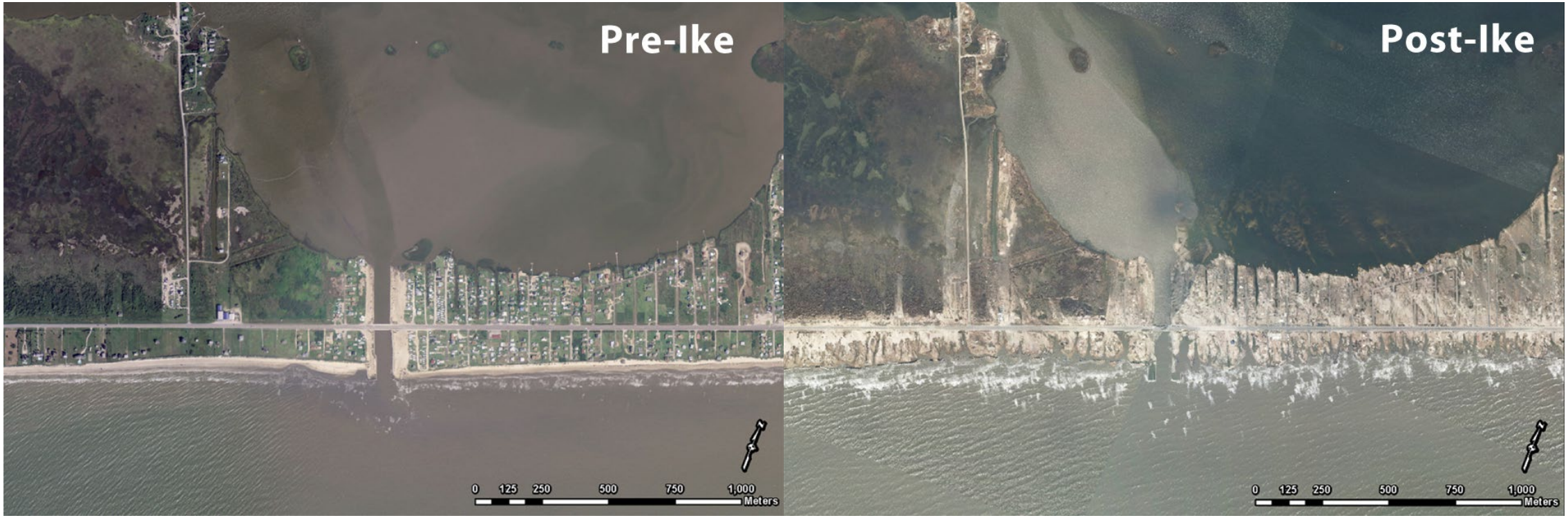


Storm Surge - primary

Hurricane Ike - 2008

Storm Surge - primary

Hurricane Ike - 2008

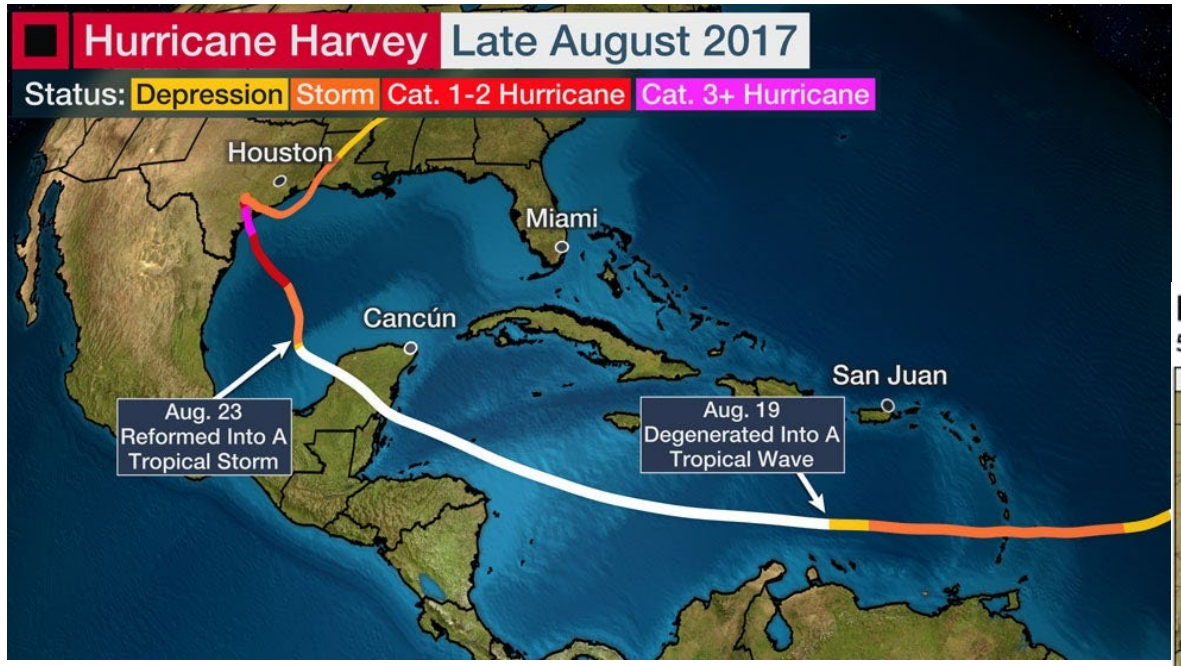


Storm Surge - primary

Ike & Galveston Seawall (2008).

On September 13, 2008, 'Hurricane Ike's large waves over-topped the seawall. As a result, a commission was established by the Texas governor to investigate preparing for and mitigating future disasters.

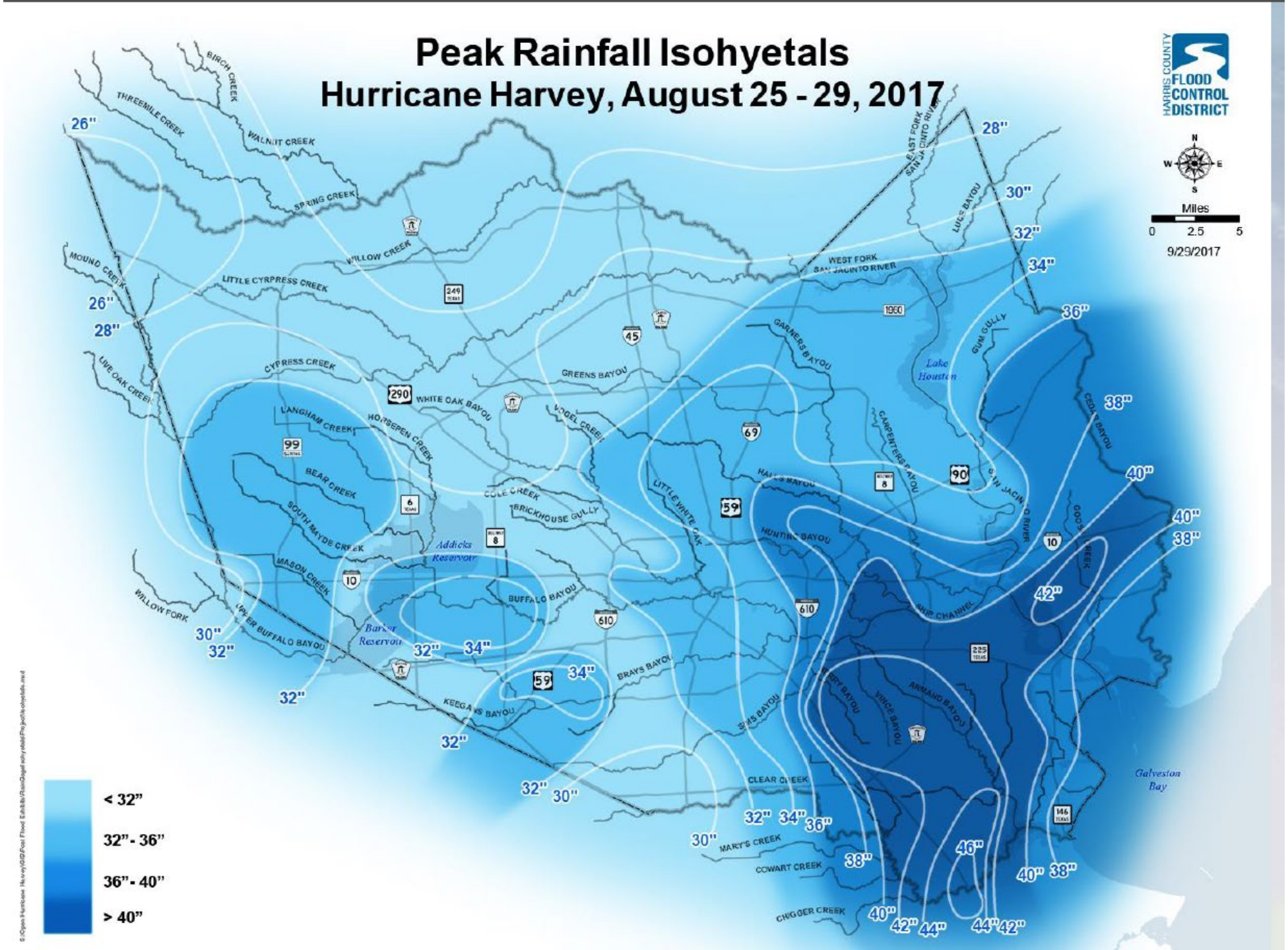
Recent Major Hurricanes in Texas: Harvey Aug 2017

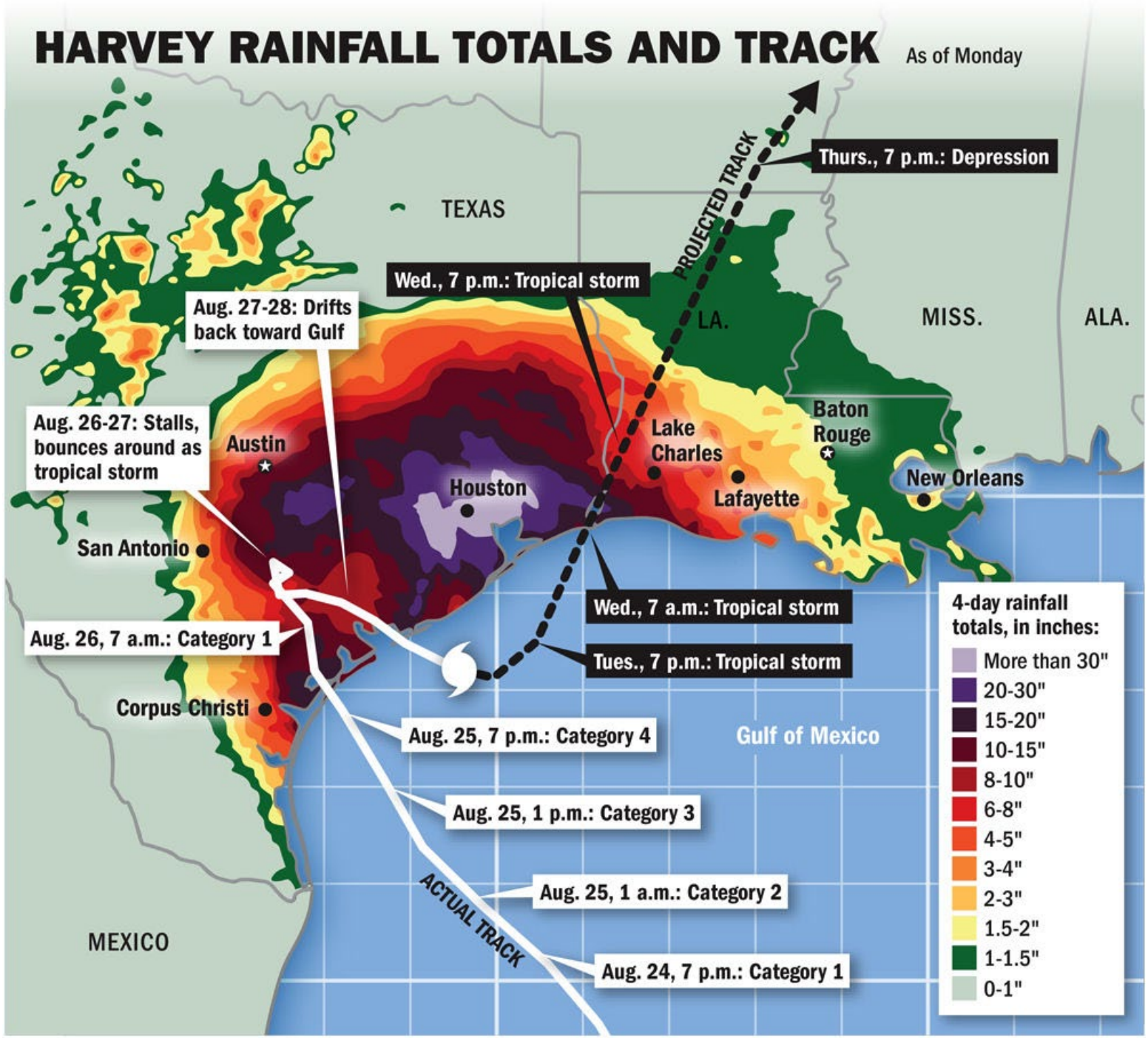


Recent Major Hurricanes in Texas: Harvey

- Primary cause of damage – rainfall, inland and coastal flooding.
- Dropped salinity in bay to near freshwater levels!
- Dolphin and oyster impacts. Changes in species composition.

Peak Rainfall Isohyetals
Hurricane Harvey, August 25 - 29, 2017



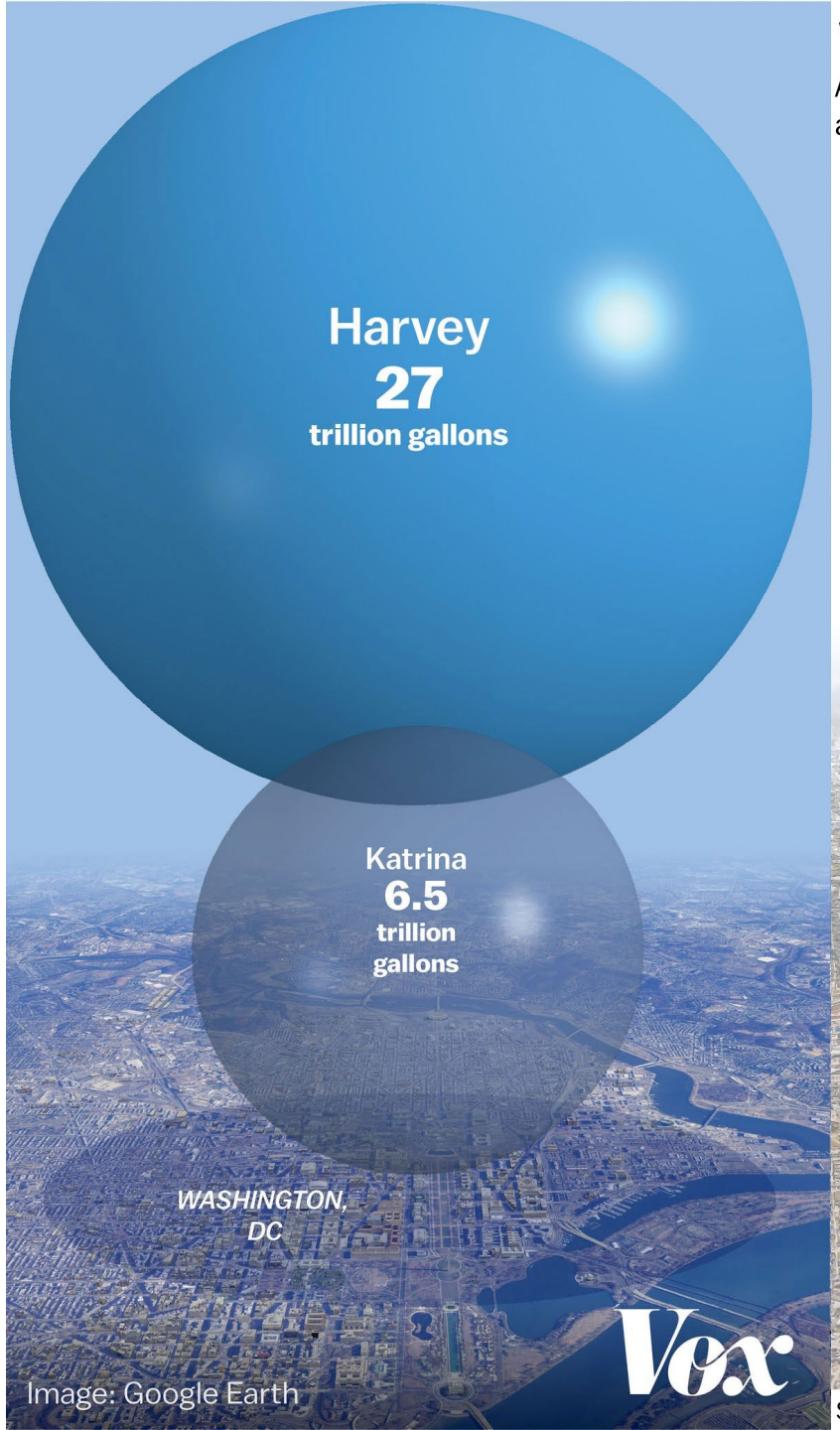


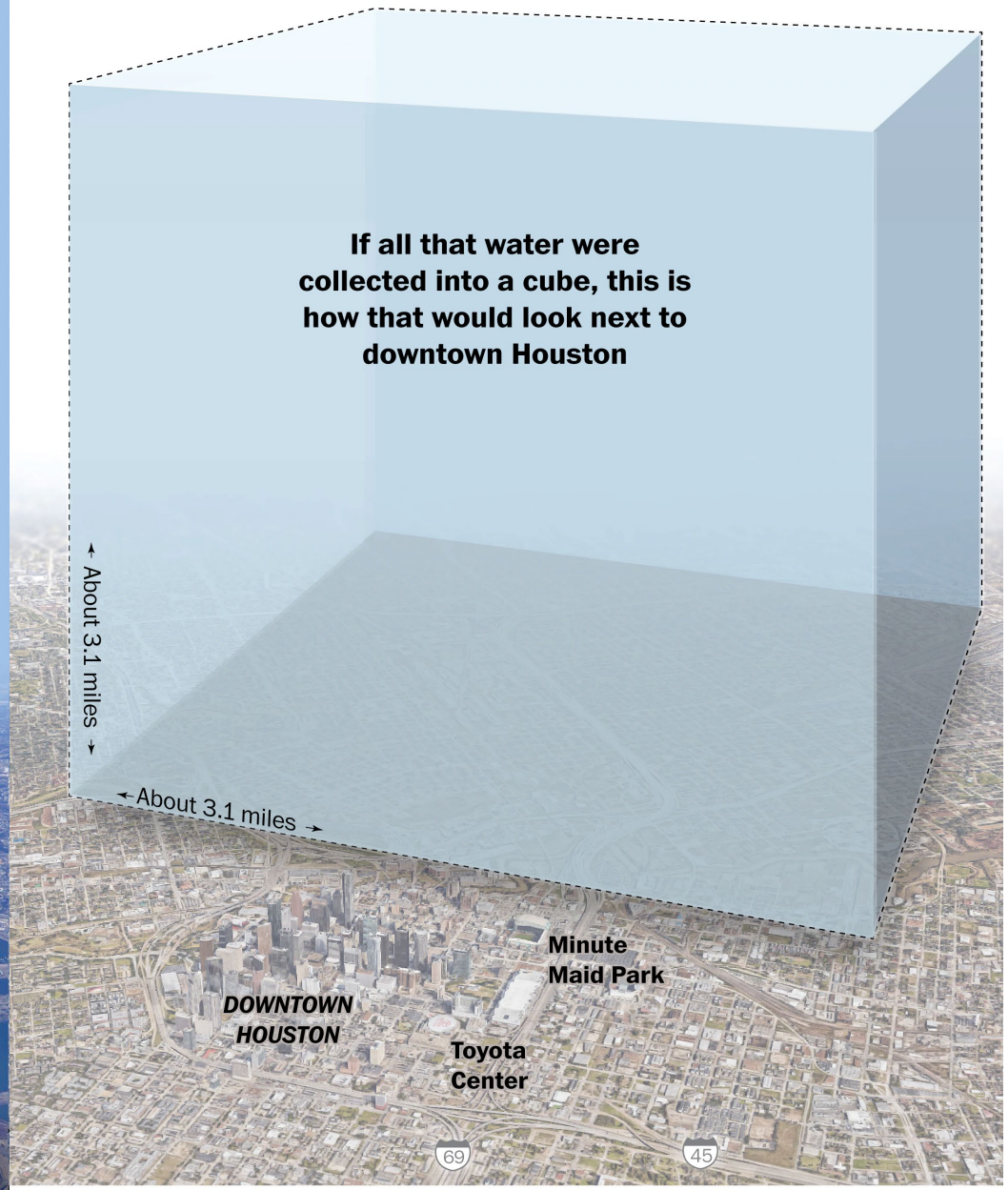
Source: National Weather Service

Advocate graphic by **DAN SWENSON**

What would 33 trillion gallons of water look like?

As of Saturday, Sep. 1, about 33 trillion gallons of rain have fallen along the Gulf of Mexico.



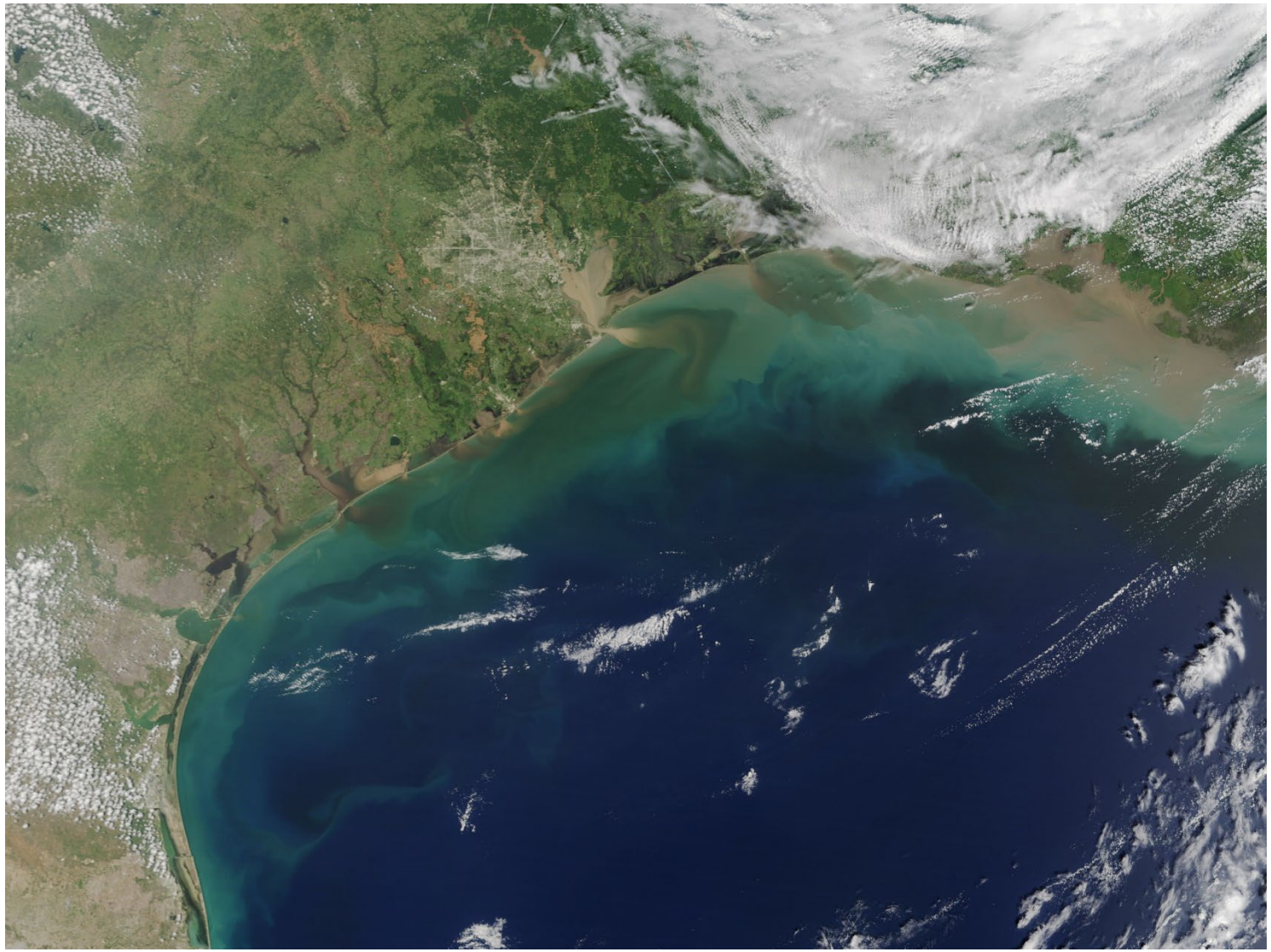


Sources: Ryan Maue, Capital Weather Gang, Google Earth

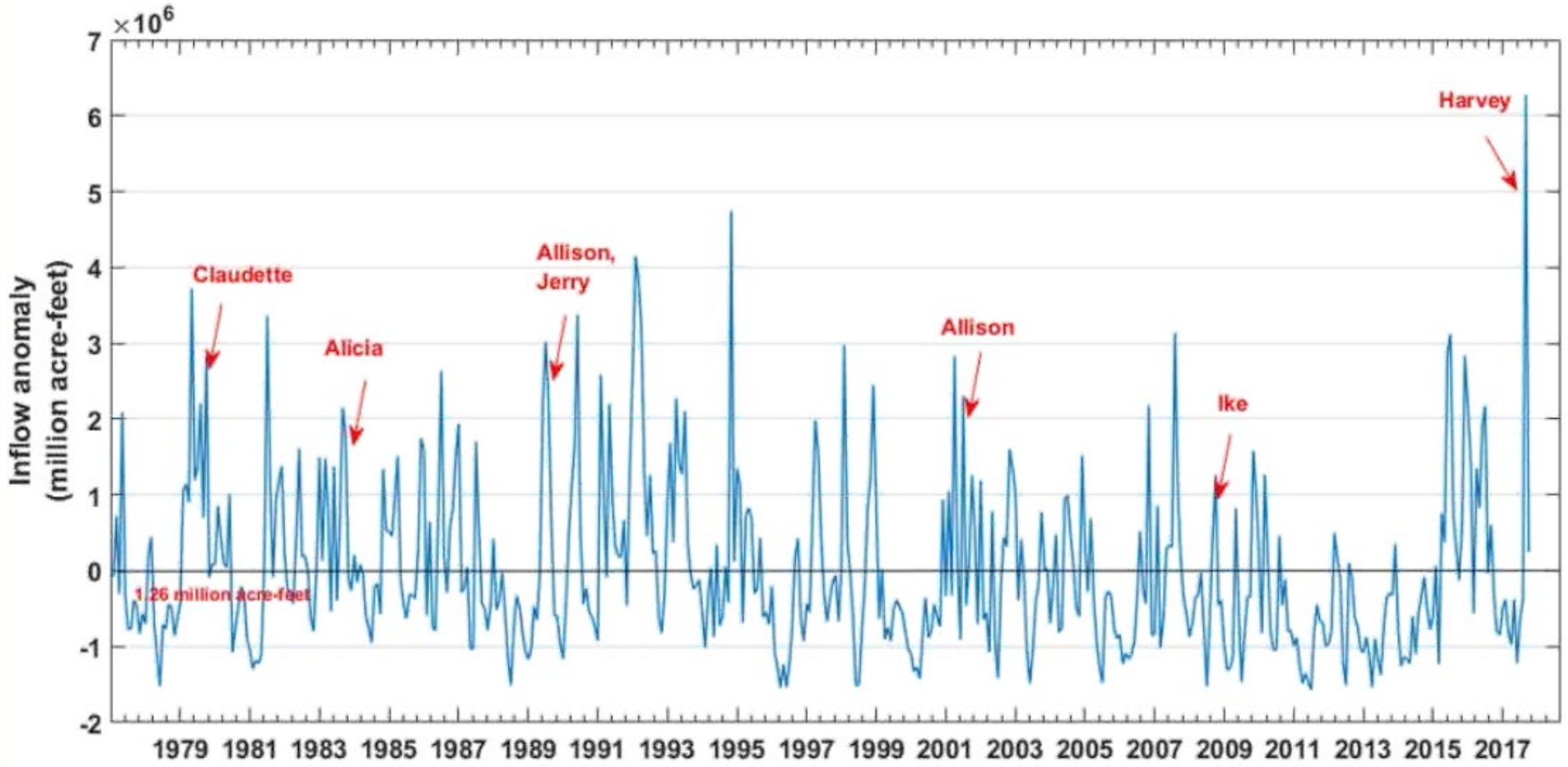
THE WASHINGTON POST


from 2017

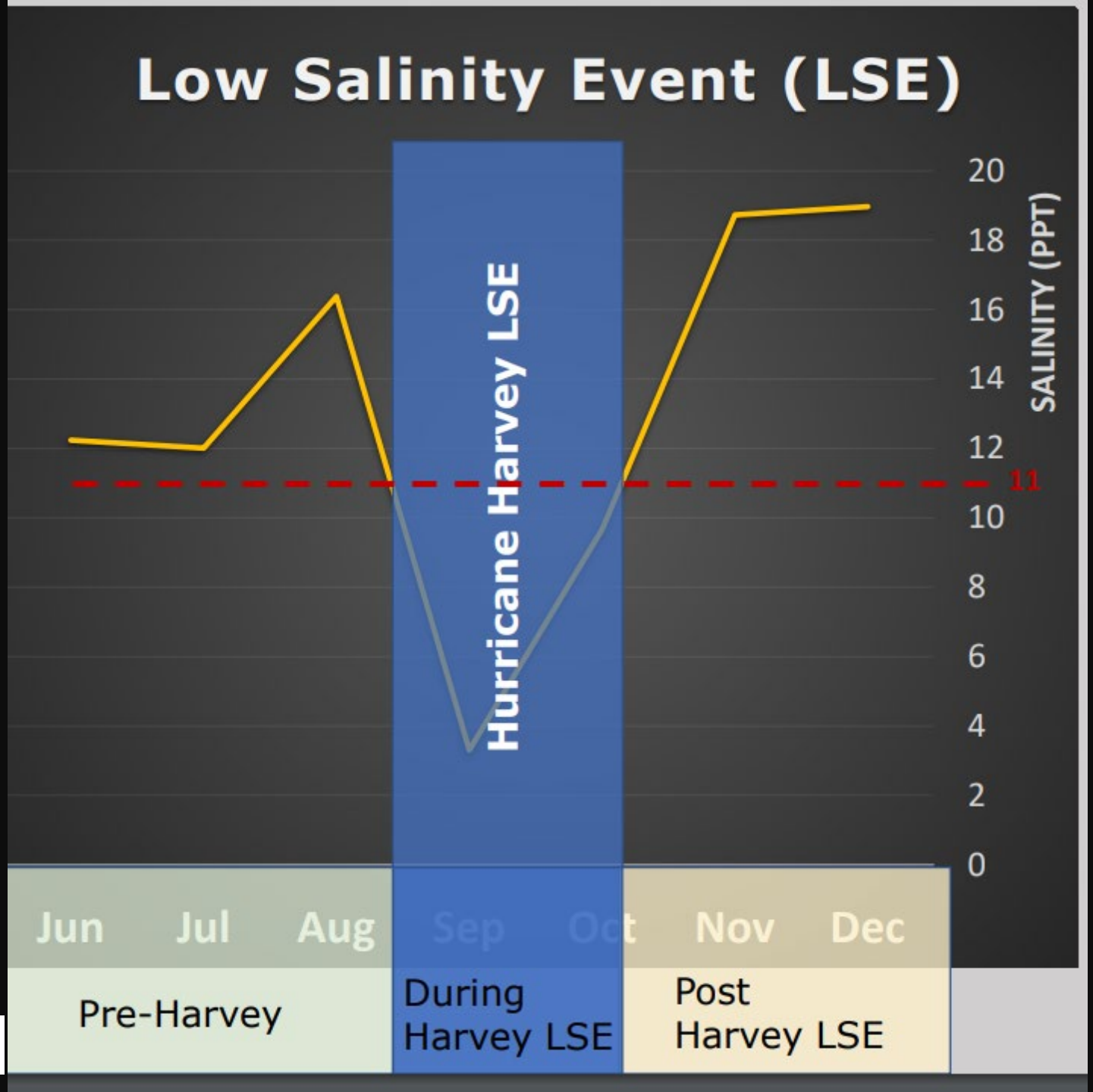
Freshwater Flooding



Monthly Inflow to Galveston Bay: 1977–2017



Caimee Schoenbaechler – TWDB 2017



Fazioli & Mintzer 2022

Short-term effects of Hurricane Harvey on dolphins in the upper Galveston Bay Estuary

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Prepared for the 9th National Summit on Coastal and Estuarine Restoration and Management, December 2018

INTRODUCTION

In August 2017, Hurricane Harvey inundated the Galveston Bay estuary system with record-breaking rainfall. Salinity levels in the Bay dropped drastically in the weeks following the storm, severely altering aquatic habitat. Since 2013, we have conducted boat-based dolphin observational surveys in upper Galveston Bay (UGB). This long-term monitoring provided a unique opportunity to evaluate the effects of Harvey on the bottlenose dolphins (*Tursiops truncatus*) inhabiting UGB (Fig. 1, 2).

Objective: To evaluate if and how dolphin encounter rates (ERs), and prevalence and extent of dolphin skin lesions, varied in the months preceding and following Harvey.

Galveston Bay (GB) is a 1600km² anthropogenically altered shallow bay system. Growth and industrialization from the 1950's – 70's contributed to massive fish kills, a 95% decline in submerged aquatic vegetation and an EPA listing on the 10 most polluted waterways. Management activities have improved water quality and health; however, concerns over pathogenic bacteria and chlorinated organic compounds persist [1].

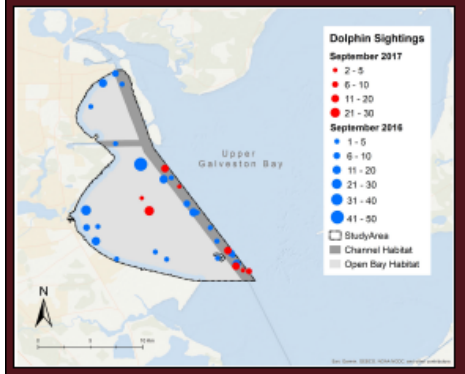


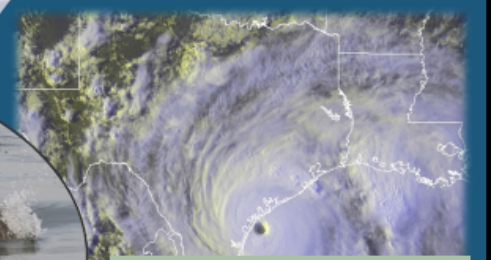
Fig. 1. Map of the primary study area in upper Galveston Bay. Two habitat types within the study area, Channel and Open Bay, are displayed along with dolphin sightings in September 2016 and September 2017.

RESULTS AND CONCLUSION

The long-term monitoring of dolphins inhabiting UGB allowed the comparison of ERs, and skin lesion prevalence and extent before, during, and after Harvey. These parameters changed considerably with time period (Fig. 5, Fig. 6, Table 1), suggesting that Harvey had population-wide effects. ERs showed that most dolphins were displaced from UGB for weeks following Harvey (Fig. 5), and the individuals that stayed developed skin lesions (Fig. 6, Table 1) potentially indicative of underlying stress. With a predicted increase in the intensity of hurricanes[13] and the potential for a large-scale coastal protection/barrier project in GB[14], research on the effects of flood events is imperative to manage dolphin populations and their estuarine habitat.

Tursiops truncatus

- Protected under federal Marine Mammal Protection Act
- Long-lived residents in estuaries [2]
- Sentinels/indicators for ecosystem health [3,4]
- Subject to negative health consequences when exposed to freshwater and toxic pollutants [5,6]



Hurricane Harvey moved over the Houston-Galveston region in late August of 2017, dumping up to 60" in 8 days and causing massive inland flooding, much of which drained into Galveston Bay [7]. The estuary was inundated with freshwater, sediment, debris, and toxic pollutants [8,9].

Image: NOAA, August 25, 2017. https://www.ospo.noaa.gov/

METHODS

- Boat-based photo-identification surveys were conducted between August 2015 and September 2018
- Individual dolphins were identified using the natural marks on their dorsal fins. [10,11]
- Dolphin ERs (dolphins/km) were calculated monthly from June 2016 to Dec. 2016 and June 2017 to Dec. 2017.
- Photographs of individuals were evaluated and, if quality criteria were met, utilized in analyses for skin lesions →
  prevalence = the proportion of identified individuals that exhibited skin lesions
  extent = % of each individual's epidermis covered by lesions (Fig. 3)
- Three periods were defined in relation to the Harvey low-salinity event, using an 11 ppt threshold for preferred dolphin habitat (Fig. 4).
  Pre → June 1-Aug 27 (>11ppt)
  During → Aug 28-Oct 20 (<11ppt)
  Post → Oct 21-Dec 31 (>11ppt)

Fig. 3. Examples of observed lesions in bottlenose dolphins in upper Galveston Bay in each extent category. Exposure to low salinity environments may contribute the development of "freshwater skin lesions" characterized by degradation and ulceration of the epidermis, often accompanied by secondary infections from opportunistic pathogens [4,12].

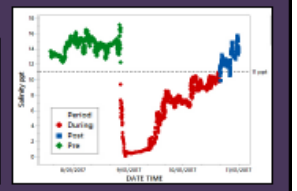


Fig. 4 Continuous automated salinity (ppt) measurements taken at the NOAA Eagle Point (Station ID 8771013) site from 7/21 to 10/31/17.

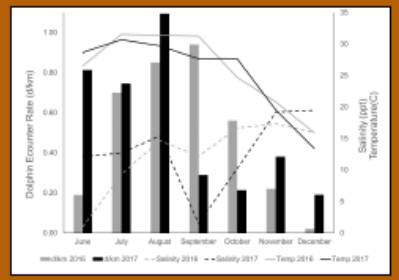


Fig. 5. Encounter rates (d/km) of bottlenose dolphins in UGB from June 2016-December 2016 and June 2017-December 2017 with average surface salinity and temperature recorded at dolphin sighting locations.

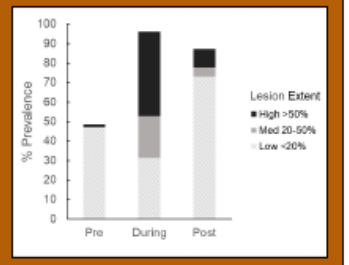


Fig. 6. Skin lesion prevalence and extent on identified dolphins during the pre-Harvey, during Harvey, and post-Harvey periods. Difference in extent according to period was found to be significant, $X^2(4, N = 248) = 130.1$, $p < .001$.

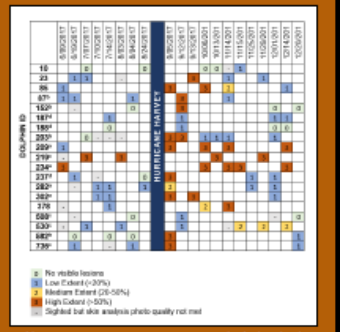


Table 1. Lesion progression over time in 19 individuals sighted in all three time periods surrounding the Hurricane Harvey low salinity event.

All work conducted under NMFS Permit# 18881

Many thanks to the staff and students at UHCL-EIH for field and data support. We also greatly appreciate the support of the following organizations:

CONSERVATION FUND
RESTORE AMERICA'S ESTUARIES
Chicago Zoological Society
Houston Zoo

Literature Cited

Galveston Bay Dolphin Research and Conservation Program www.galvbay.org/dolphin

Fazioli & Mintzer 2022

Known and Potential Effects of Climate Change

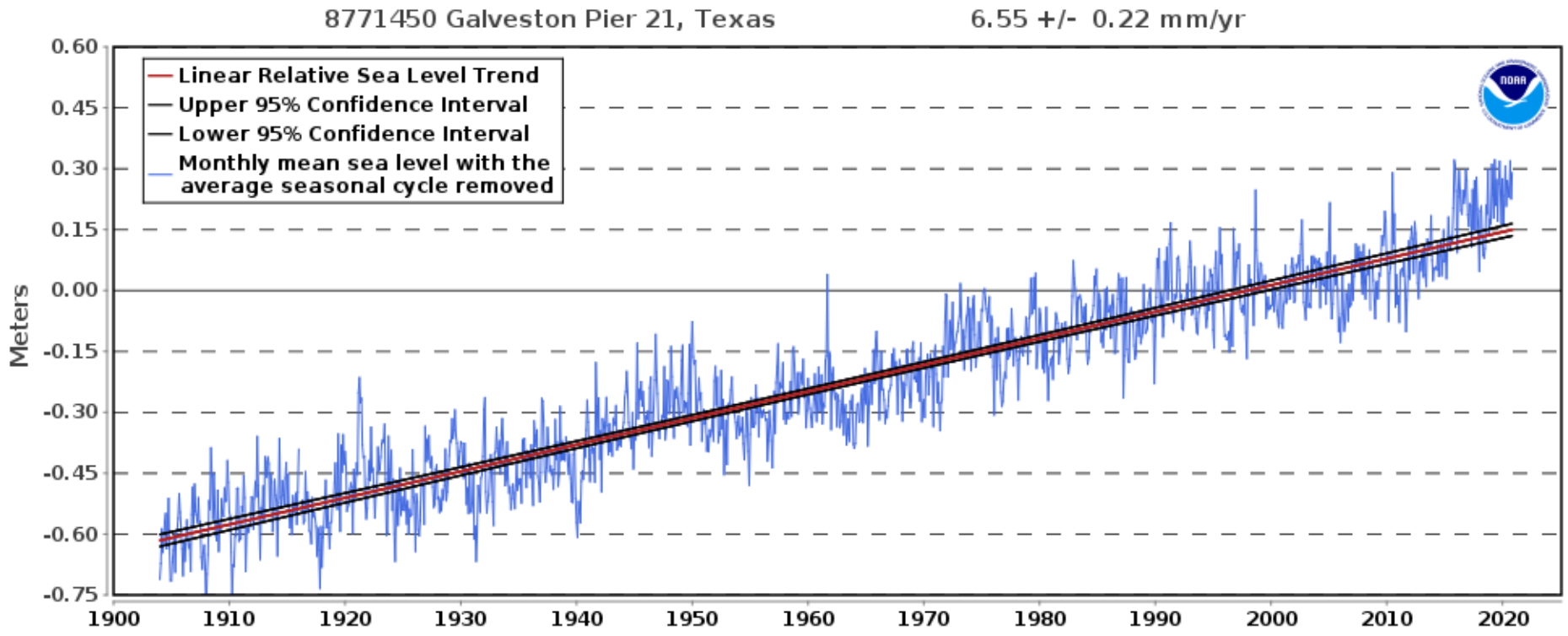
1. Rising sea level – well documented.

2. Change in precipitation

3. Stronger tropical storms (storm surge & rainfall, wind)?

4. More frequent tropical storms?

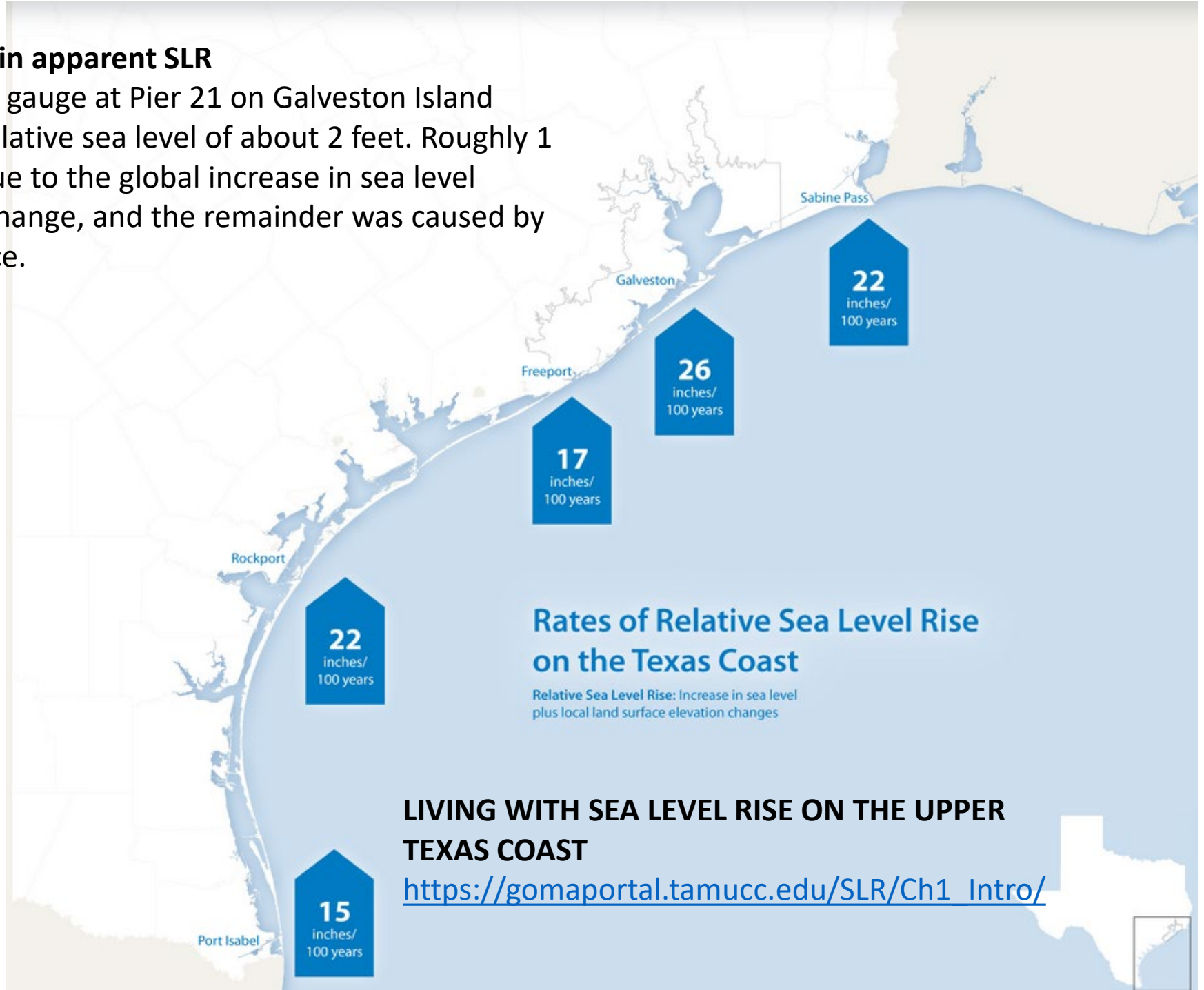
Sea Level Trends - Galveston



https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8771450

Role of Subsidence in apparent SLR

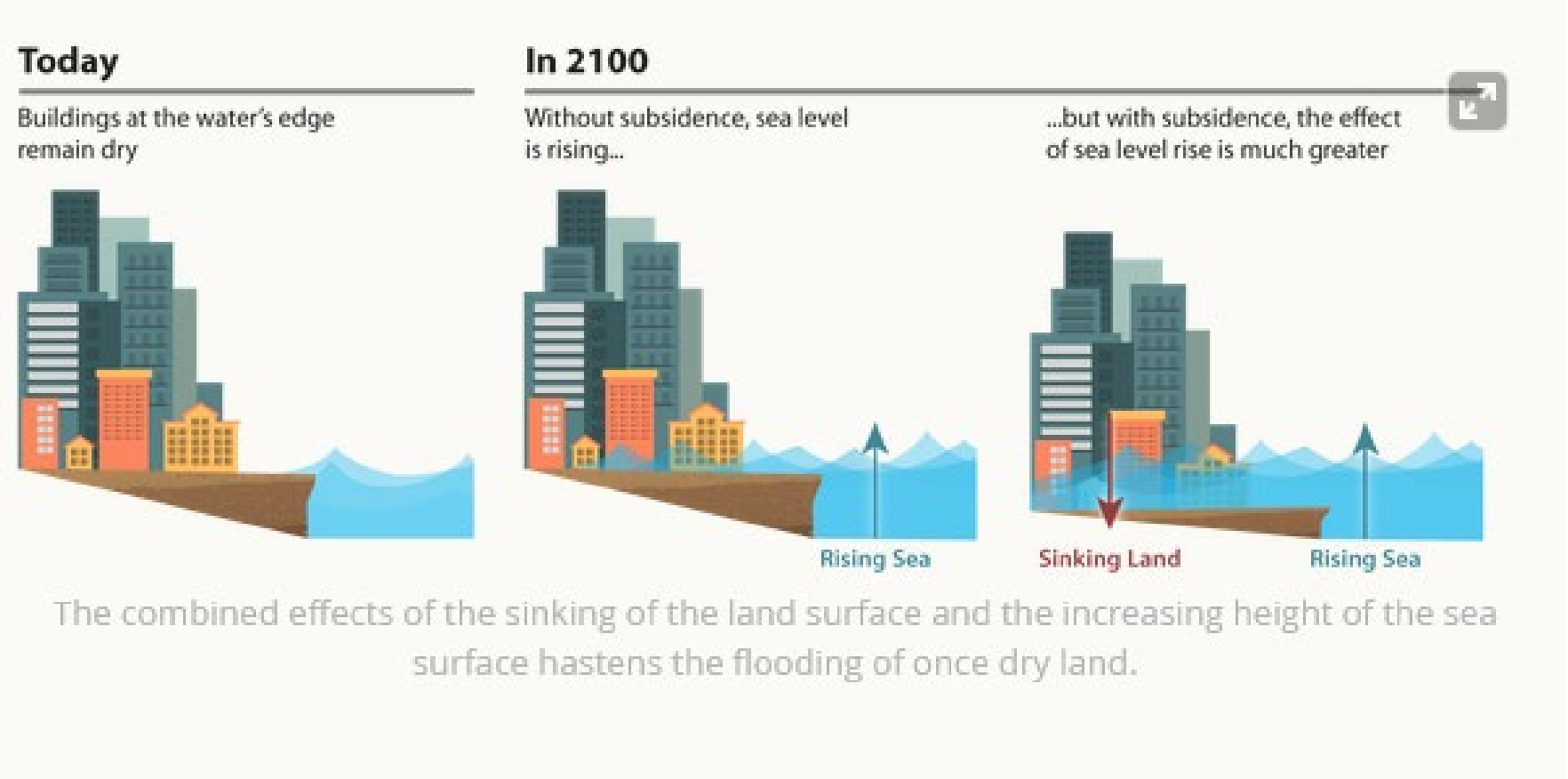
Since 1908, the tide gauge at Pier 21 on Galveston Island recorded a rise in relative sea level of about 2 feet. Roughly 1 foot of this rise is due to the global increase in sea level caused by climate change, and the remainder was caused by local land subsidence.



LIVING WITH SEA LEVEL RISE ON THE UPPER TEXAS COAST

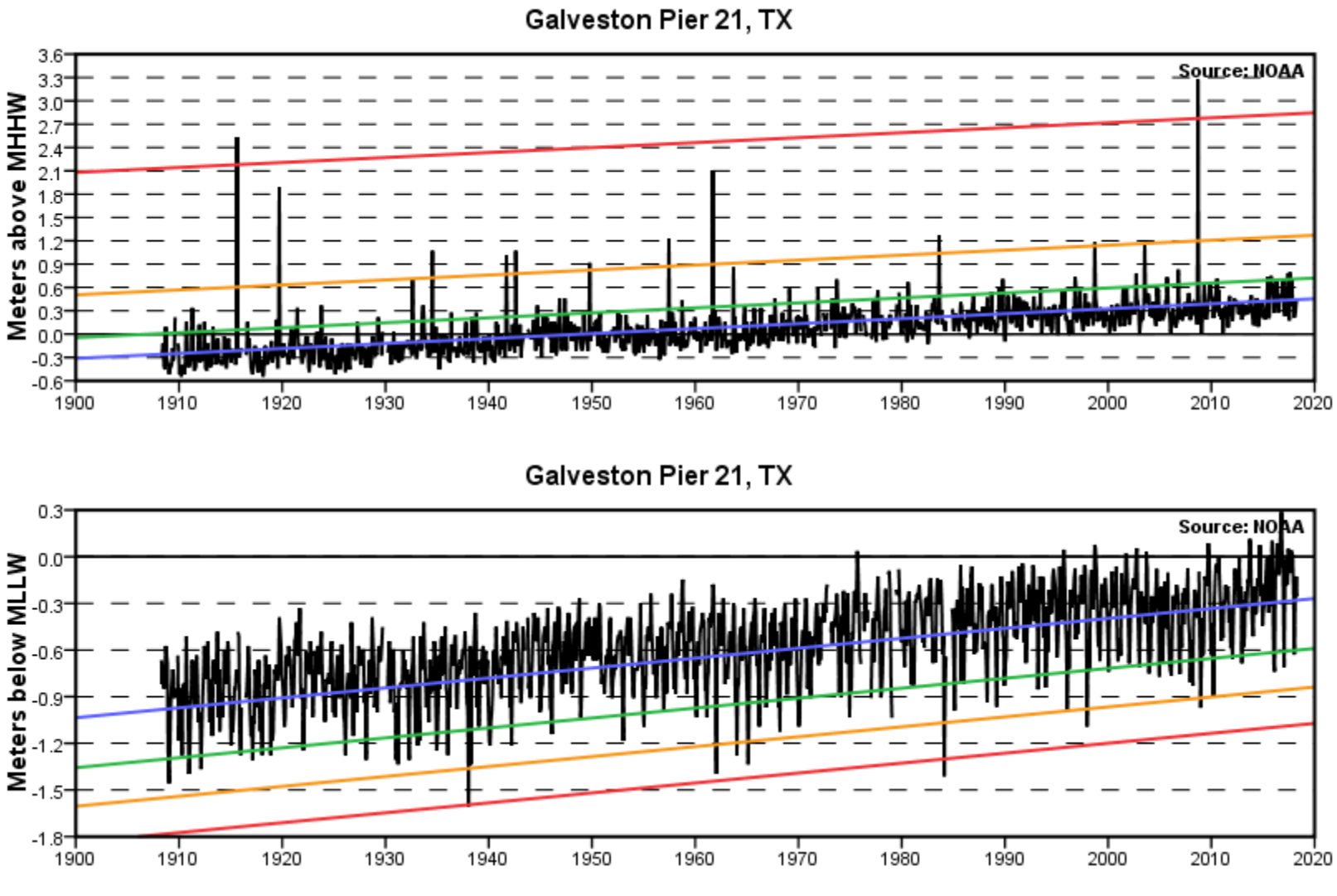
https://gomaportal.tamucc.edu/SLR/Ch1_Intro/

Subsidence + SLR



The combined effects of the sinking of the land surface and the increasing height of the sea surface hastens the flooding of once dry land.

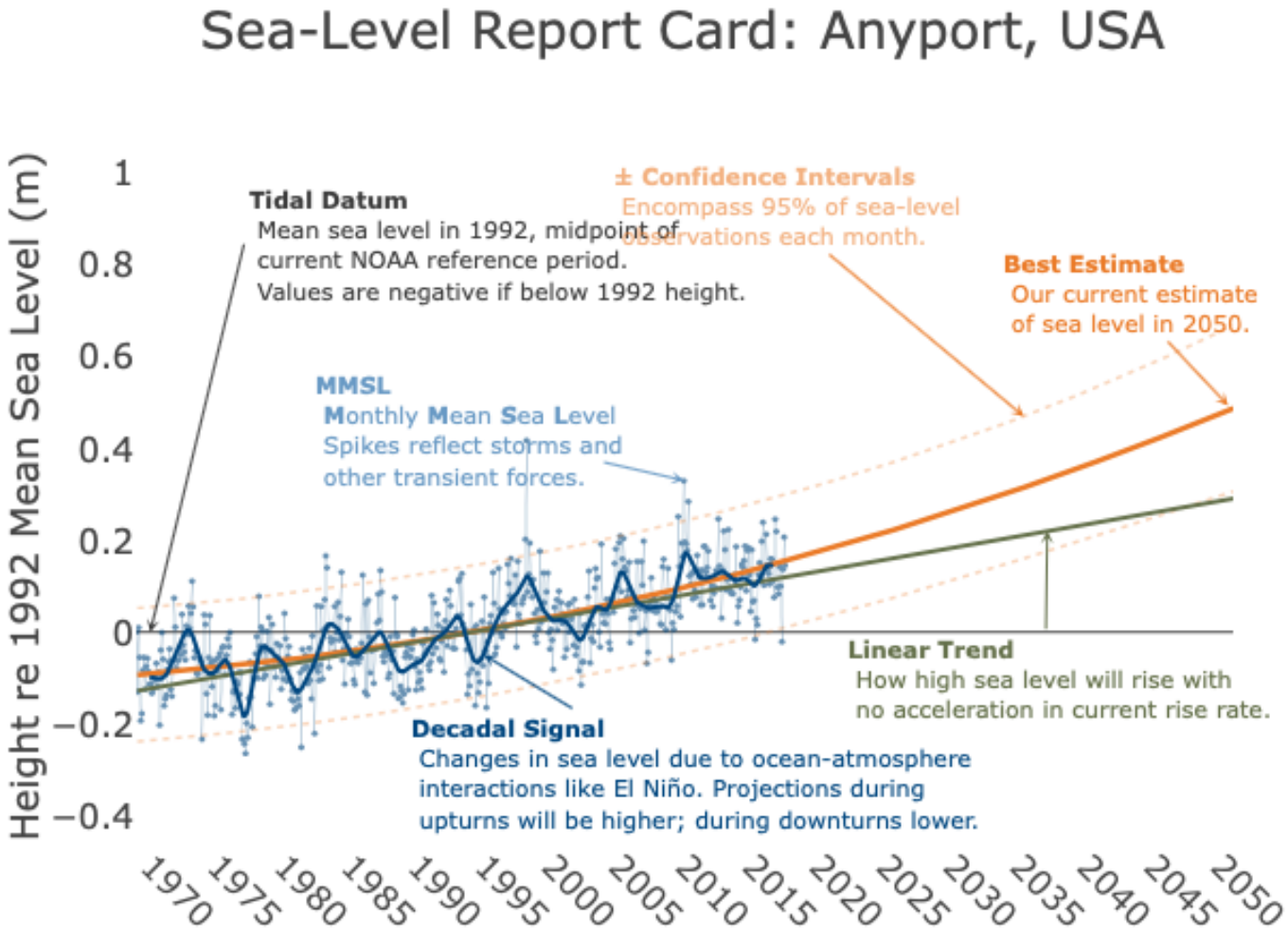
Sea Level Trends Extremes - Galveston



https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=8771450

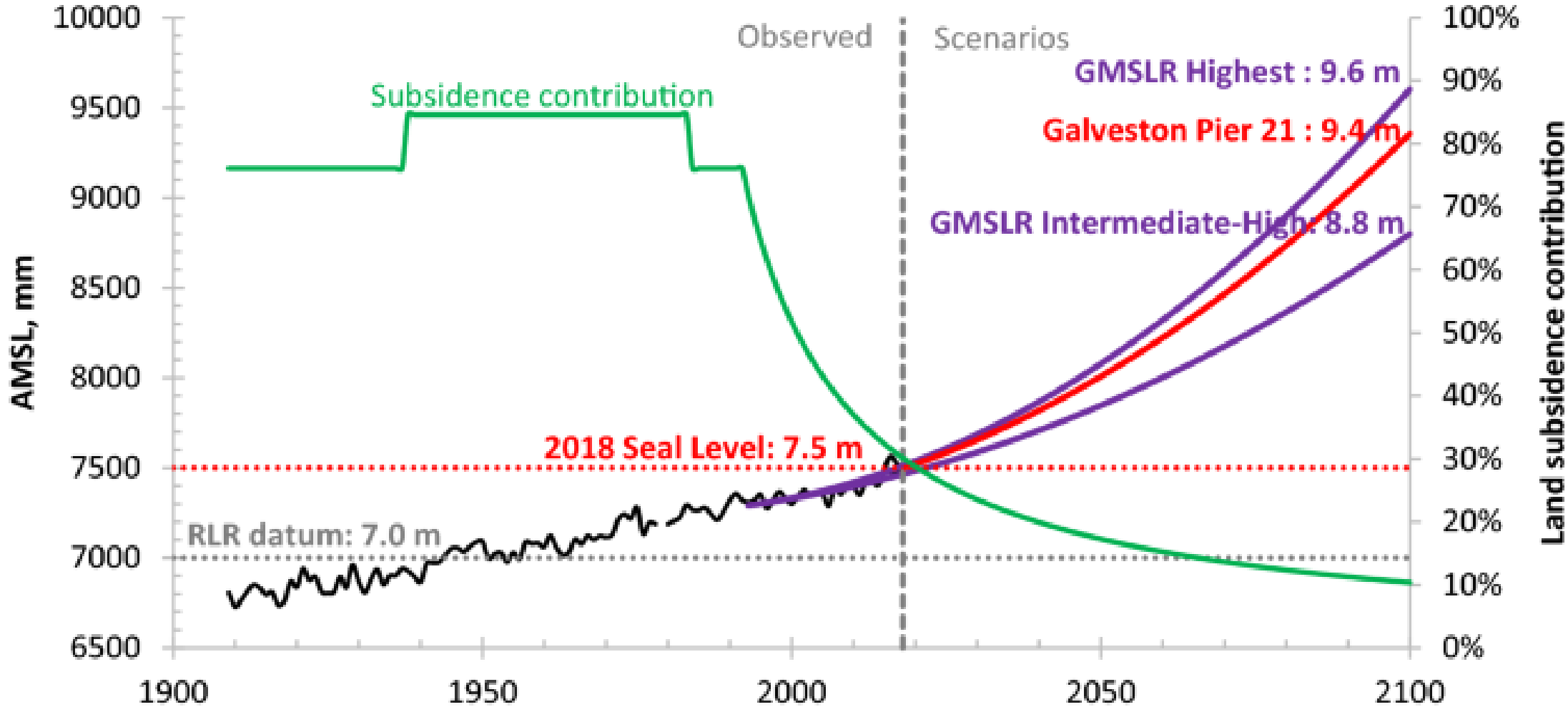
Projected SLR

- Scientists at the Virginia Institute of Marine Science measured sea-level rise at 32 tide-gauge stations along the U.S. coastline. **Rockport and Galveston had the second- and third-highest rates of rise in 2019**



Dawson 2/6/2020 Texas Climate News

Galveston Relative Sea Level Rise

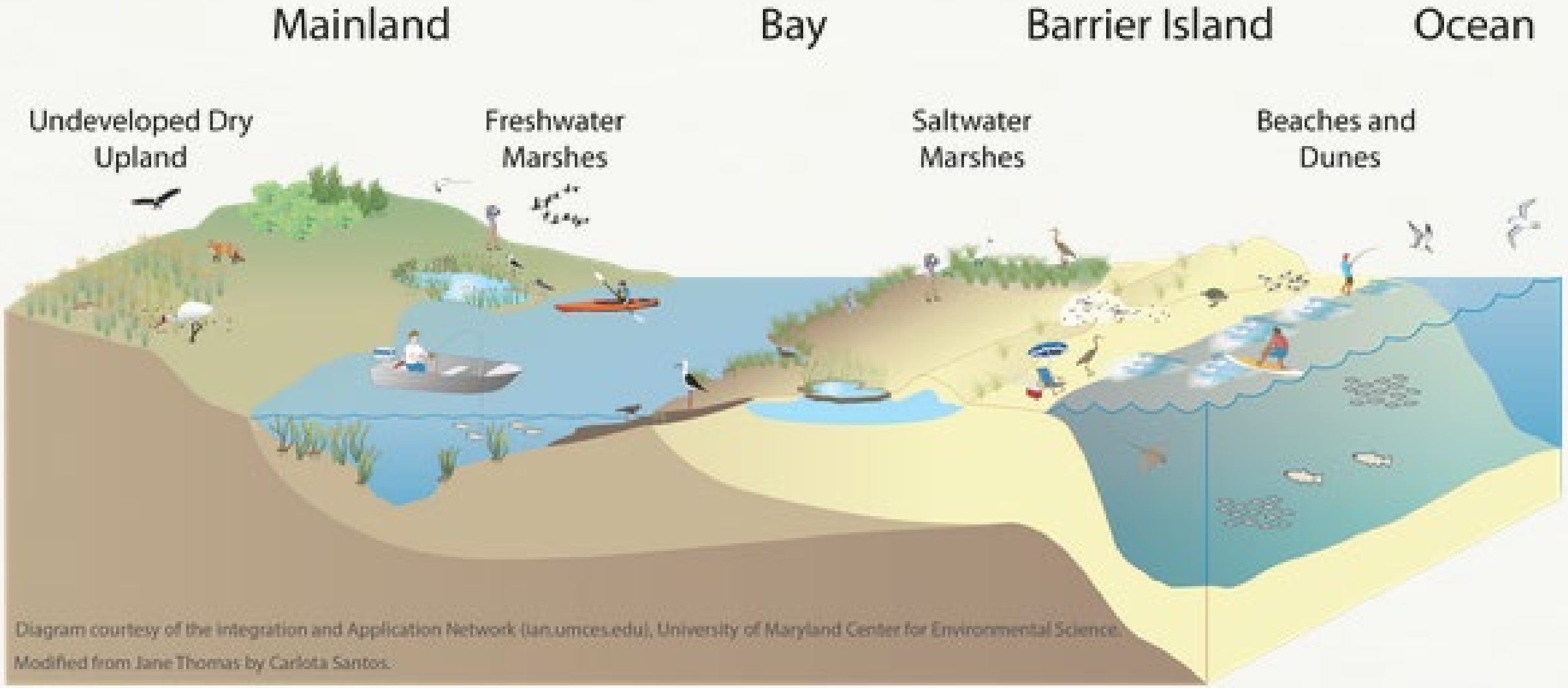


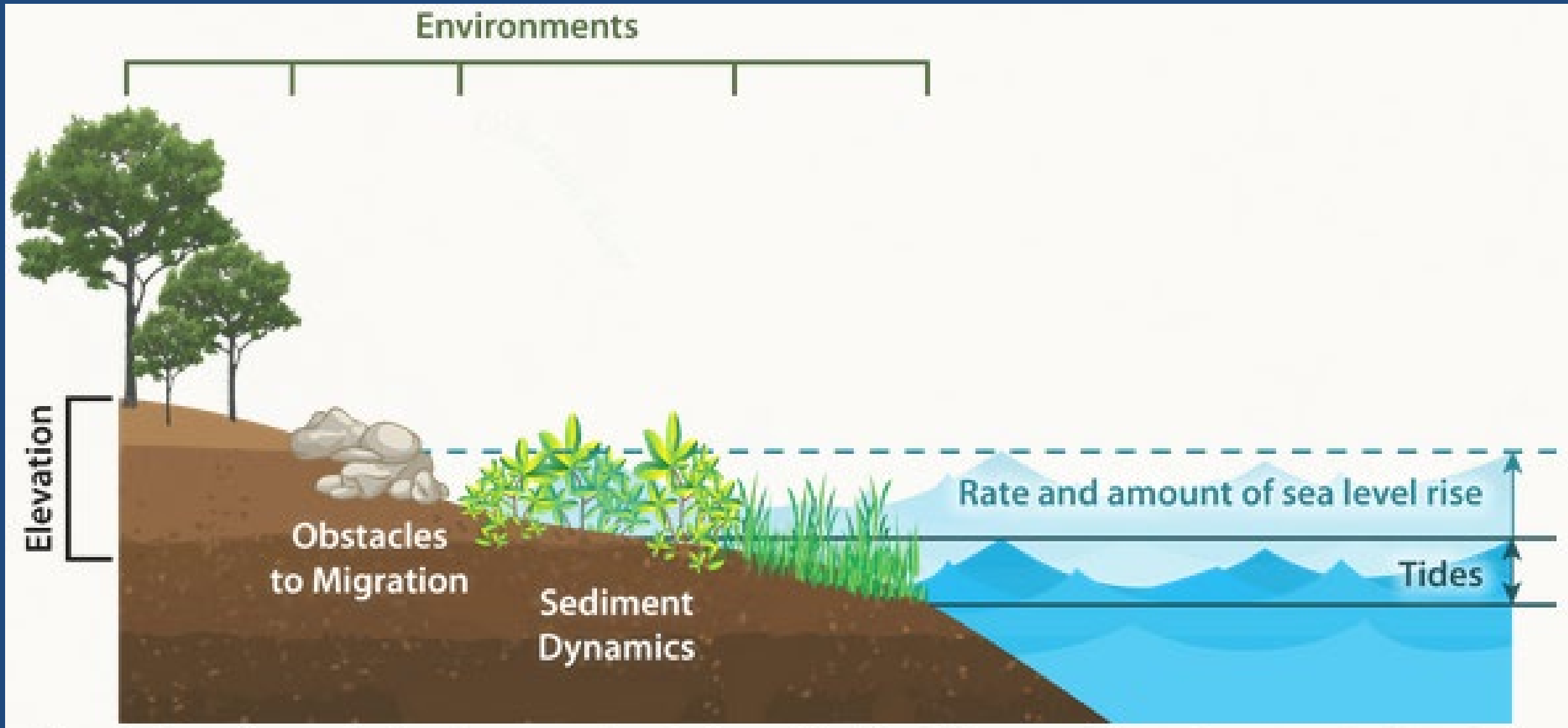
Liu et al.. 2020

Projected SLR

- The U.S. Interagency Sea Level Rise Taskforce concluded in 2017 that, averaged globally, the planetary sea level **“is very likely to rise at least 12 inches (0.3 meters) above 2000 levels by 2100** even on a low-emissions [of climate-altering pollution] pathway,” NOAA’s November 2019 report said.
- The **2050 projections for sea-level rise are 0.51 meters (1.67 feet) at Galveston.**
- **Note: Actual SL during Hurricane events = SLR + Storm Surge + Rainfall runoff**

The Texas Coast



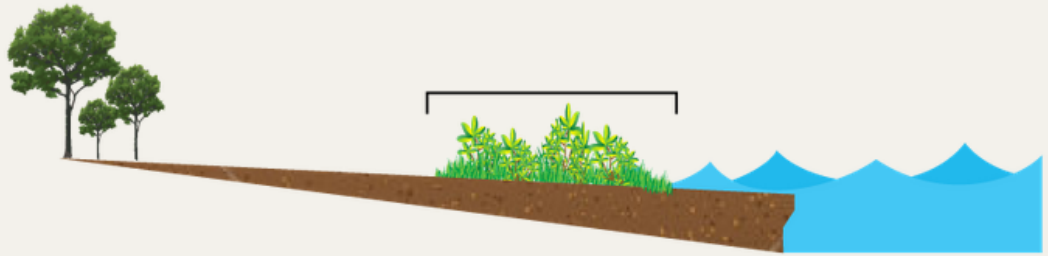


Key factors in modeling how sea level rise will affect the coastal environment. Adapted from the National Oceanic and Atmospheric Administration's **Marshes on the Move**.

Wetlands Retreat

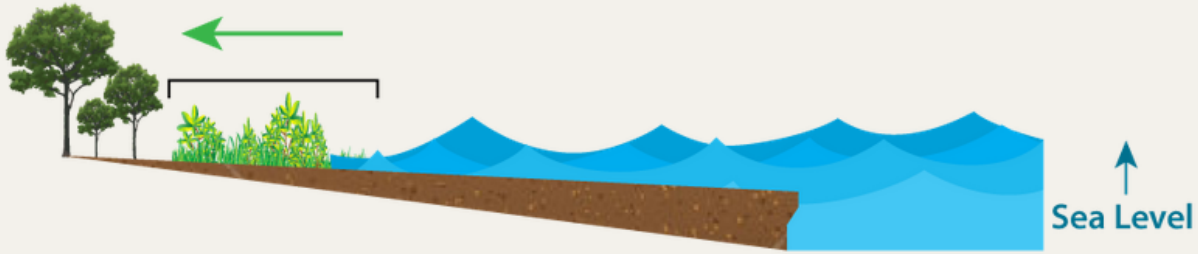
Saltmarsh at current sea level

The marsh develops on the gentle sloping shore in the intertidal zone, above water at low tide and below water at high tide



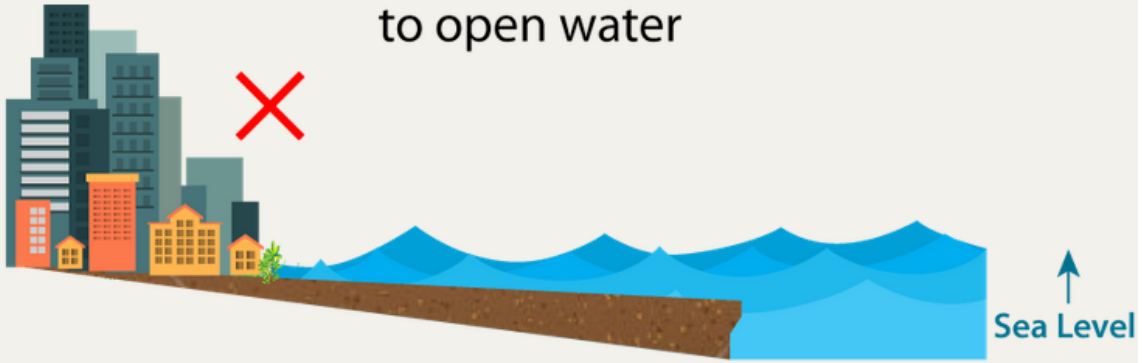
Saltmarsh migration as sea level rises

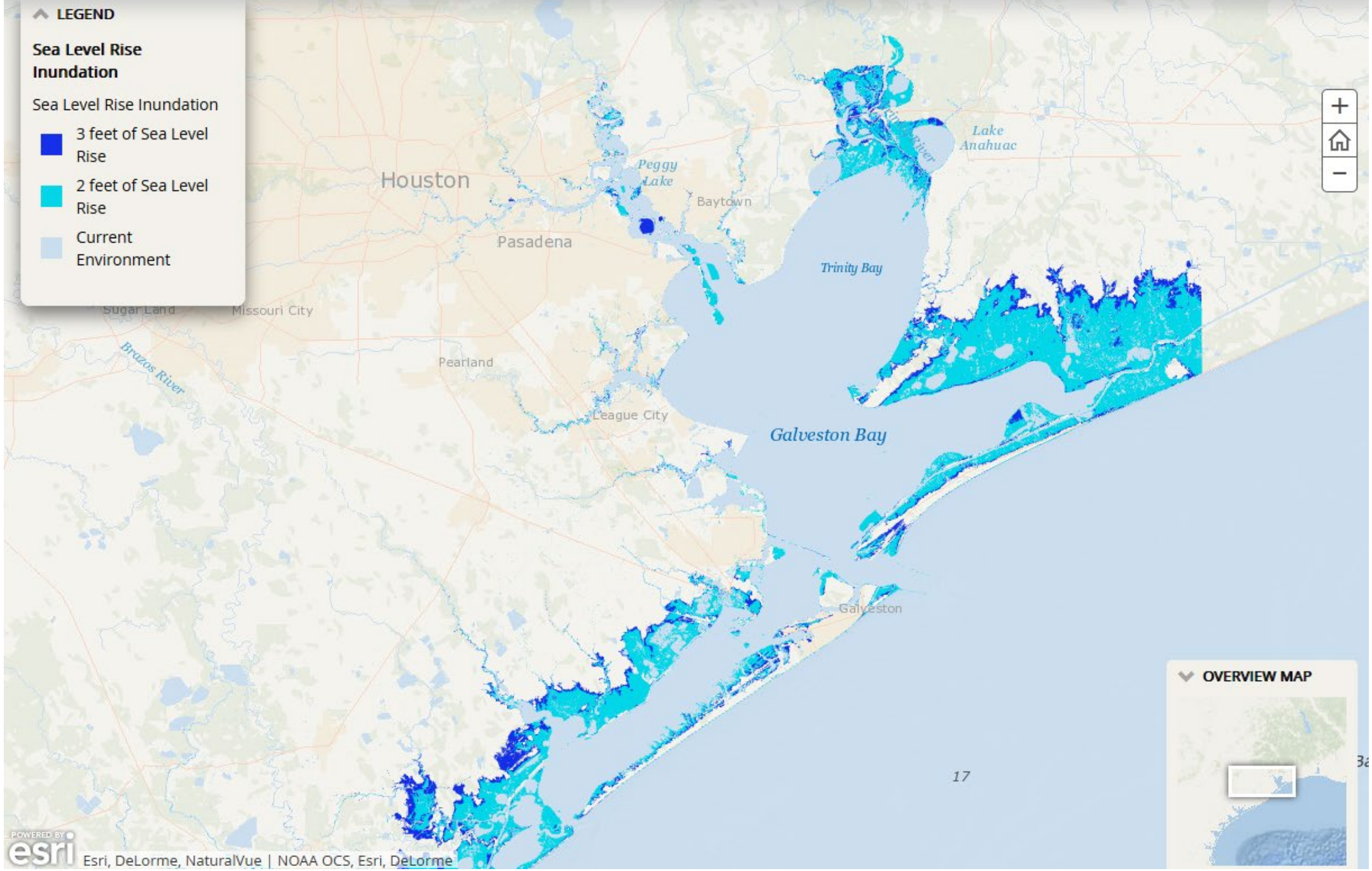
The marsh is able to migrate landward if there is available open space and the slope is not too steep



Coastal Squeeze

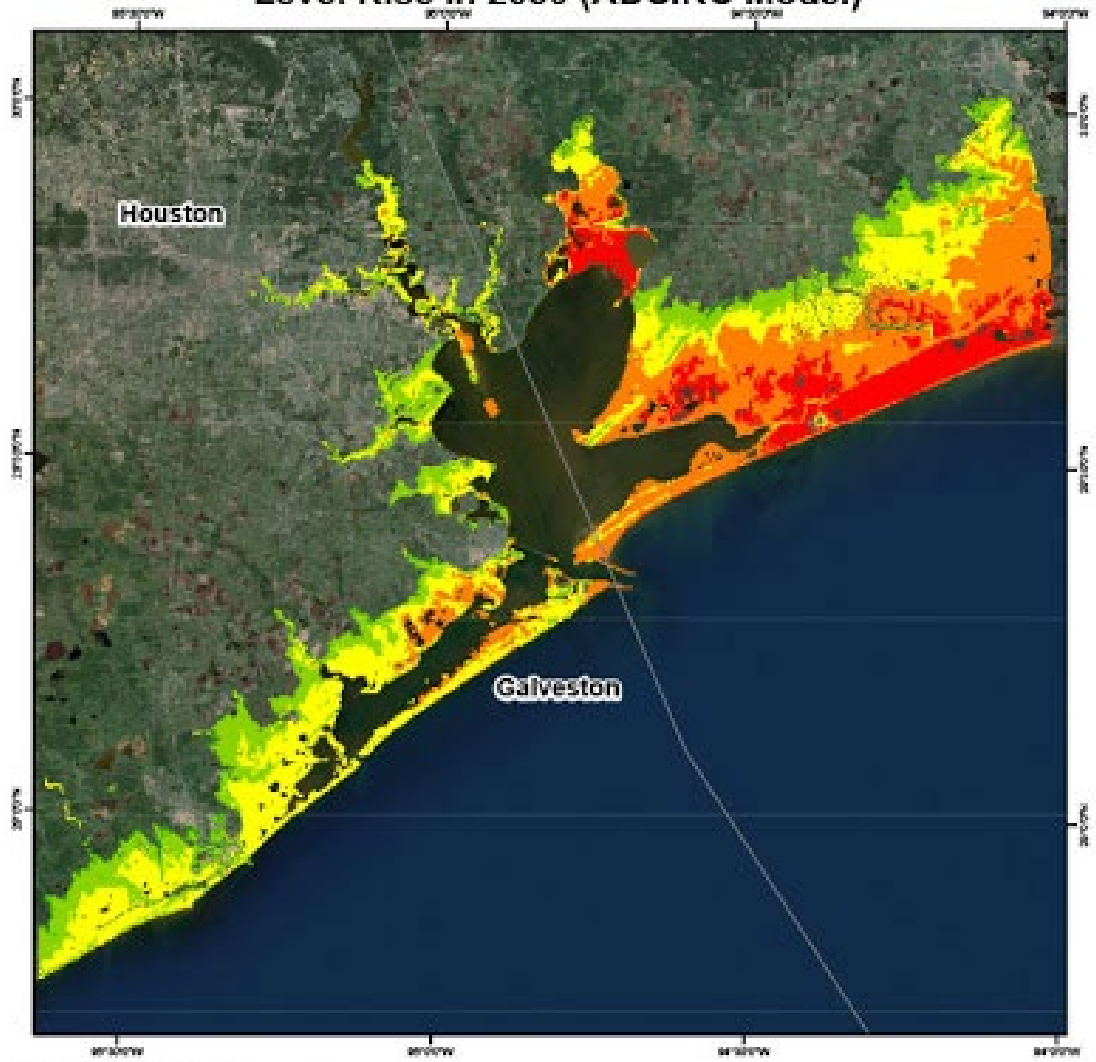
Development prevents the marsh from migrating landward and the marsh is lost to open water





Intergovernmental Panel on Climate Change's 5th Assessment Report 2013 Representative Concentration Pathways 8.5

Maximum Predicted Storm Surge Height for Galveston Bay, Texas under Hurricane Ike Conditions with 0.41 m of Sea-Level Rise in 2050 (ADCIRC Model)



Storm Surge Height

- 0.33 - 1 ft
- 1.01 - 5 ft
- 5.01 - 10 ft
- 10.01 - 15 ft
- 15.01 - 18.17 ft
- Hurricane Ike

This map was created by the Marine Program of The Nature Conservancy's Texas Chapter. The funding was provided by a grant from the Gulf of Mexico Alliance.

Coordinate System: NAD83 UTM Zone 15N
Date: January 2012

0 5 10 20 Miles

N

GULF of MEXICO FOUNDATION

The Nature Conservancy

Combating Storms

- Structural
- Natural Land buffers (e.g. wetlands)
- Policy/Behavioral – zoning, set back, sticks and carrots.

Texas City Levee

Proposed “Ike Dike” – part of Coastal Texas Plan

“Ike Dike” – part of the **Coastal Texas Plan**

- A “**Multiple Lines of Defense**” strategy was used in the Coastal Texas study to design cost-effective, environmentally friendly solutions that will reduce risks of storms impacting the coastal communities and restore important wildlife habitat at the same time.

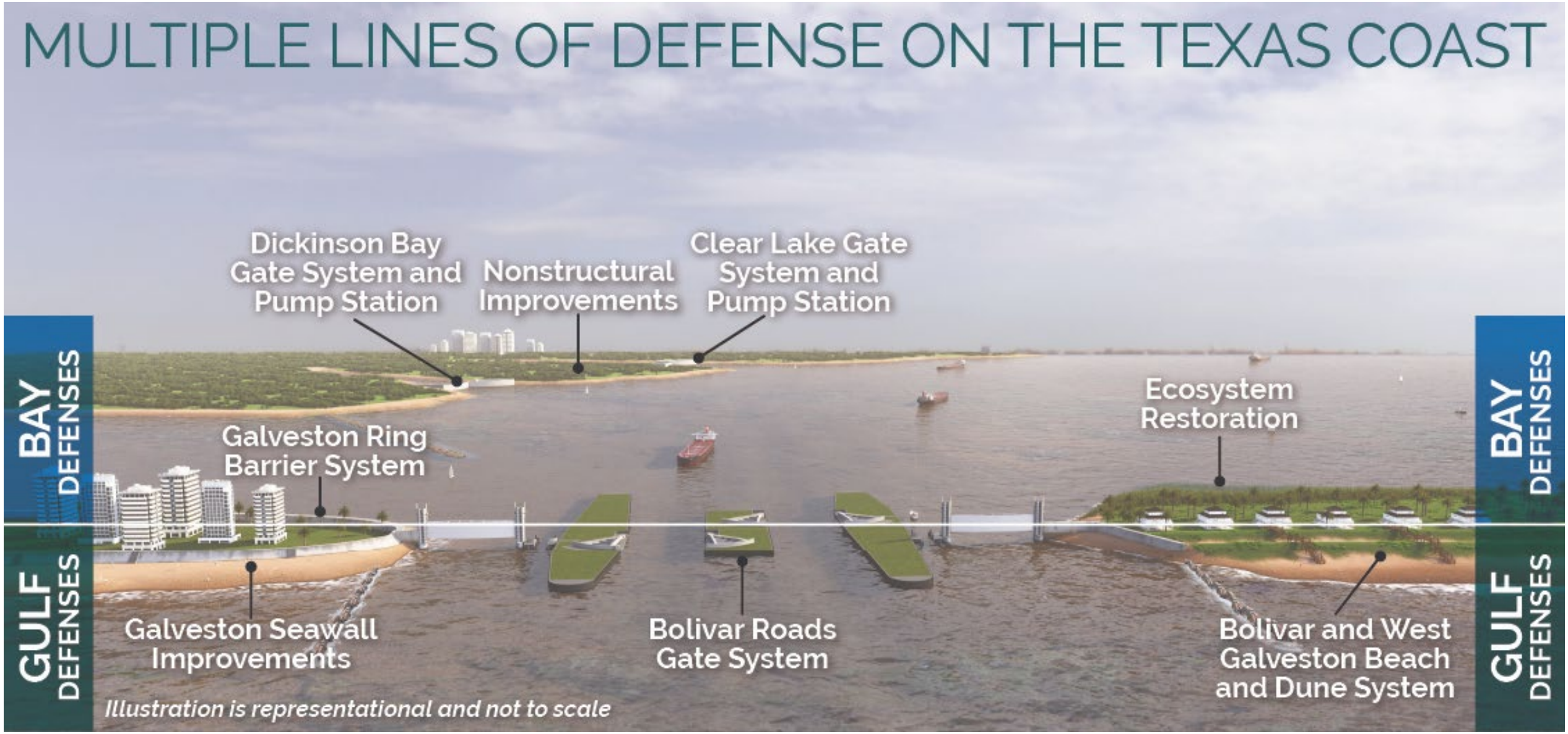
Recommended Coastal Texas Plan

- The entire proposed plan that was presented in the Coastal Texas Study include the:

1. Gate systems (i.e. Ike Dike at Bolivar Roads)
2. Galveston ring barrier (bay defenses),
3. Ecosystem Restoration,
4. Gates at Clear Lake & Dickinson,
5. + all necessary mitigation.

Recommended Coastal Plan (RP)

- **Coastal Barrier**
  - Surge gates across the Bolivar Roads inlet including two 650’ sector gates for ship traffic, two 125’ sector gates for other vessels, 15 vertical lift gates and shallow water gates for water flow
  - Tie-in structures consisting of floodwalls and levees
  - Beach and dune systems along the front of Bolivar Peninsula and Galveston Island to reduce storm surge
  - Galveston Ring Barrier System, including improvements to the Seawall, floodwalls, levees, pumping stations, and a gate system at Offatts Bayou
  - Storm Surge Gates Systems(with pump stations) at Clear Lake and Dickinson Bayou
  - Non-structural improvements along West side of Galveston Bay
  - South padre island beach nourishment and sediment management measures.
- 8 ecosystem restoration projects along areas of Texas coast


MULTIPLE LINES OF DEFENSE ON THE TEXAS COAST
Dickinson Bay Gate System and Pump Station
Nonstructural Improvements
Clear Lake Gate System and Pump Station
BAY DEFENSES
Galveston Ring Barrier System
Ecosystem Restoration
BAY DEFENSES
GULF DEFENSES
Galveston Seawall Improvements
Bolivar Roads Gate System
Bolivar and West Galveston Beach and Dune System
GULF DEFENSES
Illustration is representational and not to scale

Current Status

- The latest update is that the Coastal Texas Program was authorized under **WRDA 2022 in December**.
- The USACE has not received any dedicated funding as of yet, *so no new work has been started.*
- **There is no updated timeline yet.**
- The website has not been updated. The USCOE may issue a press release if and when funded.
- The TGLO does have a Coastal Texas Study website, Story map, & USACE links are posted below.
- https://coastalstudy.texas.gov/
- https://coastal-texas-hub-usace-swg.hub.arcgis.com/
- https://www.swg.usace.army.mil/

Gulf Defenses

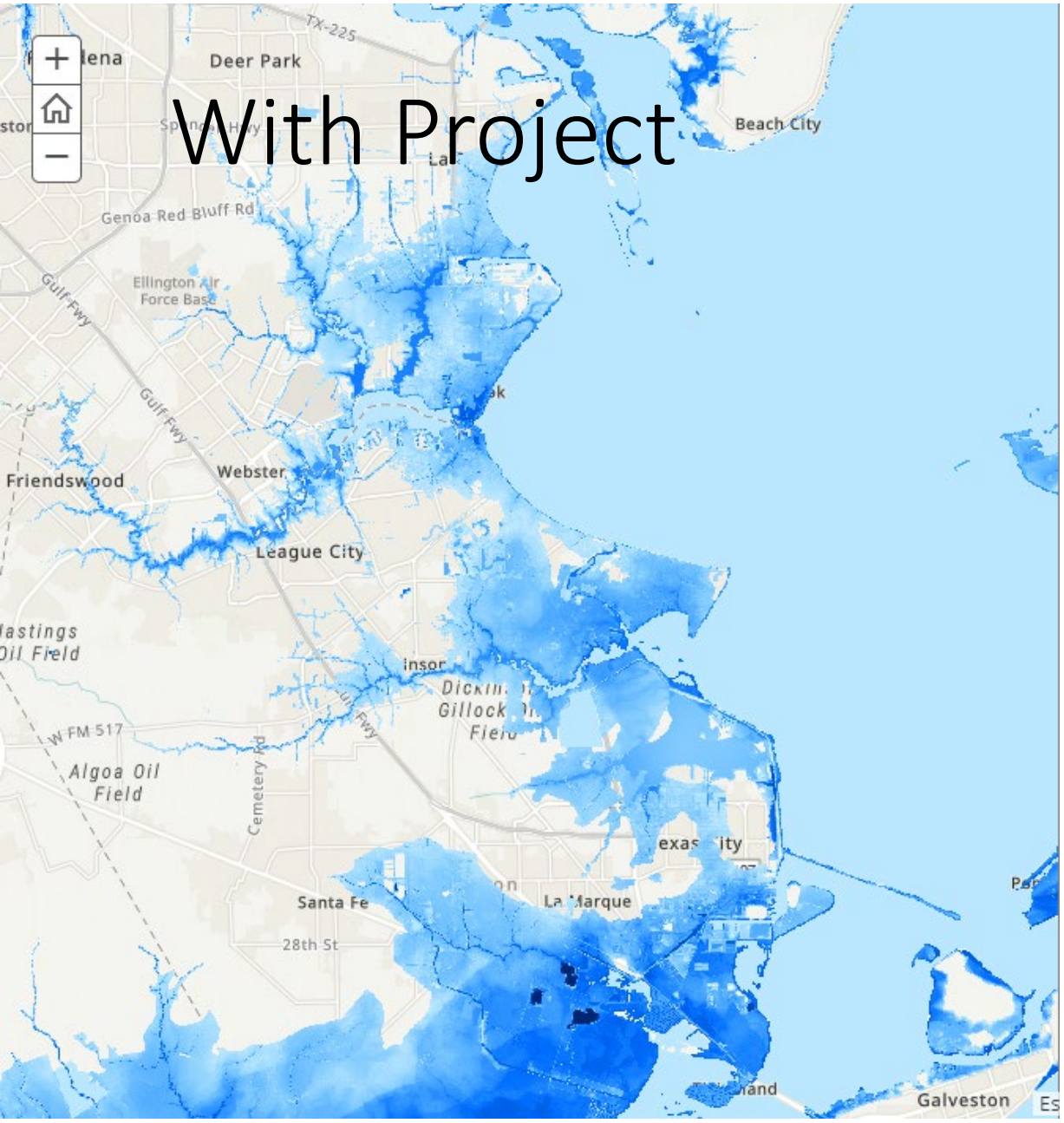
- With a focus on redundancy and robustness, the first objective is to keep the storm surge in the Gulf.
- The “Gulf Defenses” meet this challenge with a combination of surge gates at Bolivar Roads, seawall modifications on Galveston, and dune and beach systems on Galveston Island and Bolivar Peninsula.

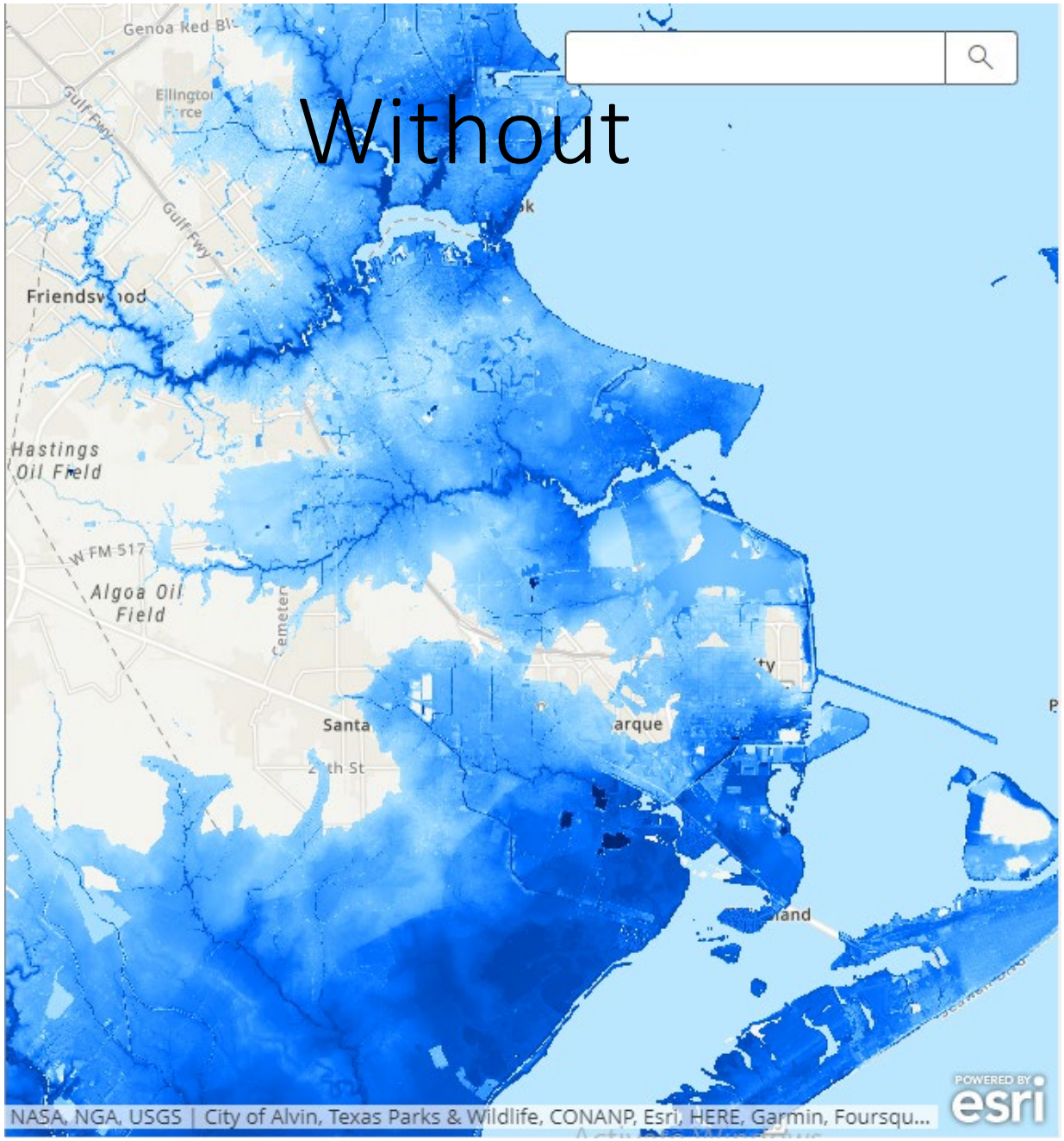
"Ike Dike"

Figure 3.17: Bolivar Roads Gate System – conceptual rendering

Bay Defenses

- However, a combination of water from Galveston Bay and Gulf surge that could overtop the front-line defenses must be addressed through a second line of defense.
- The “Bay Defenses,” comprised of a ring barrier system on Galveston Island, surge gates (and pumping stations) on the mainland, and nonstructural measures such as flood-proofing and the raising of buildings on the mainland, offer this second line defense.


With Project
Deer Park
Beach City
Genoa Red Bluff Rd
Ellington Air Force Base
Gulf Fwy
Webster
Friendswood
League City
Hastings Oil Field
W FM 517
Algoa Oil Field
Cemetery Rd
Santa Fe
La Marque
28th St
Galveston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Hastings Oil Field
W FM 517
Algoa Oil Field
Cemetery
Santa
28th St
NASA, NGA, USGS | City of Alvin, Texas Parks & Wildlife, CONANP, Esri, HERE, Garmin, Foursqu...
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Coastal Resilience

- To further ensure Coastal Resilience and support the multiple lines of defense strategy, the
- Recommended Plan includes the restoration of 6,600+ acres of critical fish and wildlife habitat to provide a third buffer against coastal storms and erosion processes.

Potential negative effects

- Construction activities and operations
- Sound – construction
- Channel velocities.
- Change in bay circulation
- Lower salinities
- Sediment transport
- Impacts on marine mammals, sea-turtles, fish, shellfish andbirds.
- Migration of fish, larval transport

Technical Consultation for Compliance with the Marine Mammal Protection Act in Support of the Coastal Texas Protection and Restoration Study

Final Report

EIH Final Report #18-003
October 24, 2018

Prepared by the Environmental Institute of Houston University of Houston – Clear Lake in cooperation with the Texas General Land Office

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References

- **LIVING WITH SEA LEVEL RISE ON THE UPPER TEXAS COAST**
- https://gomaportal.tamucc.edu/SLR/Ch1_Intro/

Questions?

Acronyms

- USACE – U.S. Army Corp of Engineers
- TGLO – Texas General Land Office
- NOAA – National Oceanic Atmospheric Administration