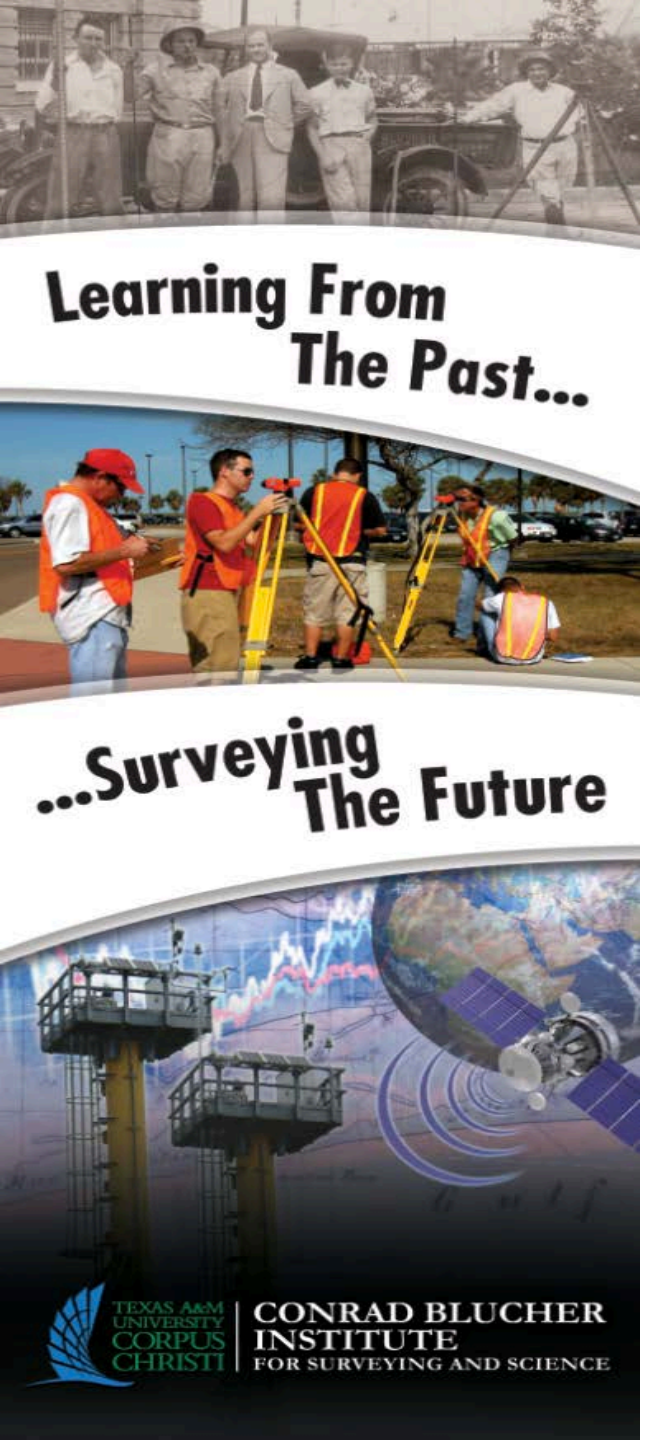
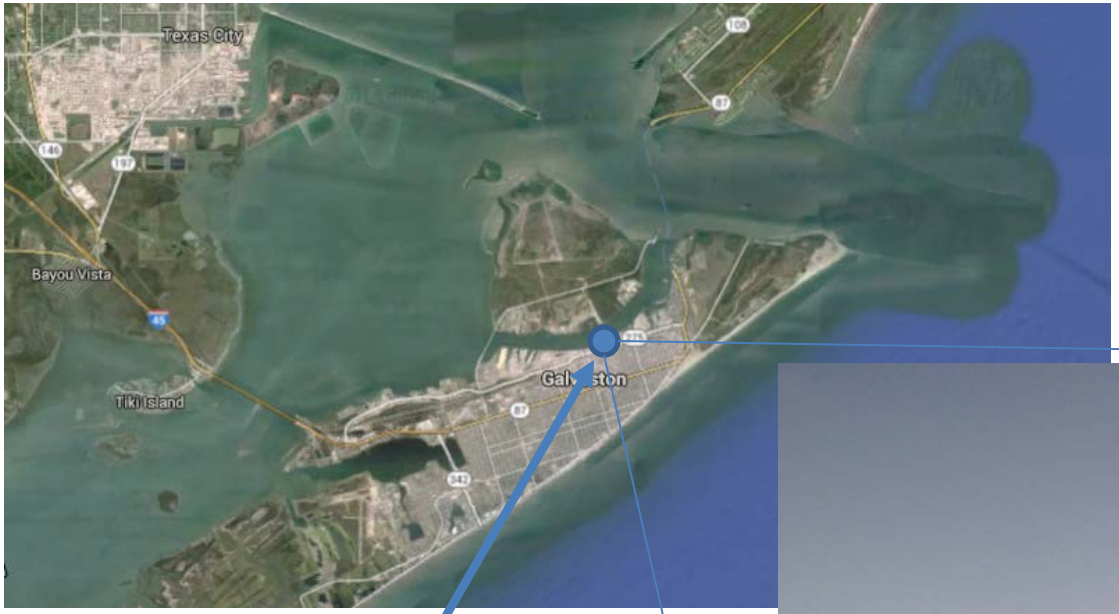


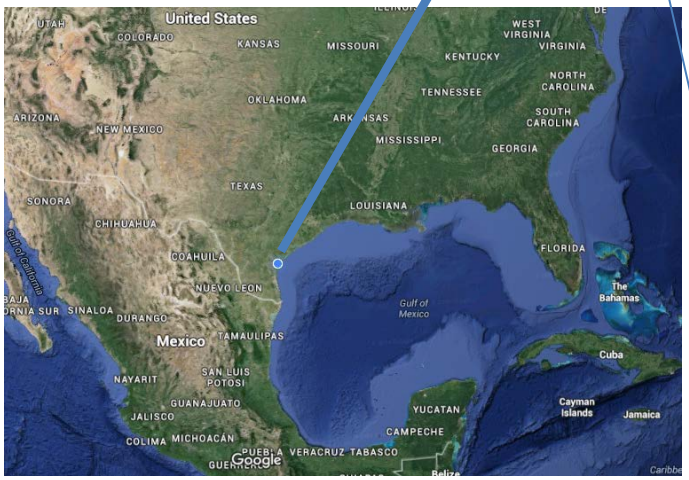
Relative Sea Level Rise around the Gulf of Mexico and its Impact: from Nuisance Flooding to Large Surges

Philippe Tissot
Associate Director
Conrad Blucher Institute
Texas A&M University-Corpus Christi

Hydrographic Services Review Panel Meeting
Galveston March 15-17, 2016

Water Levels: Galveston Pier 21

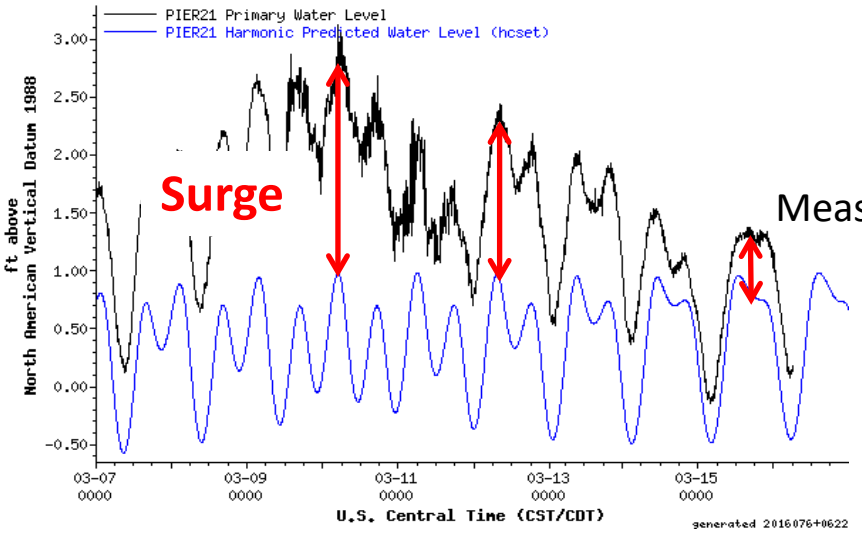




Water Level Time Series: 1908-

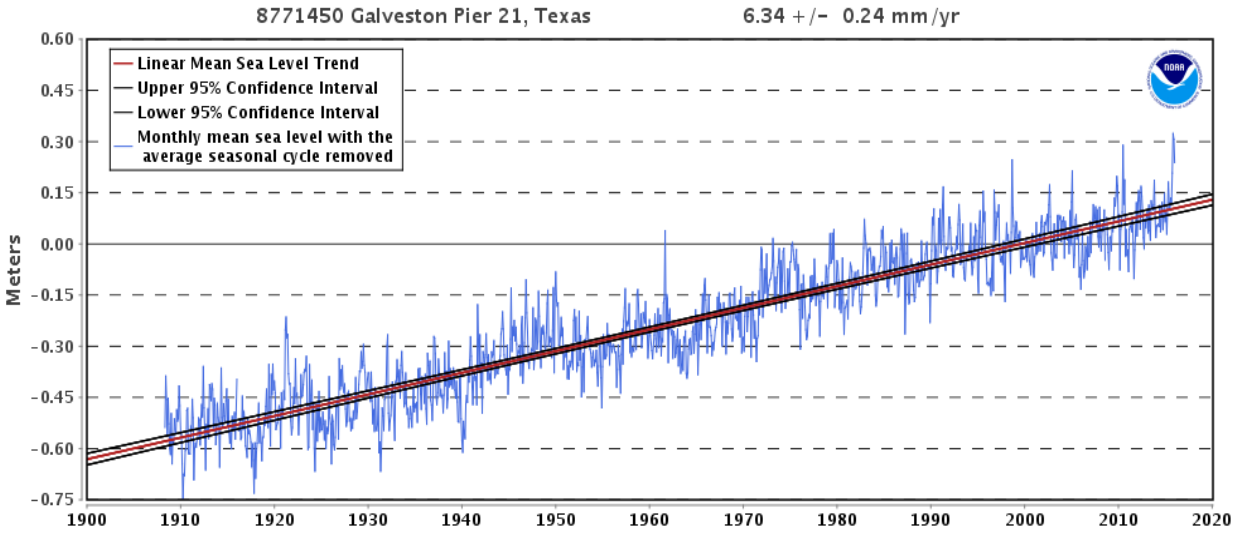
Water Levels: Galveston Pier 21

Short Term Measurements: Past 10days



Long Term Mean Sea Level Trend: 1908-2014

Long Term Trend:
6.34 mm / year
0.25” / year
2.1ft / 100 years



Overview

Relative Sea Level Rise around the Gulf of Mexico and its Impact: from Nuisance Flooding to Large Surges

- Importance of Measurements
  - Local Planning
  - Tidal Datums & Inundation Frequencies
  - Communicating Datums
- Importance of Spatial Variability
  - Sea Level Rise is ***Relative***
  - Storm Surges: Large & Nuisance Flooding
  - Changes in Inundation Frequencies
- Requires Consistent Local Measurements

What information do you need on sea levels?

Sea Levels: Temporal Variability

Long Term Sea Level Rise: 24K years

Recently sea level rise has been very moderate

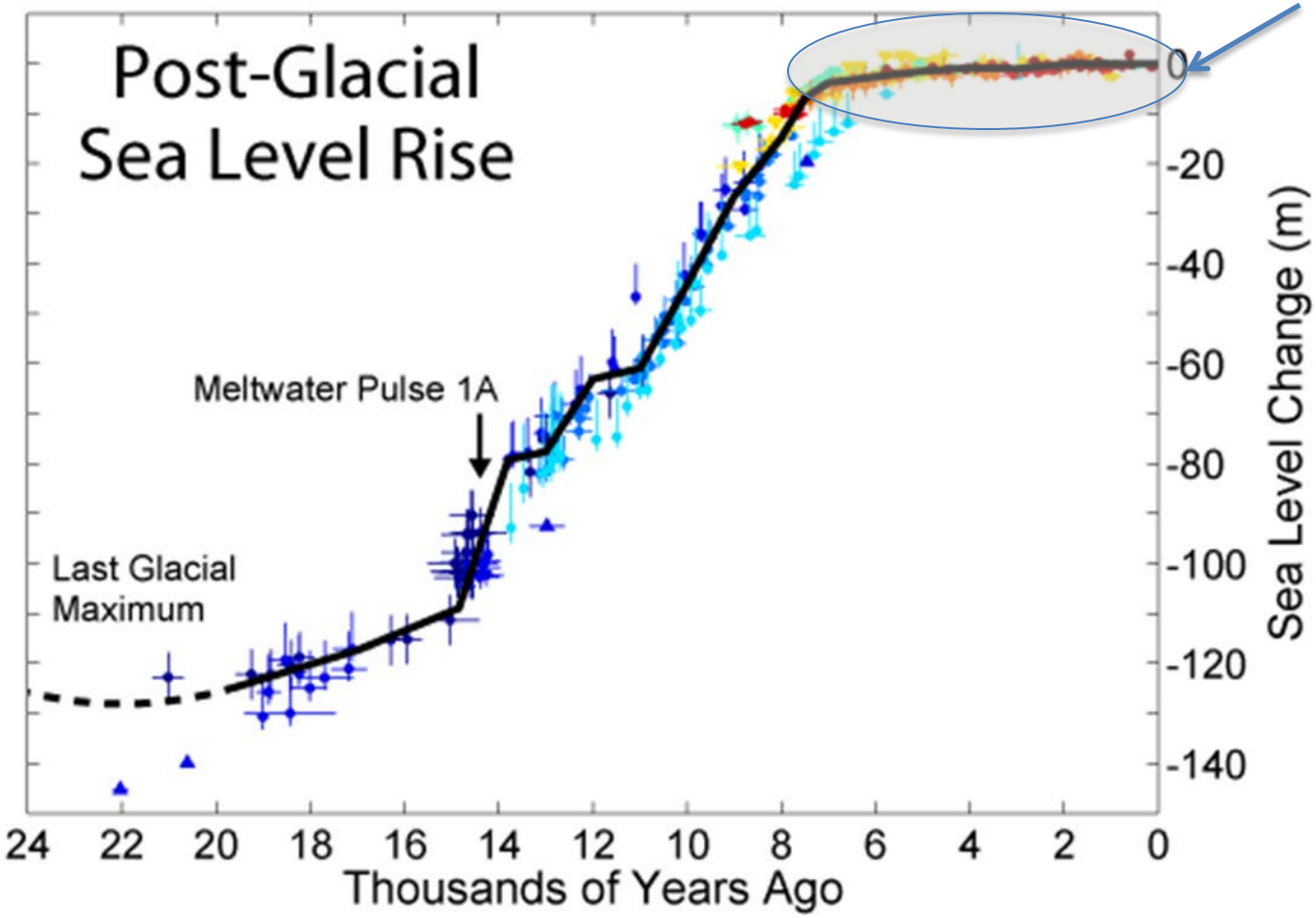
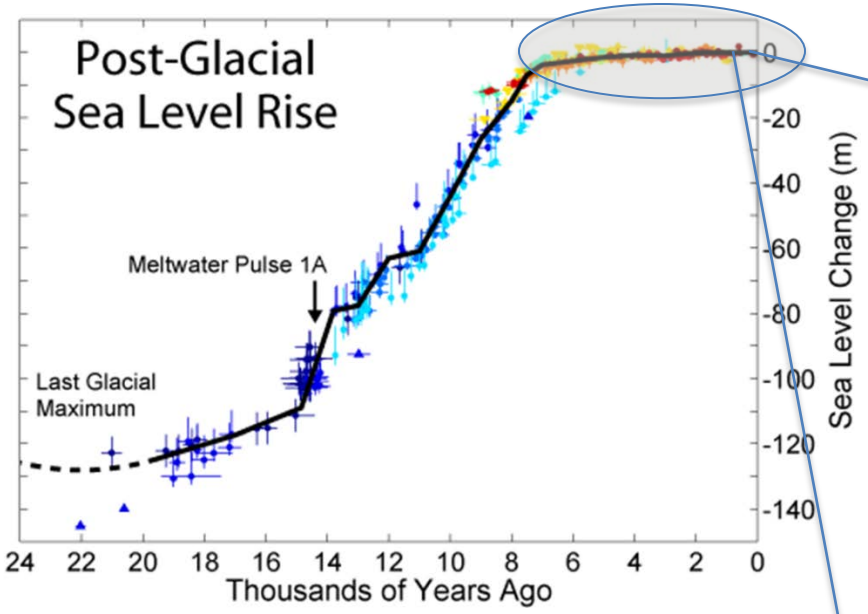
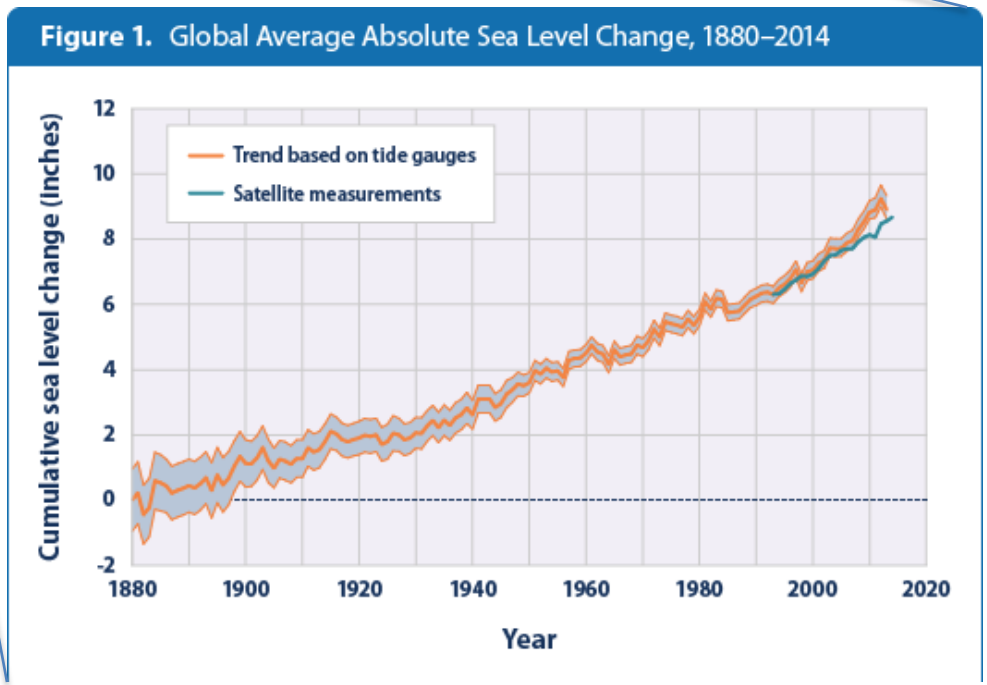


Figure: (http://en.wikipedia.org/wiki/Current_sea_level_rise)

Sea Levels: Temporal Variability





More recent sea level rise:

1.7 +/- 0.2 mm/yr (tide gauges)

3.3 +/- 0.4 mm/yr (Satellite 1993-2015)

Galveston Pier 21:

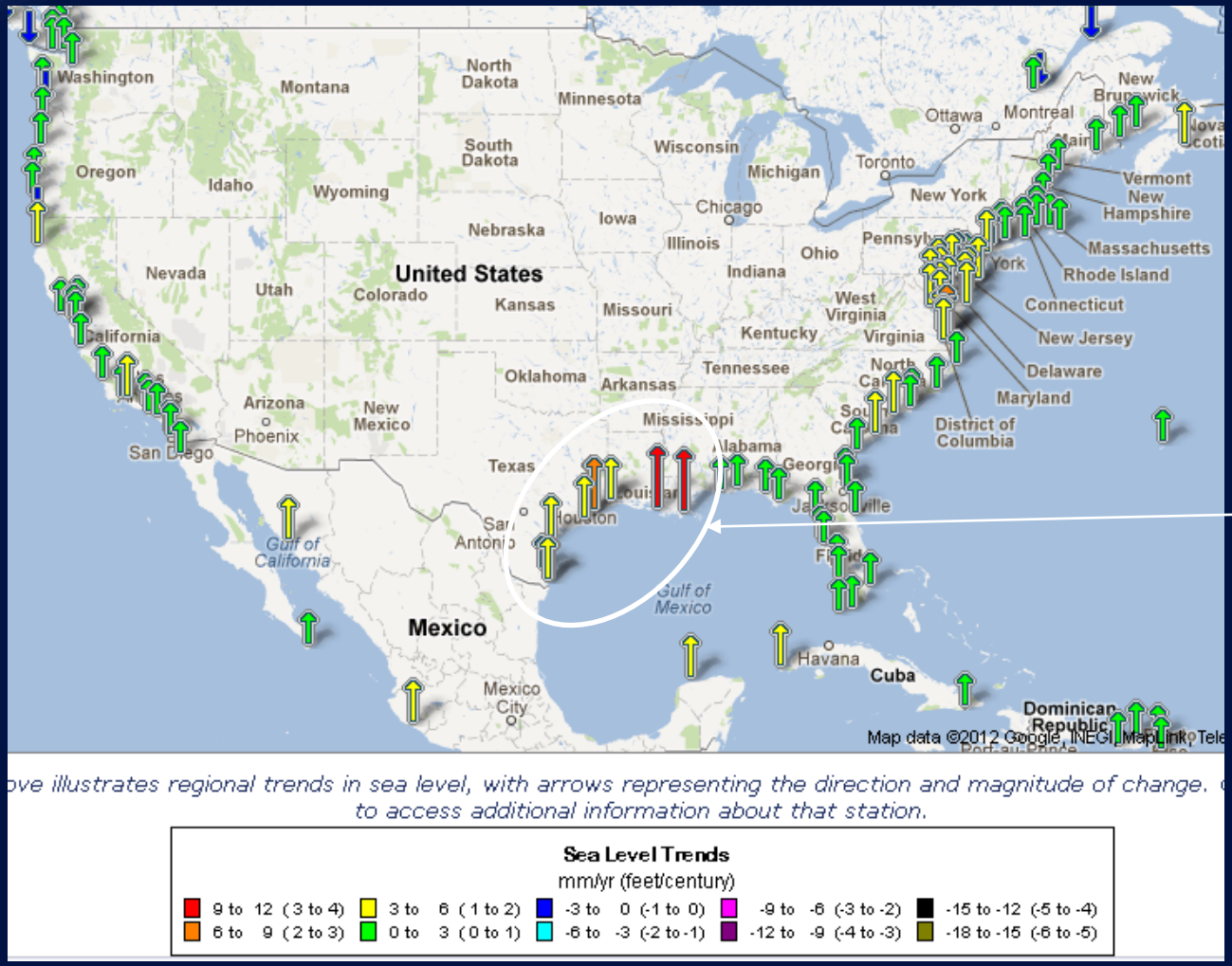
6.3 +/- 0.3 mm/yr (tide gauge)

Relative sea level rise

Top Figure : (http://en.wikipedia.org/wiki/Current_sea_level_rise)

Bottom Figure: (https://www3.epa.gov/climatechange/science/indicators/oceans/sea-level.html)

Relative Sea Level Rise in the NW Gulf of Mexico



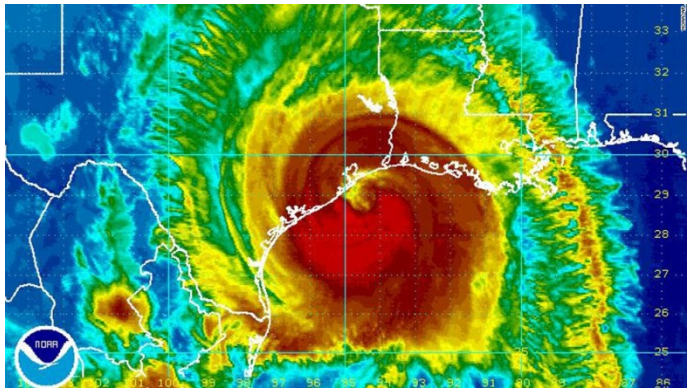
The Northwest Gulf of Mexico is home to the largest rates of relative sea level rise in the US and 10 of the largest 13 US ports by tonnage (USDOT 2016)

Figure: NOAA CO-OPS (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml)

Surge & Inundation

RSLR Impact: Changes in Inundation Frequencies?

- Large Surges (e.g. Hurricane Ike):



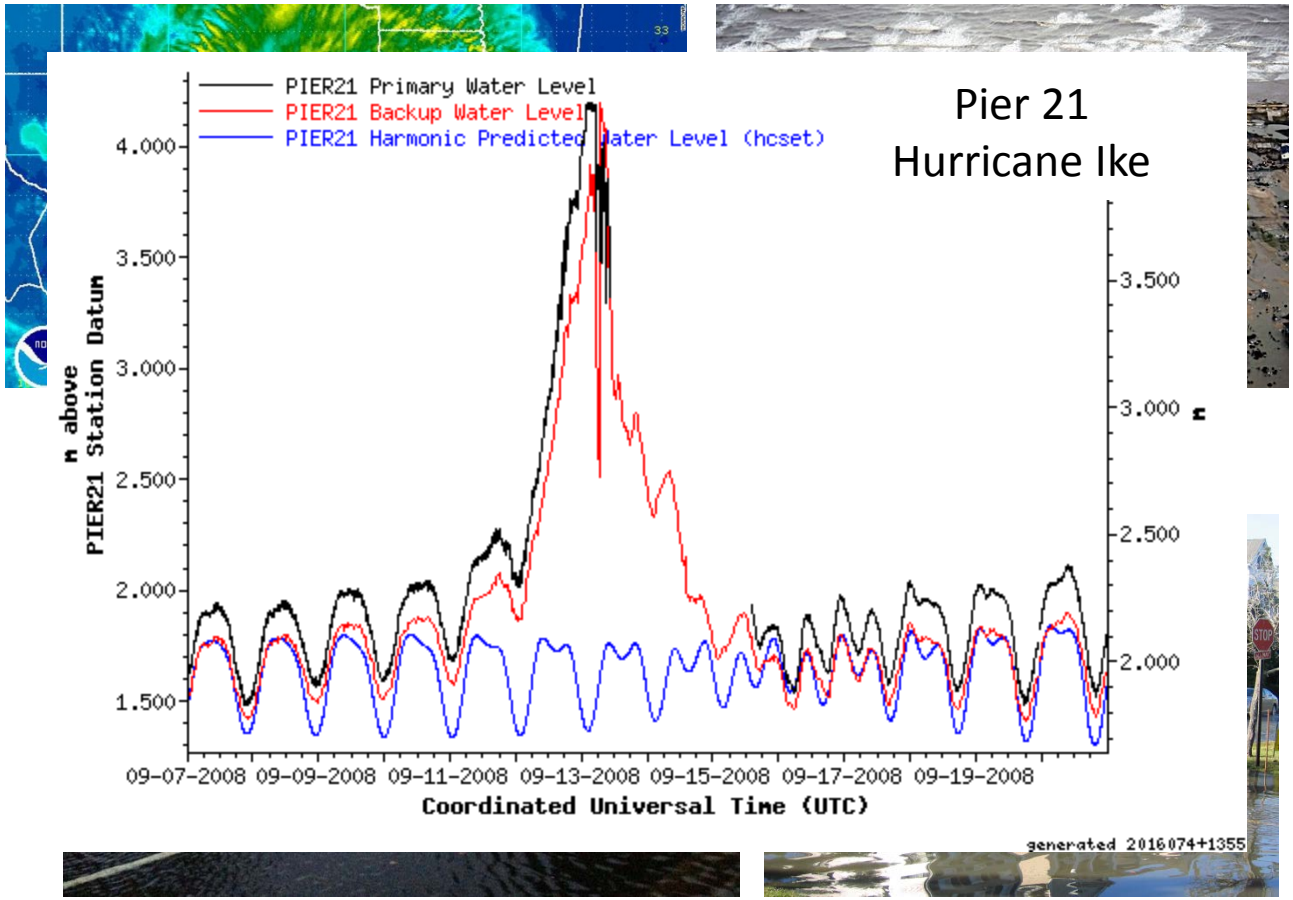
- "Nuisance" Flooding:



Surge & Inundation

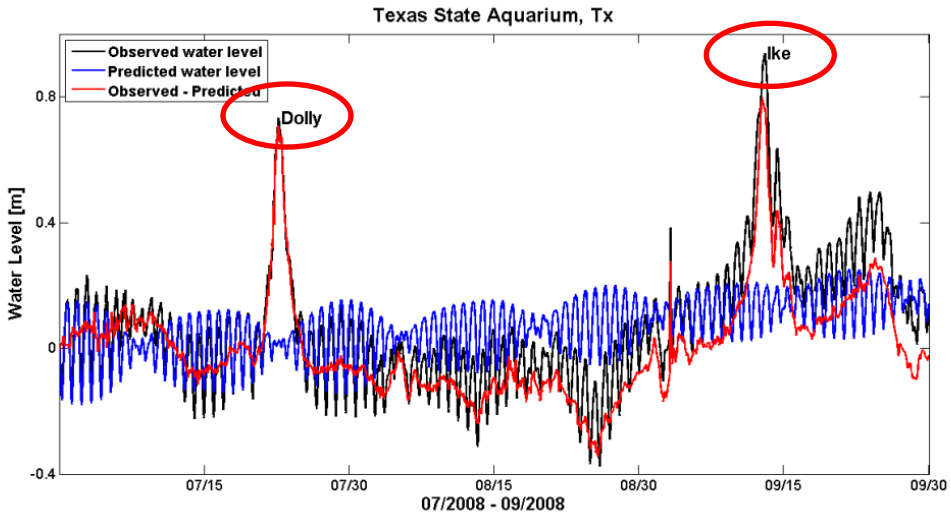
RSLR Impact: Changes in Inundation Frequencies?

- Large Surges (e.g. Hurricane Ike):



Changes in Inundation Frequency

As the century progresses coastal communities will have to deal with increasingly frequent small to medium inundations resulting in growing insurance claims.

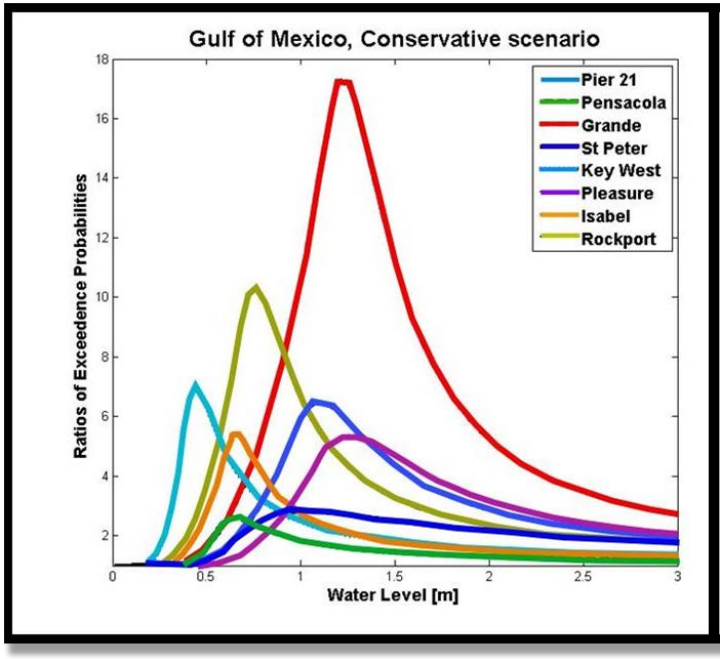


Corpus Christi
North Beach
2 inundations in 2008

Method to Compare Impact of RSLR

- Goal: quantify, compare and estimate future changes in inundation frequencies & spatial variability

- Results: Importance of Local
  - Relative Sea Level Rise
  - Surge Range
  - Coastal Geology
  - Hurricane Climatology



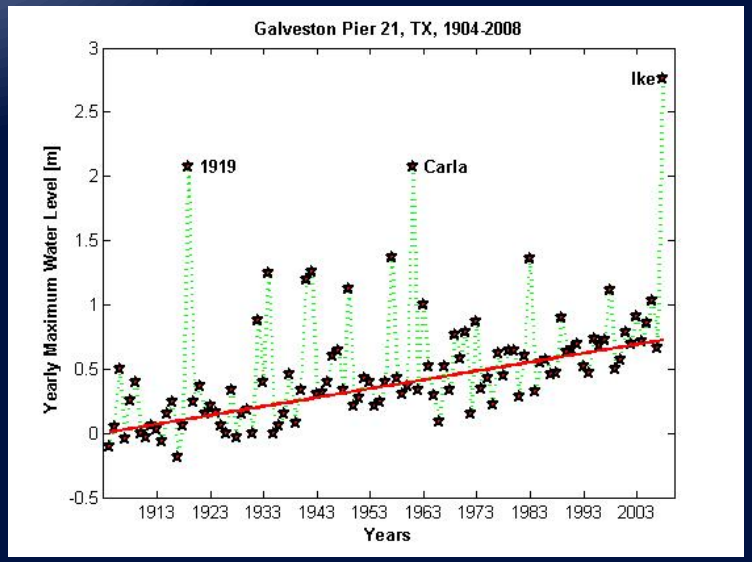
Publications:

Warner, N., and Tissot, P.E. (2012) Storm Flooding Sensitivity to Sea Level Rise for Galveston Bay, Texas", Ocean Engineering, 44, 23-32. doi: 10.1016/j.oceaneng.2012.01.011.

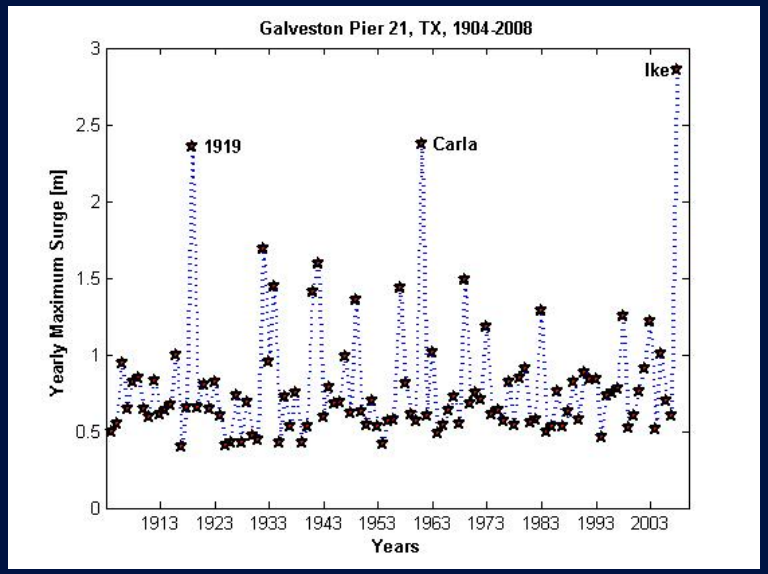
Warner, N., Sterba-Boatwright, B., Tissot, P.E. and Jeffress, G. (2012) Estimated Increase in Inundation Probability with Confidence Intervals for Galveston, Texas. Proc. Estuarine and Coastal Modeling 2011, 528-541. doi: 10.1061/9780784412411.00031.

TEXAS A&M UNIVERSITY CORPUS CHRISTI | CONRAD BLUCHER INSTITUTE FOR SURVEYING AND SCIENCE

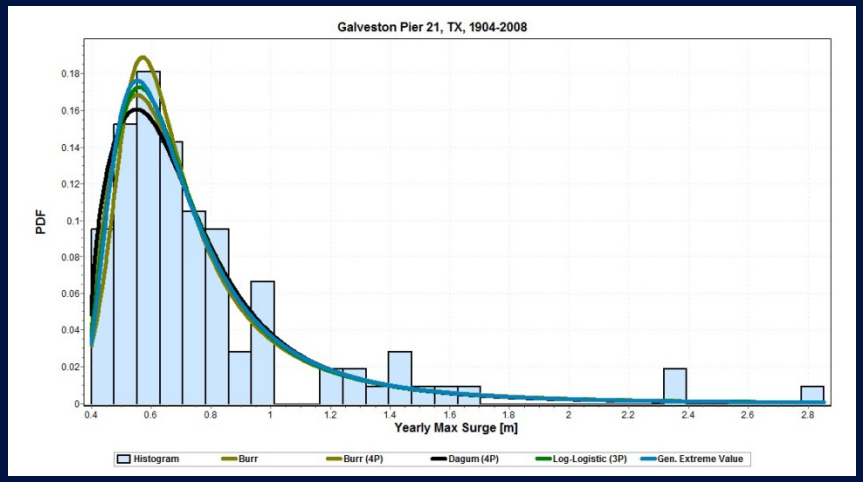
Surge Modeling for Galveston Pier 21



Remove trend & tidal signal



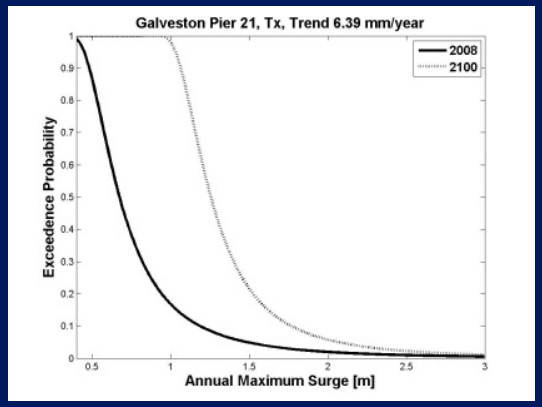
Fit extreme value distributions, GEV, Log Logistic, Burr, Dagum… and compare performance

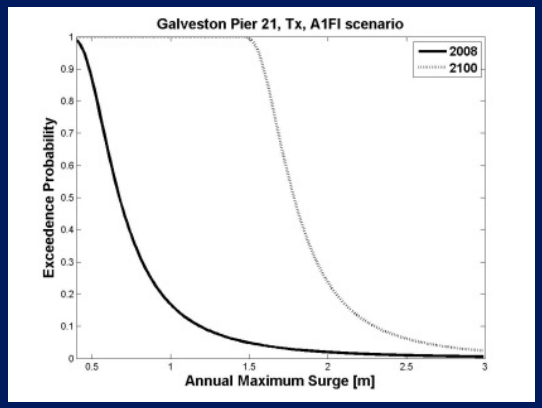


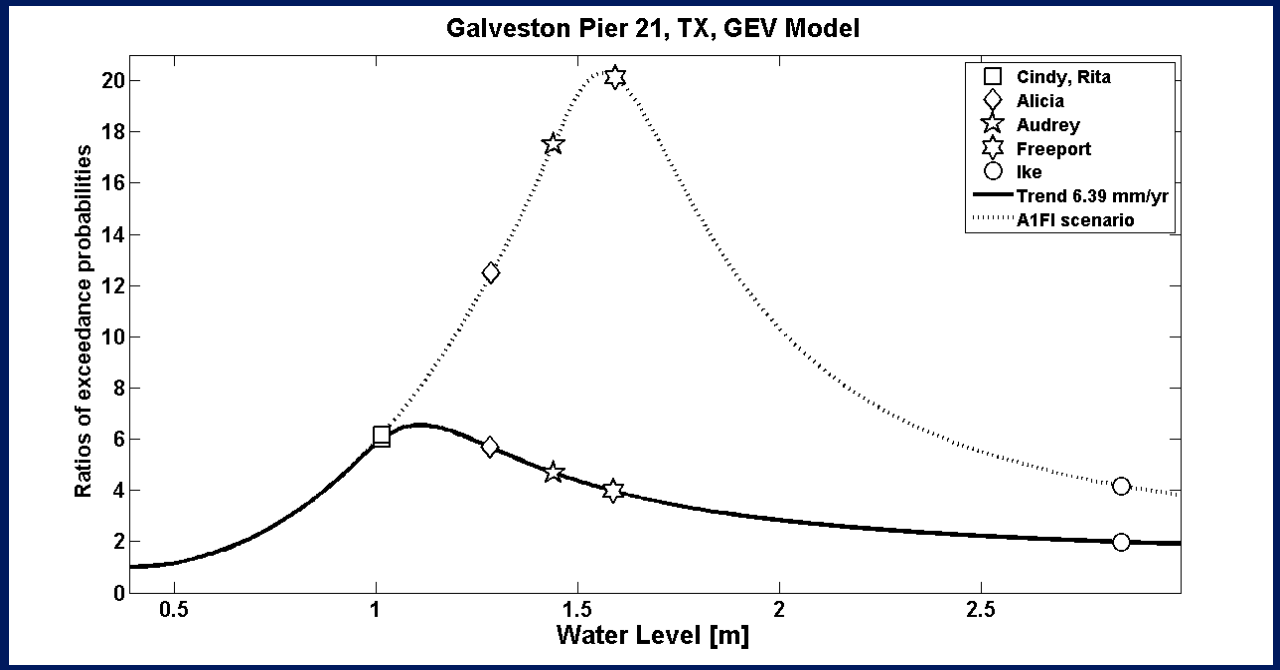
Changes in Inundation Frequencies

Annual Exceedance Probabilities

$$Ratio = \frac{Exceedance\ Probability\ in\ 2100}{Exceedance\ Probability\ in\ 2008}$$





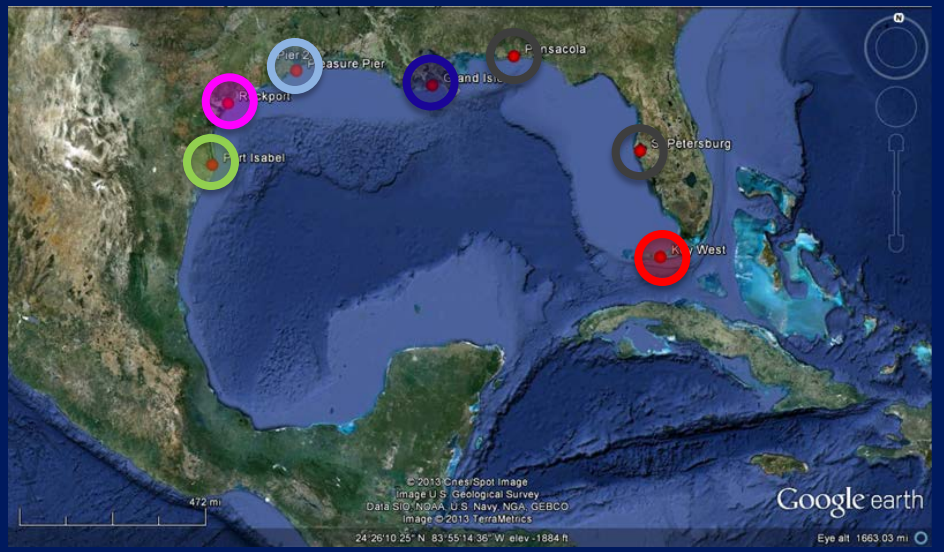


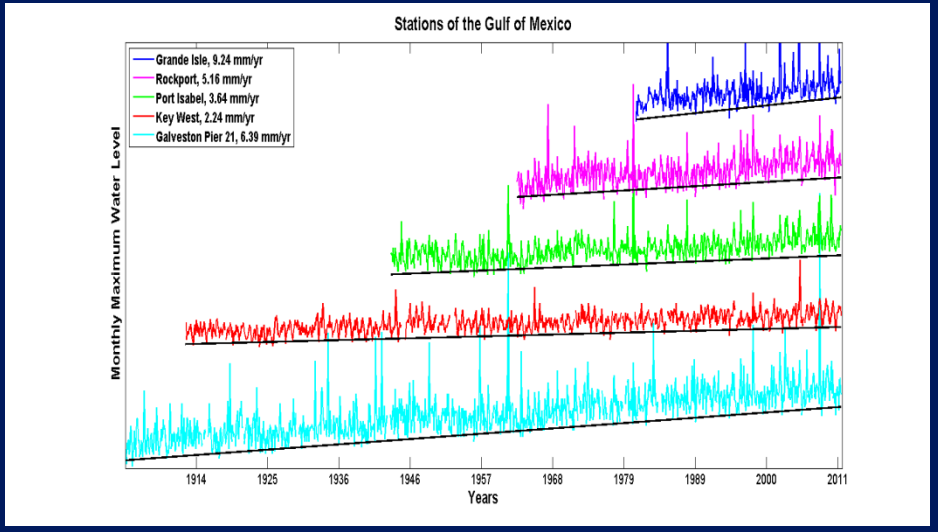
- ***6.39 mm/yr***: six fold increase for 1 m & two fold for 2.8 m (Ike)
- ***RCP 4.5 / A1FI based Scenario***: 6 fold increase for 1 m, twenty fold for 1.6 m & four fold 2.8 m (Ike)

Study Area and Data

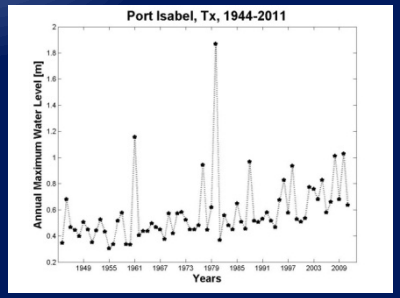
Spatial Variability of Relative Sea Level Rise

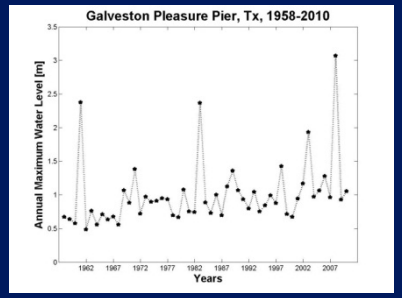
Station Name	State	Years of Data Available	Sea Level Trend [mm/yr]	Distance from Shelf [km]
Port Isabel	Tx	69	3.6	25
Rokport	Tx	49	5.2	40
Galeveston Pier 21	Tx	108	6.4	80
Galveston Pleasure Pier	Tx	53	6.8	78
Grande Isle	La	32	9.2	25
Pensacola	Fl	88	2.1	41
St Petersburg	Fl	65	2.4	65
Key West	Fl	99	2.2	9

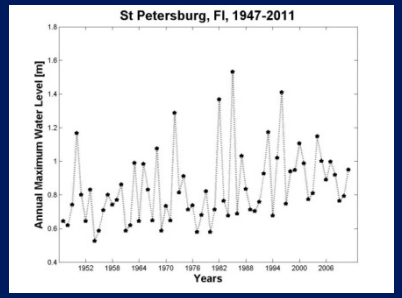


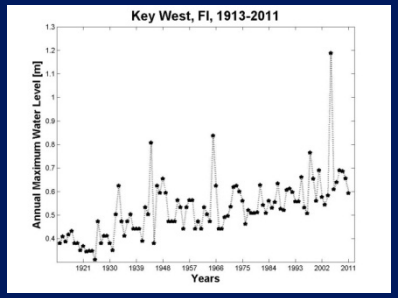


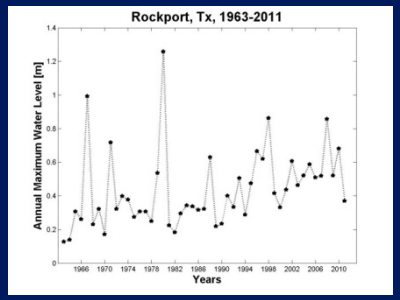
Differences in Surge Distributions

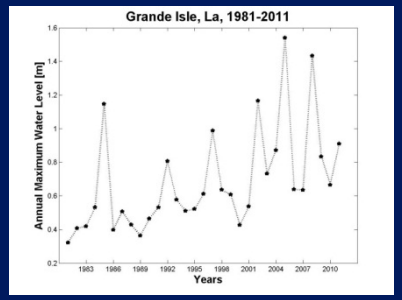


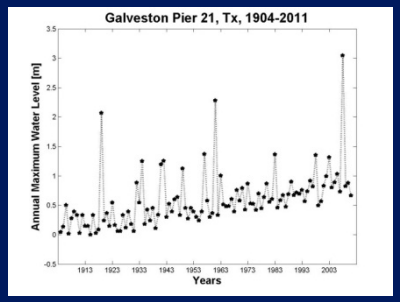


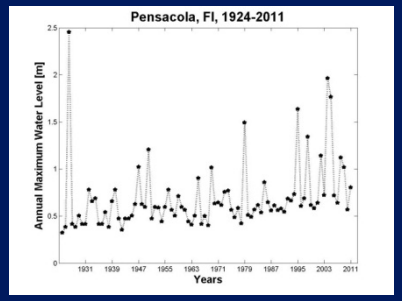




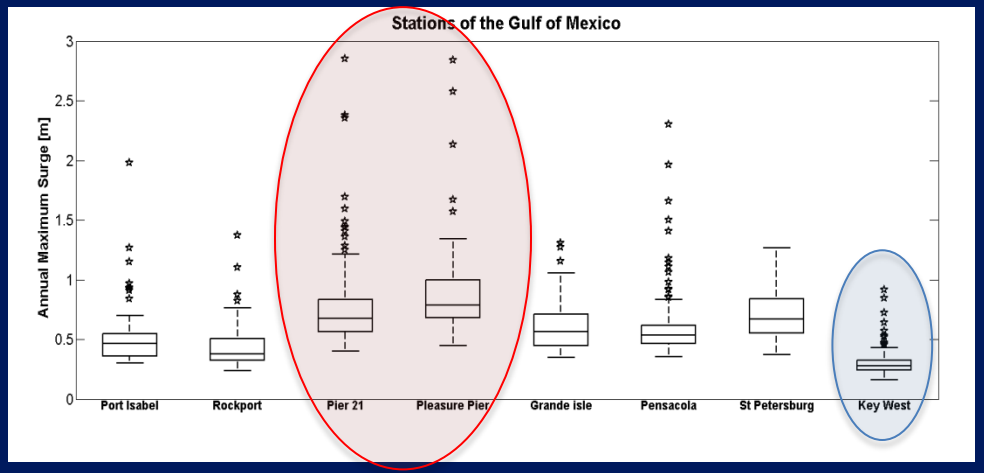








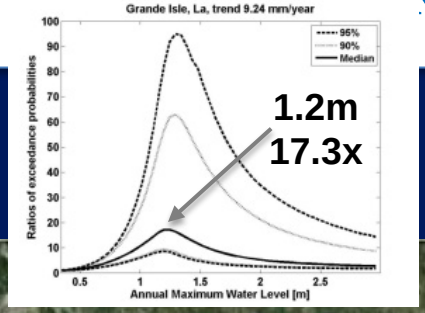
Surge Distributions (rslr trend removed)

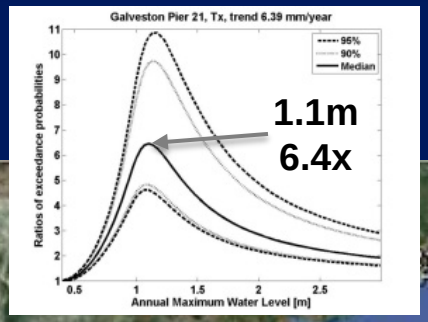


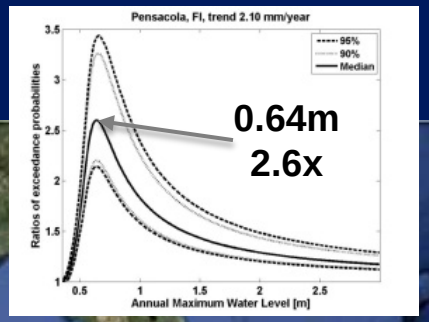
Substantial differences in surge ranges/distributions depending on locations, in large part related to the extent of the continental shelf offshore of the study stations

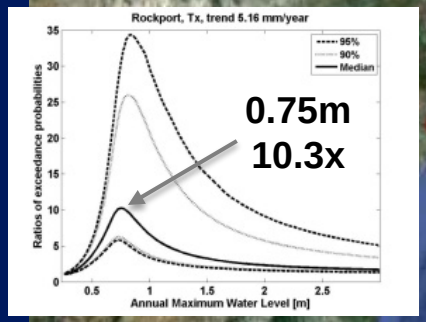
TEXAS A&M UNIVERSITY CORPUS CHRISTI | CONRAD BLUCHER INSTITUTE FOR SURVEYING AND SCIENCE

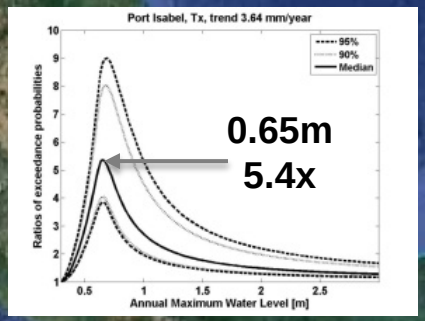
Results for Continuous RSLR

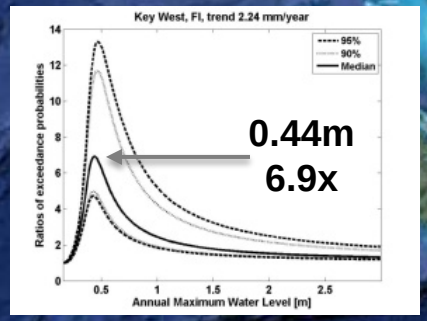








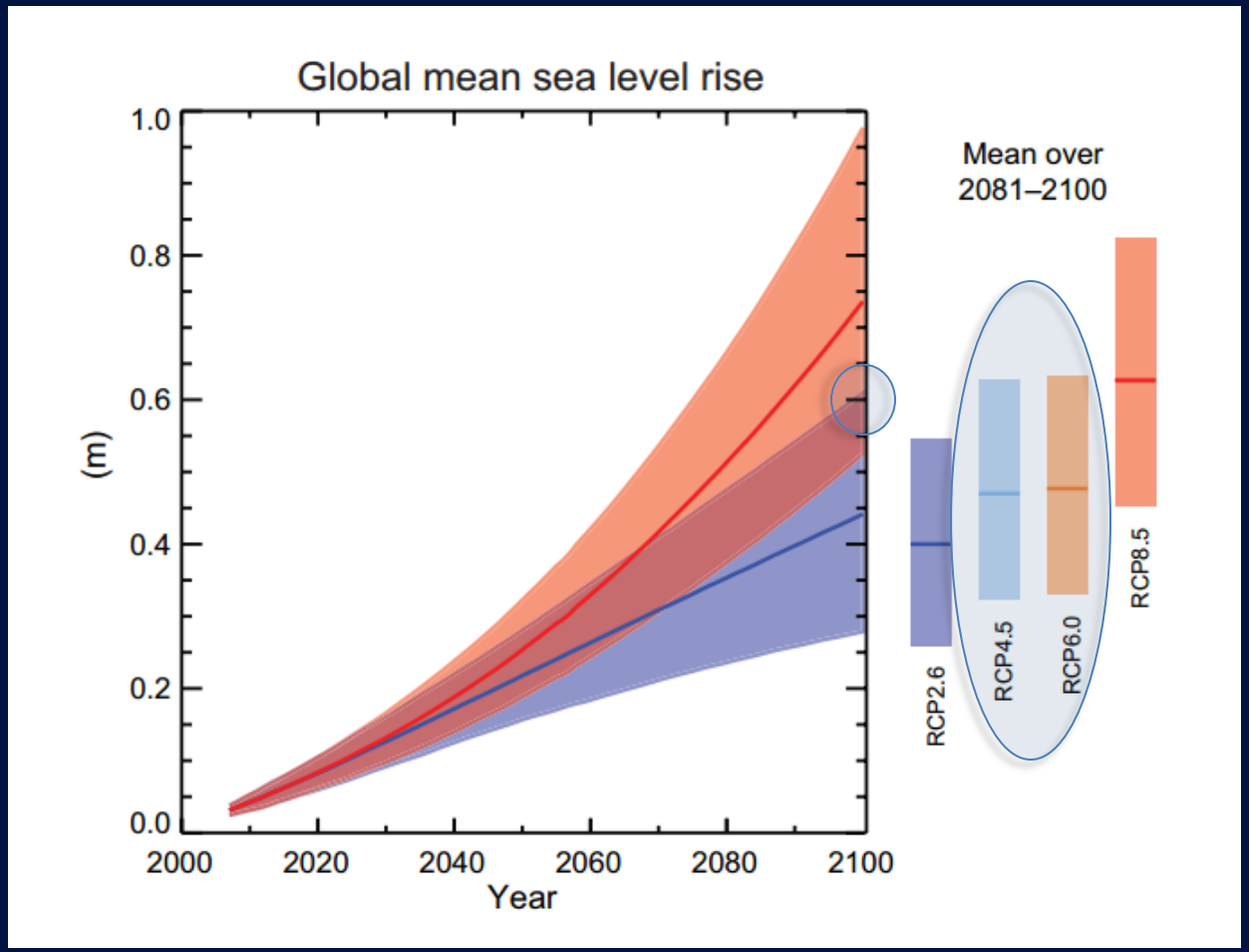




Pleasure Pier
Pensacola
Grand Isle
Rockport
Port Isabel
St.Petersburg
Key West
© 2013 CnesiSpot Image
Image U.S. Geological Survey
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2013 TerraMetrics
472 mi
24°26'10.25" N 83°55'14.36" W elev -1884 ft
Google earth
Eye alt 1663.03 mi

Sea Level Rise Scenarios

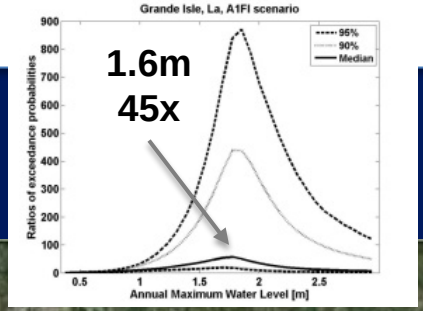
Accelerating Sea Level Rise Scenario: A1FI, RCP 4.5, RCP 6.0

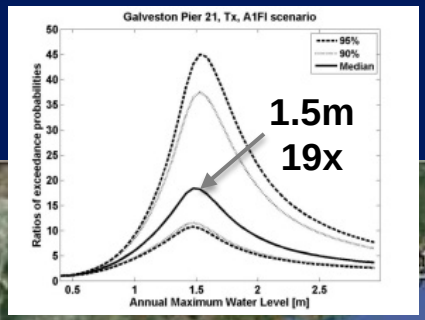


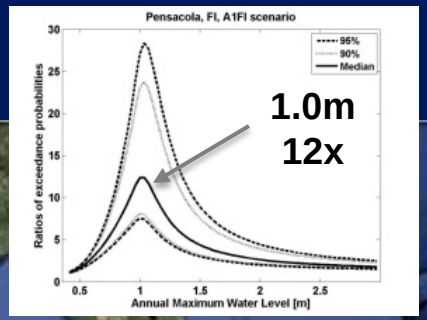
Assume increased eustatic sea level rise of 60cm between 2011 & 2100

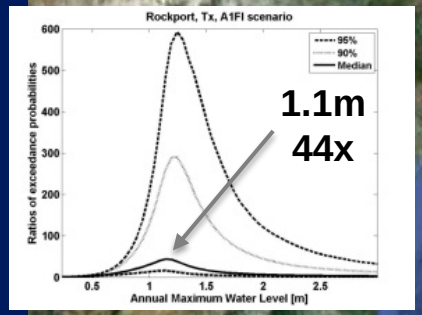
TEXAS A&M UNIVERSITY CORPUS CHRISTI | CONRAD BLUCHER INSTITUTE FOR SURVEYING AND SCIENCE

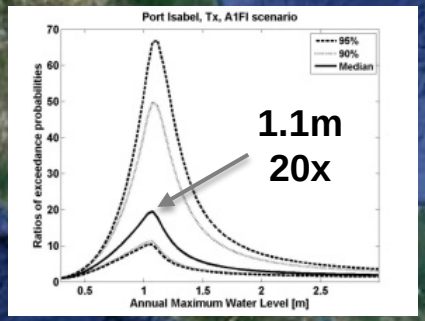
Results for Continuous RSLR

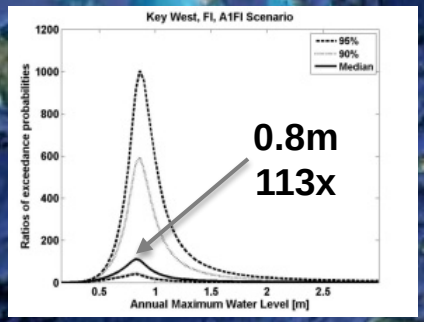






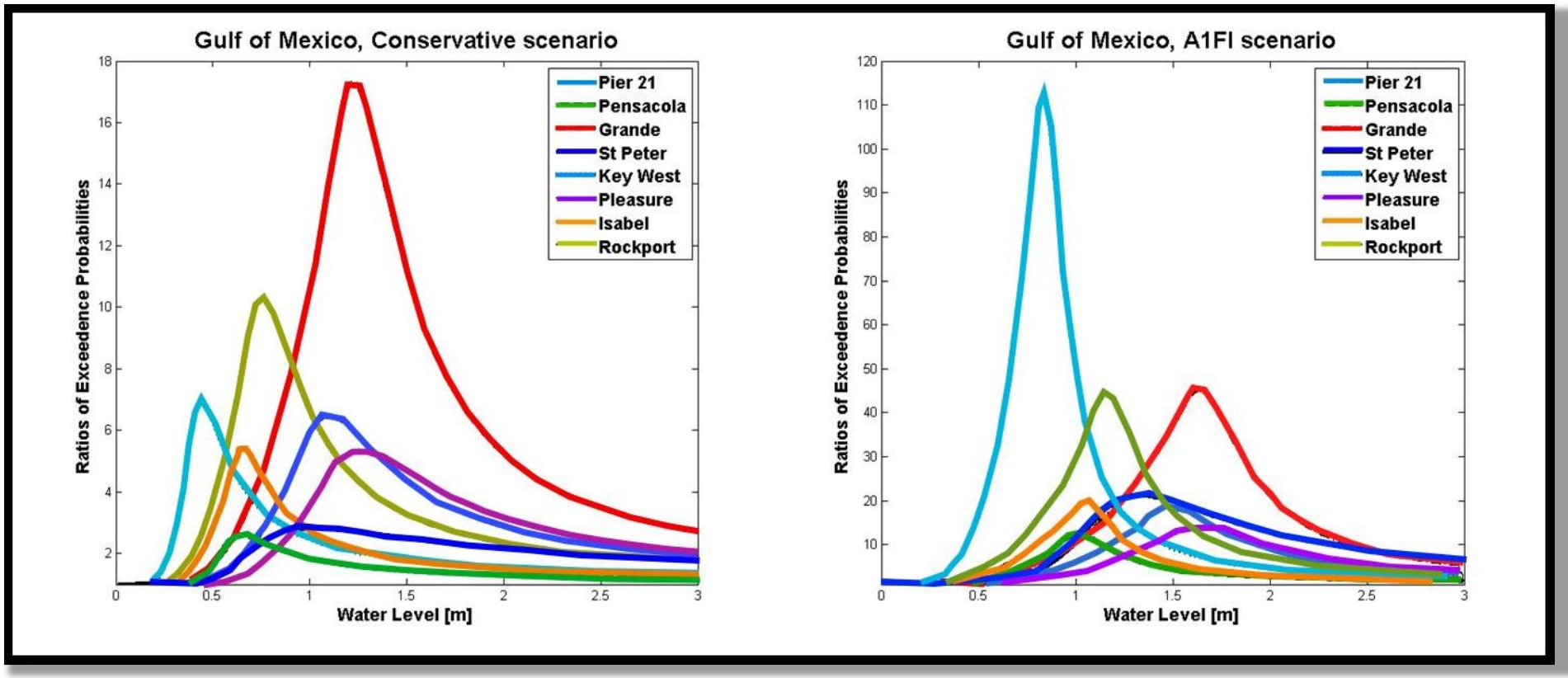




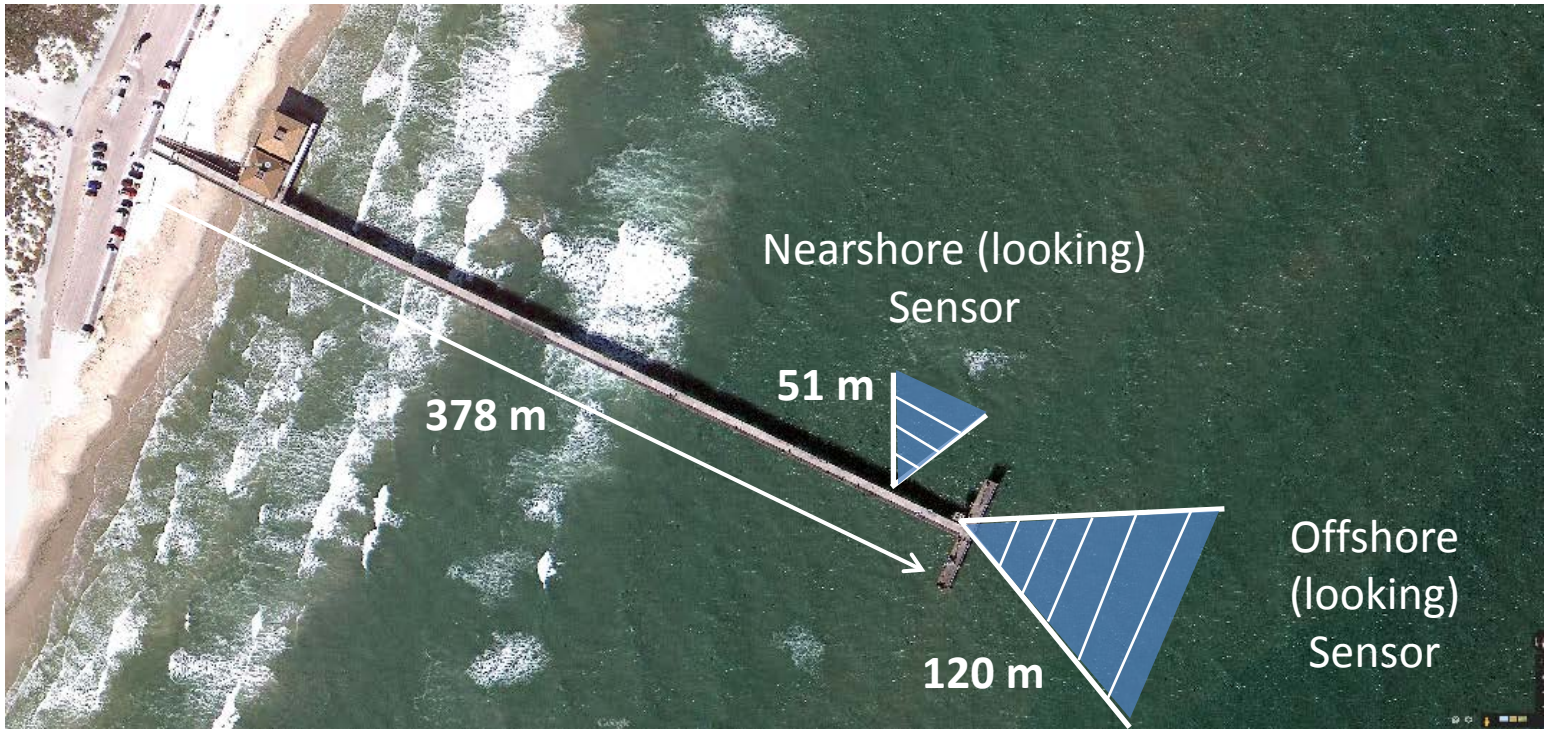


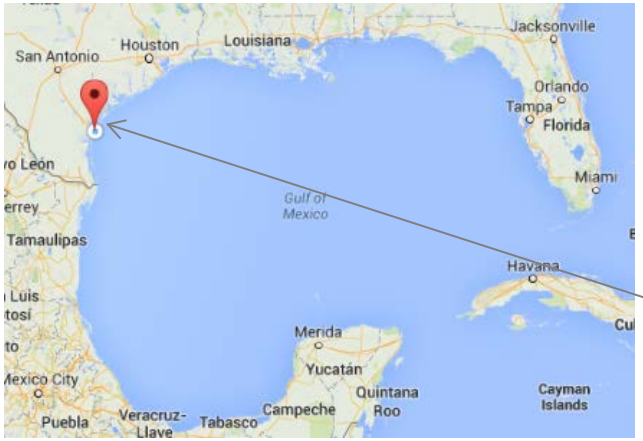
Comparison of Gulf of Mexico Locations

Comparison of Spatial variability of relative sea level rise impact on increased in inundation frequency



Local Inundation Frequencies

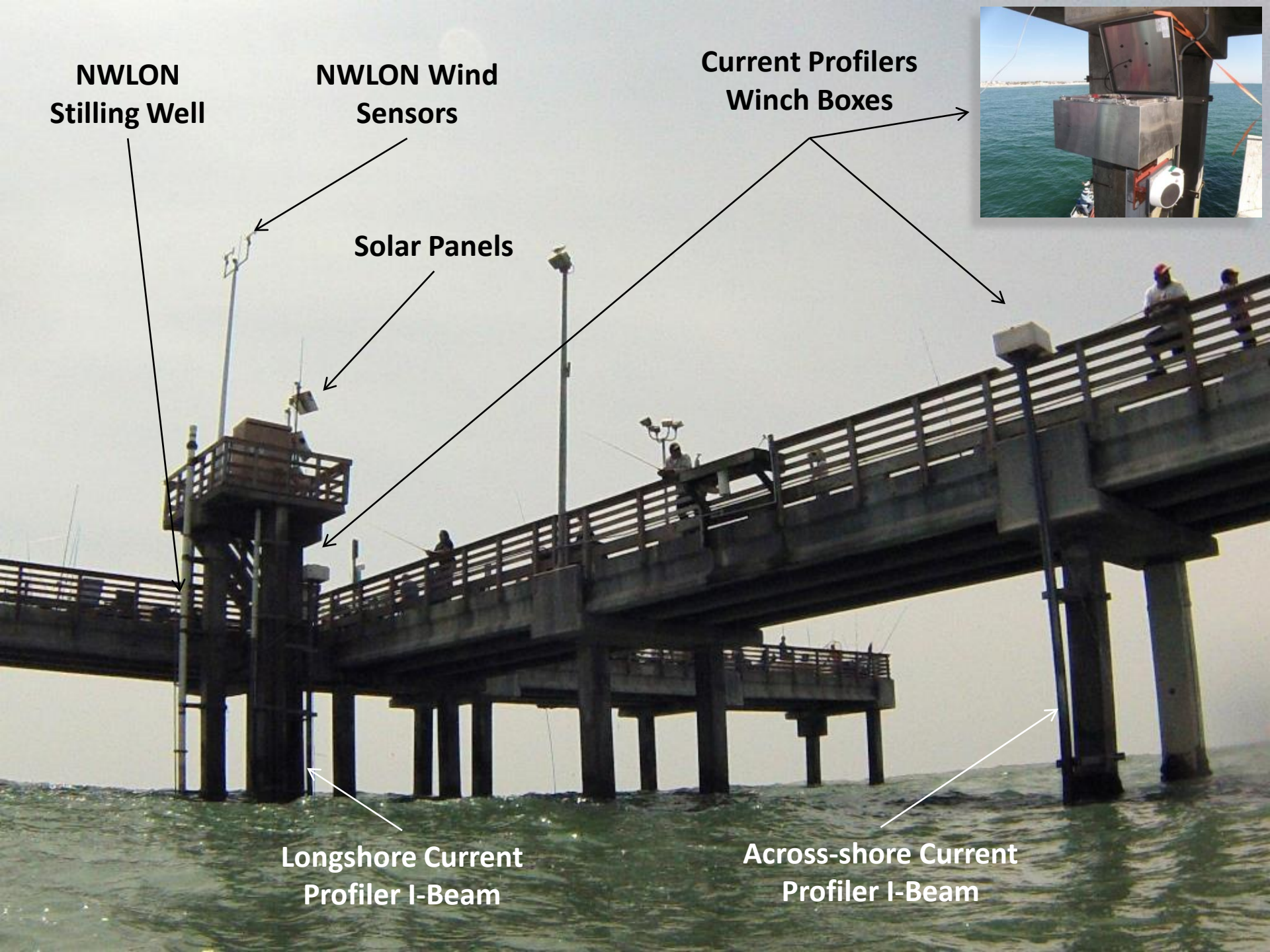




Current Profilers & Wave Gauges

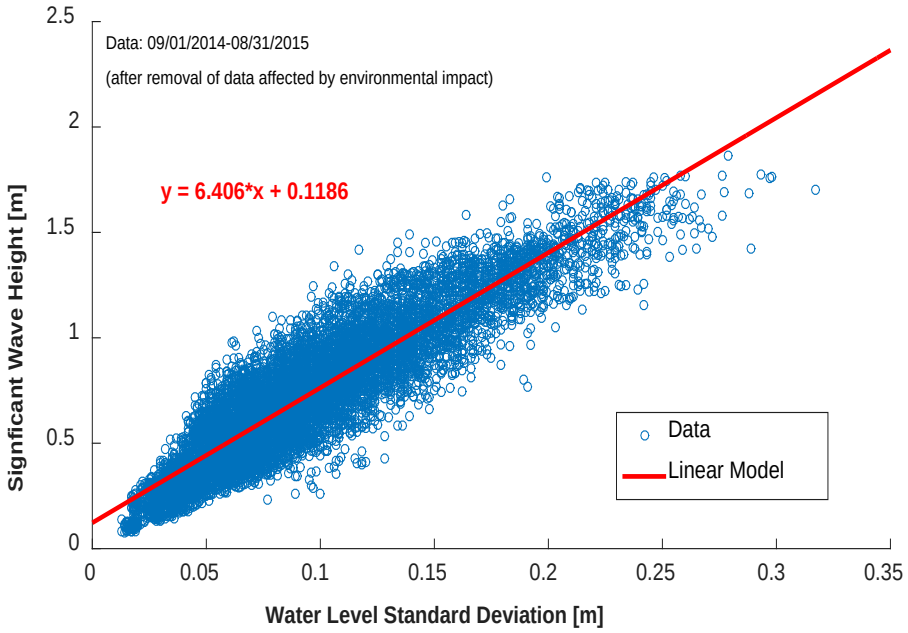
Bob Hall Pier, North Padre Island, Corpus Christi, Texas

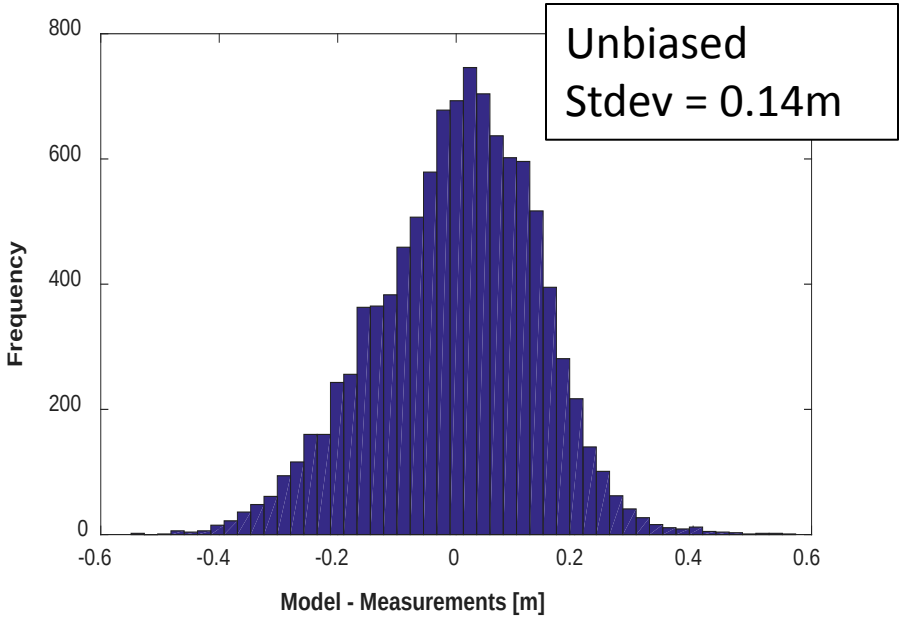
Map/sattelite imagery from Google


NWLON
Stilling Well
NWLON Wind
Sensors
Current Profilers
Winch Boxes
Solar Panels
Longshore Current
Profiler I-Beam
Across-shore Current
Profiler I-Beam

Nearshore Wave Nowcast

Use relationship between significant wave height (H_{m0}) and water level standard deviation (σ) *: $\hat{H}_{m0} = \alpha\sigma$

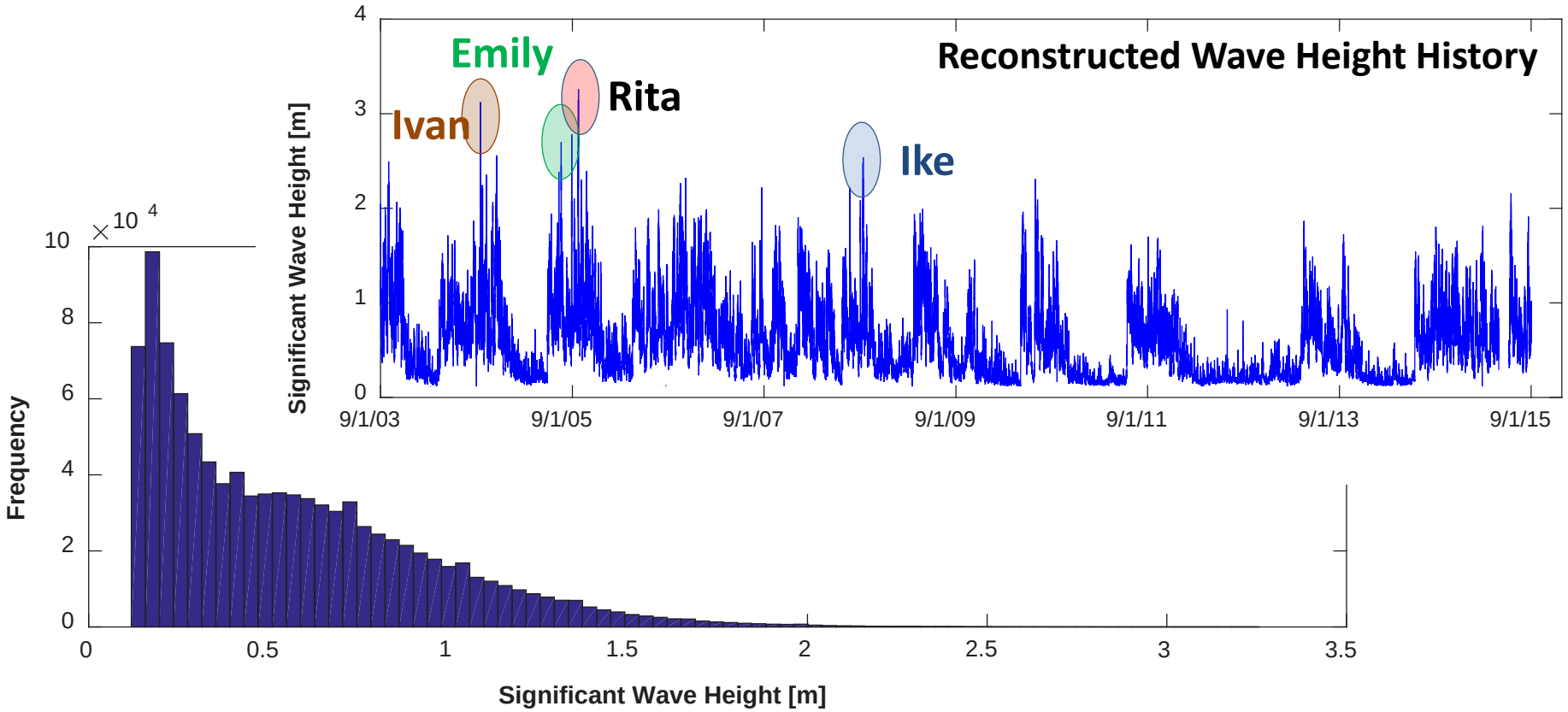




*See: Park, Heitsenrether & Sweet (2014) Water Level and Wave Height Estimates at NOAA Tide Stations from Acoustic and Microwave Sensors, J. Atm. Oc. Tech 31, 2294-2308. Also Park & Gill (1995), Shih & Rodgers (1981).

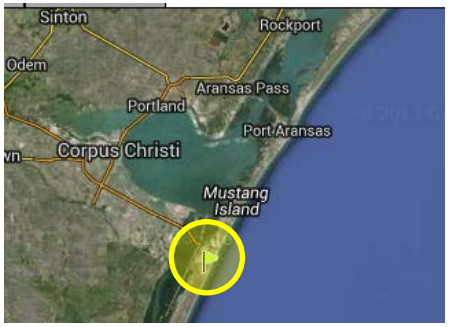
Nearshore Wave Nowcast

- Historical reconstruction of significant wave height:
  swh = 6.406 (stdev of water levels) + 0.1186
- Applied to hourly data from Bob Hall Pier 9/1/2003-8/31/2015

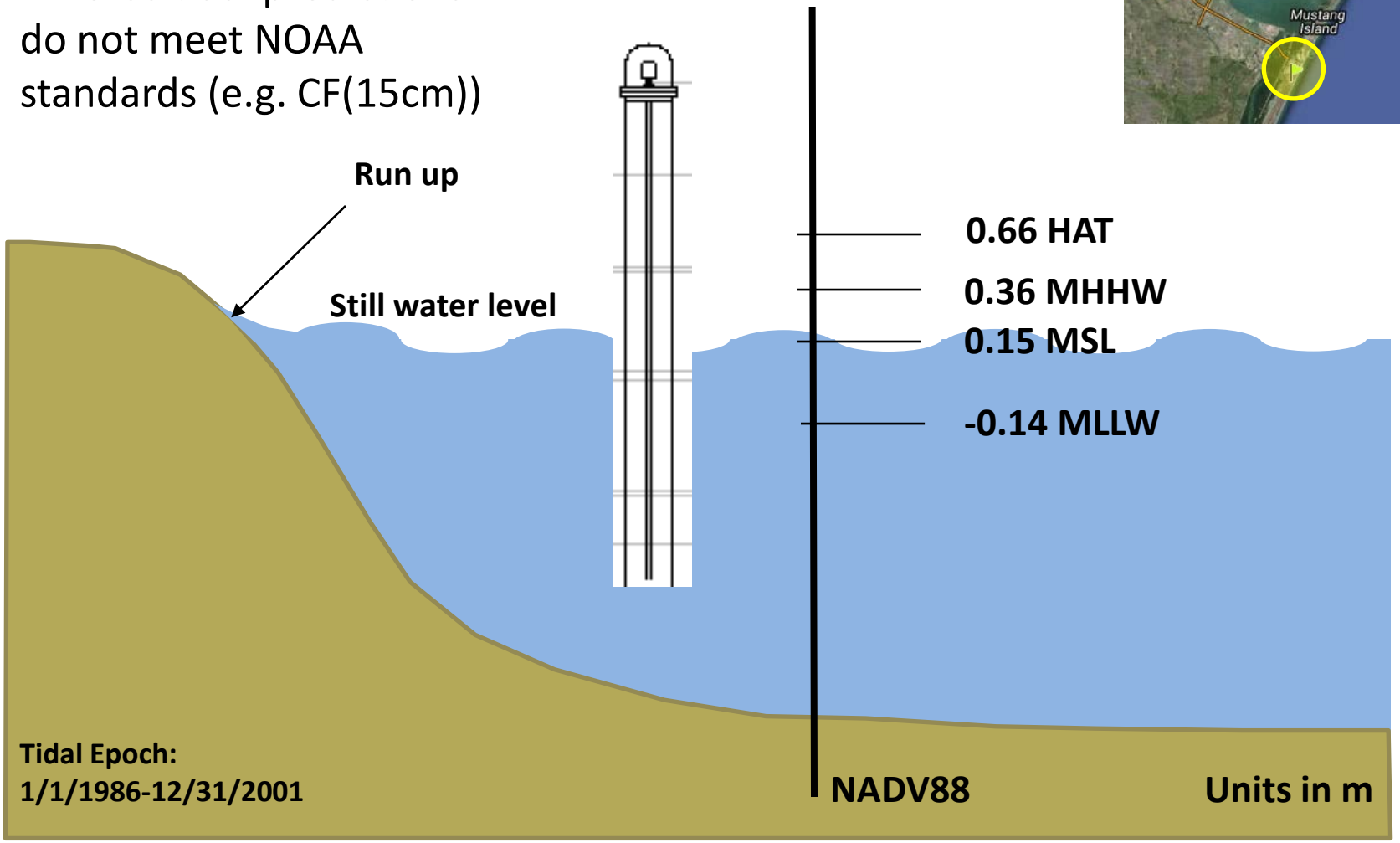


Tissot, P., and Larry Dell (2016) Coastal Currents and Waves along the Texas Coastal Bend: Measurements and Model Comparisons, Proc. AMS 96th Annual Meeting, 10-14 January 2016.

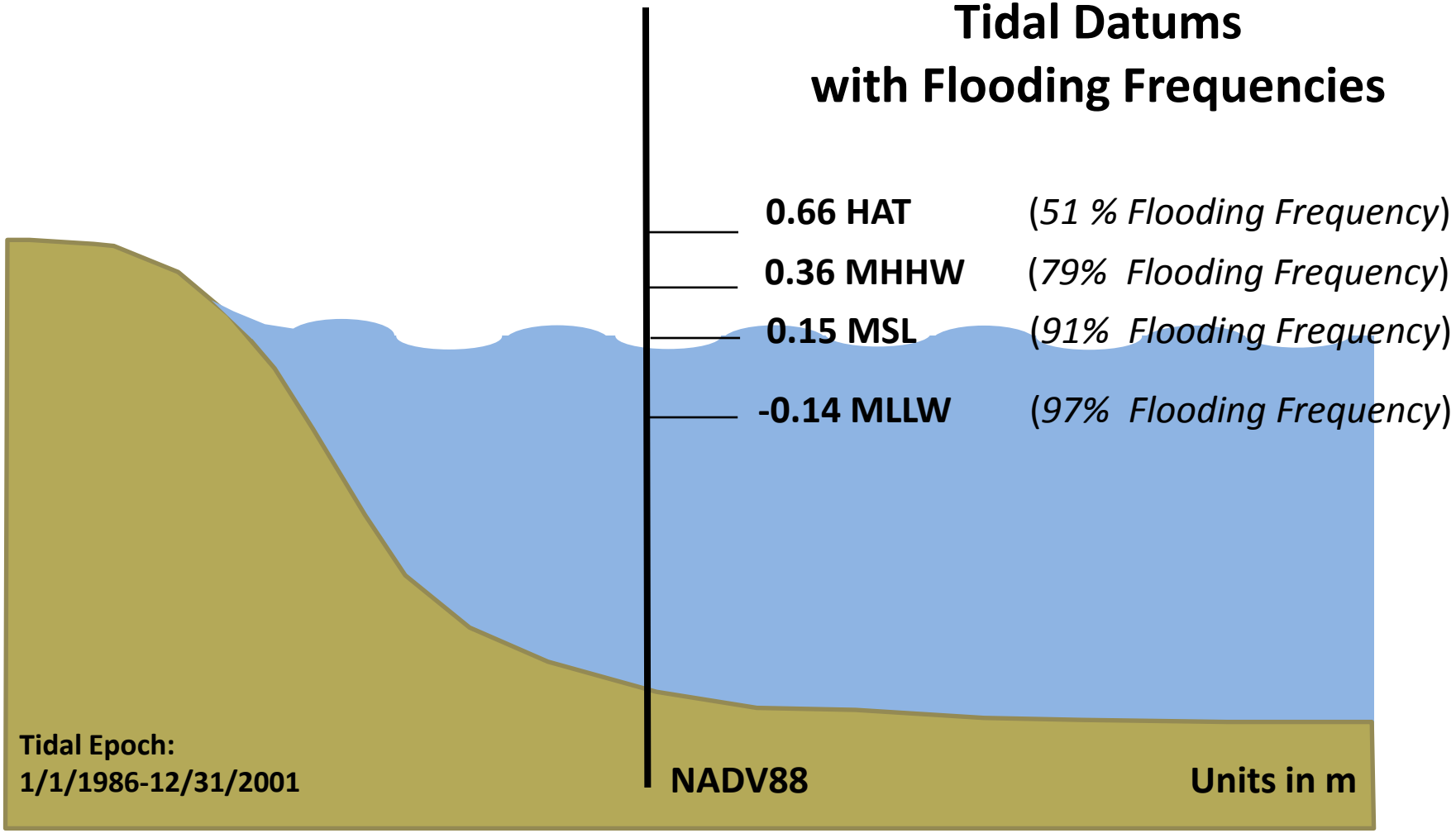
Tidal Datums & Still Water Level Flooding Frequencies
Bob Hall Pier, Texas



In Texas tidal predictions do not meet NOAA standards (e.g. CF(15cm))

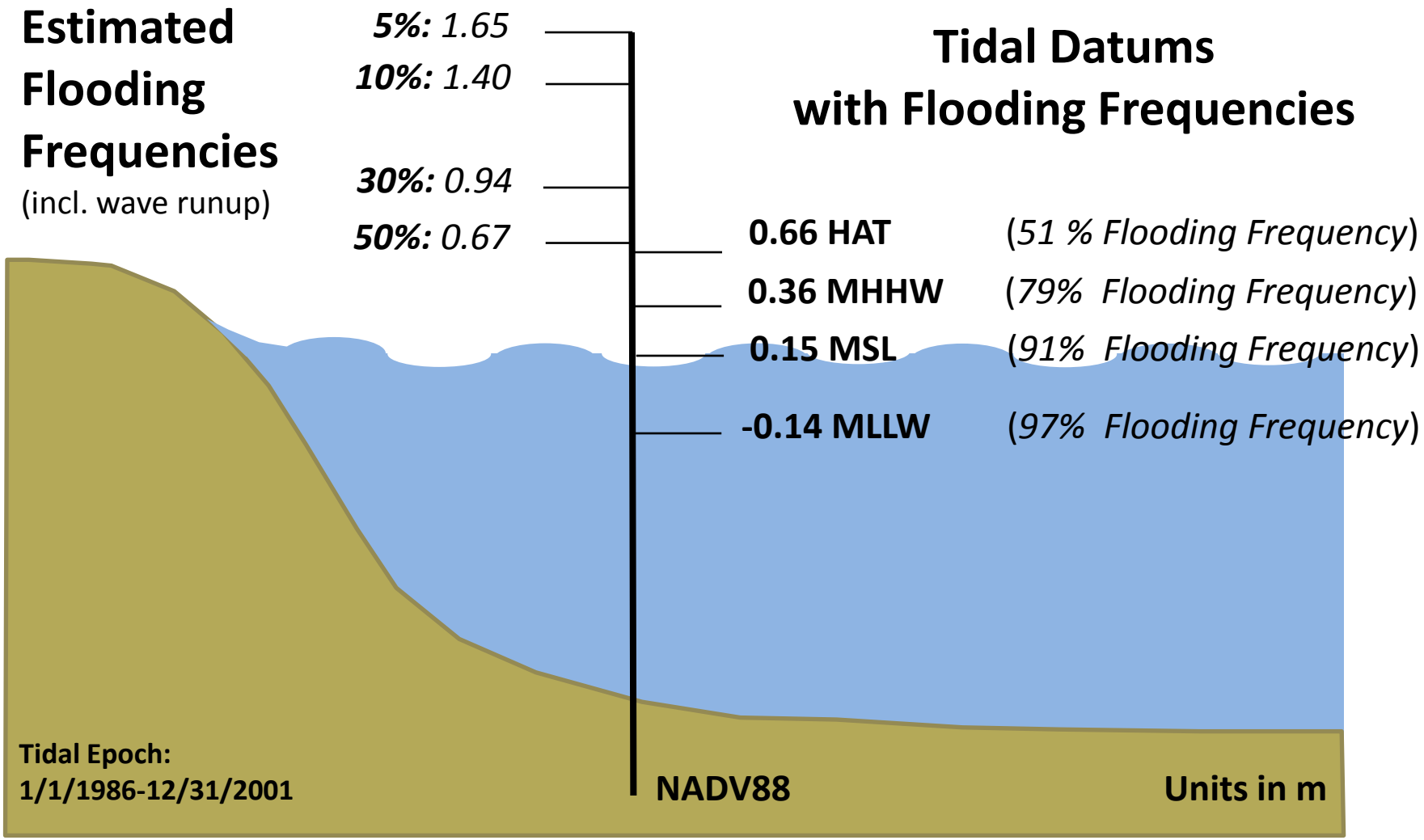


Tidal Datums & Estimated Total Water Level Flooding Frequencies, Bob Hall Pier, Texas



Statistics based on NOAA Datums and data collected 09/01/2003-08/31/2015

Tidal Datums & Estimated Total Water Level Flooding Frequencies, Bob Hall Pier, Texas



Statistics based on NOAA Datums and data collected 09/01/2003-08/31/2015

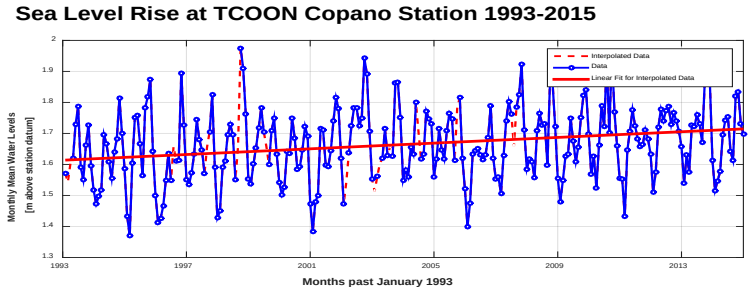
Visualization of Tidal Datums & "Inundation Frequencies"
Bob Hall Pier, Texas

Measurements & statistics approximate, for conceptual use, not survey grade

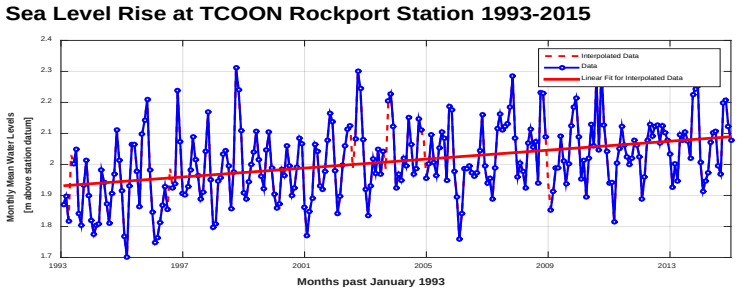
TEXAS A&M UNIVERSITY CORPUS CHRISTI | CONRAD BLUCHER INSTITUTE FOR SURVEYING AND SCIENCE

Estimated Relative Sea Level Rise in the Coastal Bend (1993-2015)

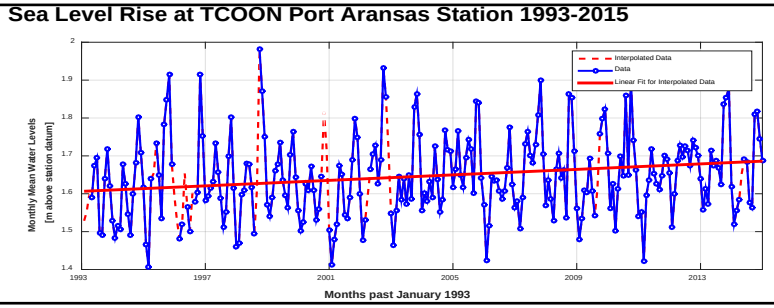
Copano Bay: 4.6mm/yr



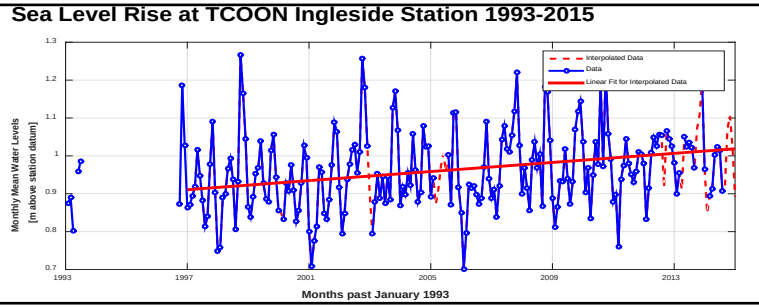
Rockport: 7.2mm/yr



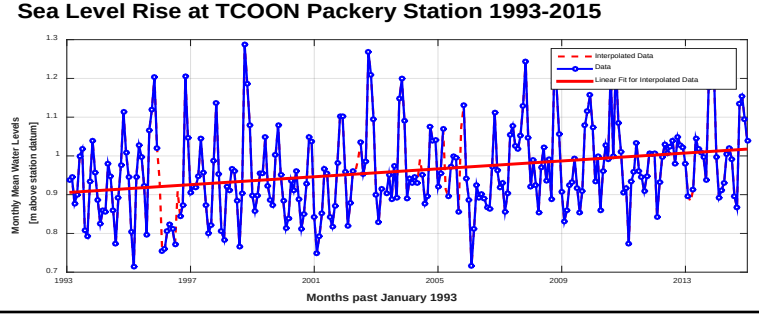
Port Aransas: 3.6mm/yr



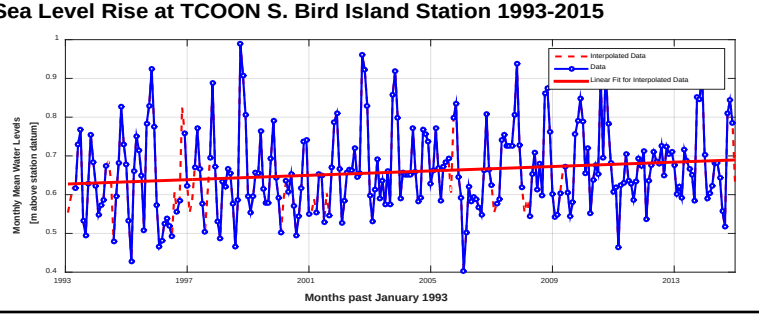
Ingleside: 6.0mm/yr



Packery Channel: 5.1mm/yr



Bird Island: 2.8mm/yr



Conclusions

Relative Sea Level Rise around the Gulf of Mexico and its Impact: from Nuisance Flooding to Large Surges

- Importance of Spatial Variability
  - Sea Level Rise is ***Relative***
  - Consistent Local Measurements
  - Storm Surges: Large & Nuisance Flooding
  - Increases in Inundation Frequencies
- Planning Implications:
  - Tidal Datums & Inundation Frequencies
  - Communicating Datums

What Information do you need on Sea Levels?

Questions/Discussion

Global Mean Sea Level Budget

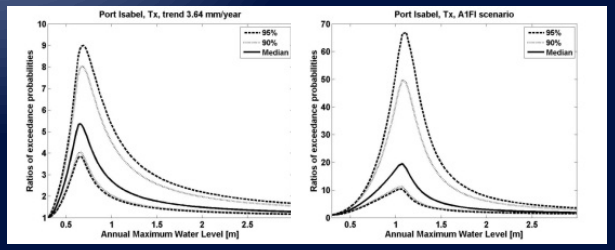
Table 13.1 | Global mean sea level budget (mm yr^{-1}) over different time intervals from observations and from model-based contributions. Uncertainties are 5 to 95%. The Atmosphere–Ocean General Circulation Model (AOGCM) historical integrations end in 2005; projections for RCP4.5 are used for 2006–2010. The modelled thermal expansion and glacier contributions are computed from the CMIP5 results, using the model of Marzeion et al. (2012a) for glaciers. The land water contribution is due to anthropogenic intervention only, not including climate-related fluctuations.

Source	1901–1990	1971–2010	1993–2010
Observed contributions to global mean sea level (GMSL) rise			
Thermal expansion	–	0.8 [0.5 to 1.1]	1.1 [0.8 to 1.4]
Glaciers except in Greenland and Antarctica[a]	0.54 [0.47 to 0.61]	0.62 [0.25 to 0.99]	0.76 [0.39 to 1.13]
Glaciers in Greenland[a]	0.15 [0.10 to 0.19]	0.06 [0.03 to 0.09]	0.10 [0.07 to 0.13][b]
Greenland ice sheet	–	–	0.33 [0.25 to 0.41]
Antarctic ice sheet	–	–	0.27 [0.16 to 0.38]
Land water storage	–0.11 [–0.16 to –0.06]	0.12 [0.03 to 0.22]	0.38 [0.26 to 0.49]
Total of contributions	–	–	**2.8 [2.3 to 3.4]**
Observed GMSL rise	**1.5 [1.3 to 1.7]**	**2.0 [1.7 to 2.3]**	**3.2 [2.8 to 3.6]**
Modelled contributions to GMSL rise			
Thermal expansion	0.37 [0.06 to 0.67]	0.96 [0.51 to 1.41]	1.49 [0.97 to 2.02]
Glaciers except in Greenland and Antarctica	0.63 [0.37 to 0.89]	0.62 [0.41 to 0.84]	0.78 [0.43 to 1.13]
Glaciers in Greenland	0.07 [–0.02 to 0.16]	0.10 [0.05 to 0.15]	0.14 [0.06 to 0.23]
Total including land water storage	**1.0 [0.5 to 1.4]**	**1.8 [1.3 to 2.3]**	**2.8 [2.1 to 3.5]**
Residual[c]	**0.5 [0.1 to 1.0]**	**0.2 [–0.4 to 0.8]**	**0.4 [–0.4 to 1.2]**

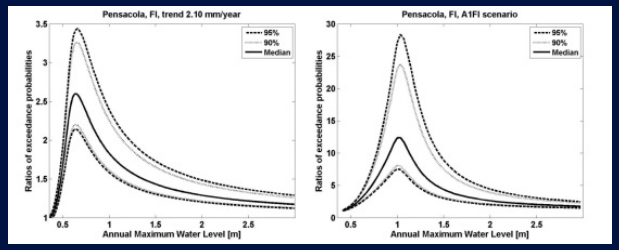
IPCC AR 5 Report: 13 Sea Level Change "Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA."

Confidence Intervals

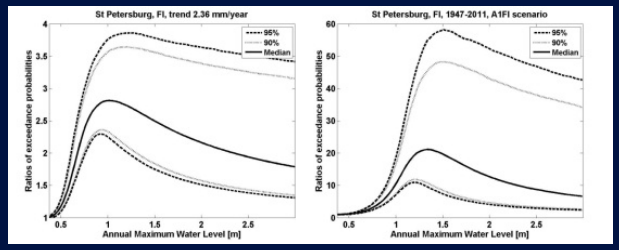
Port Isabel



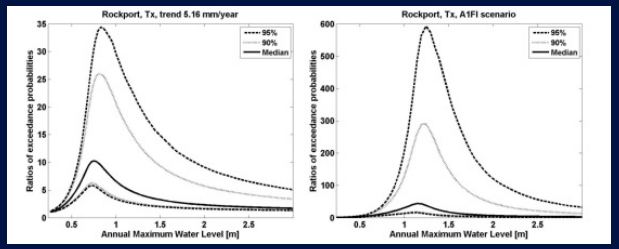
Pensacola



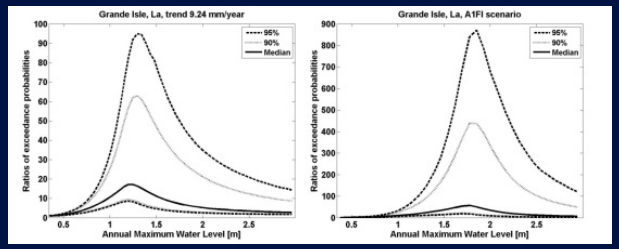
St Petersburg



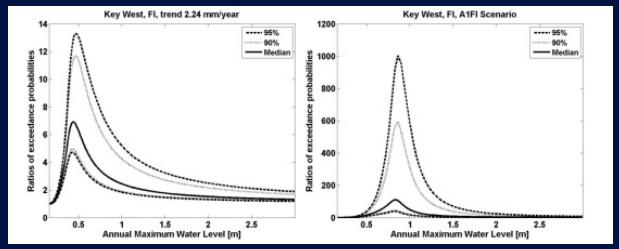
Rockport



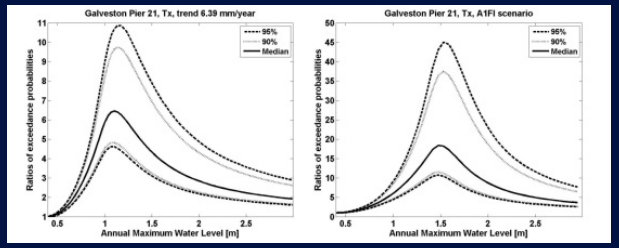
Grand Isle



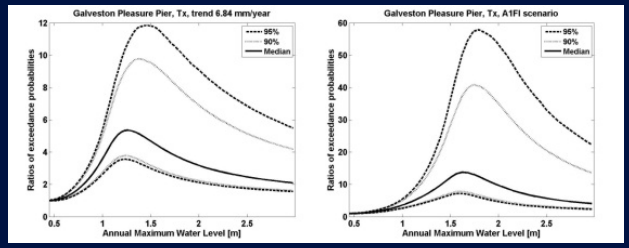
Key West



Galveston, Pier 21



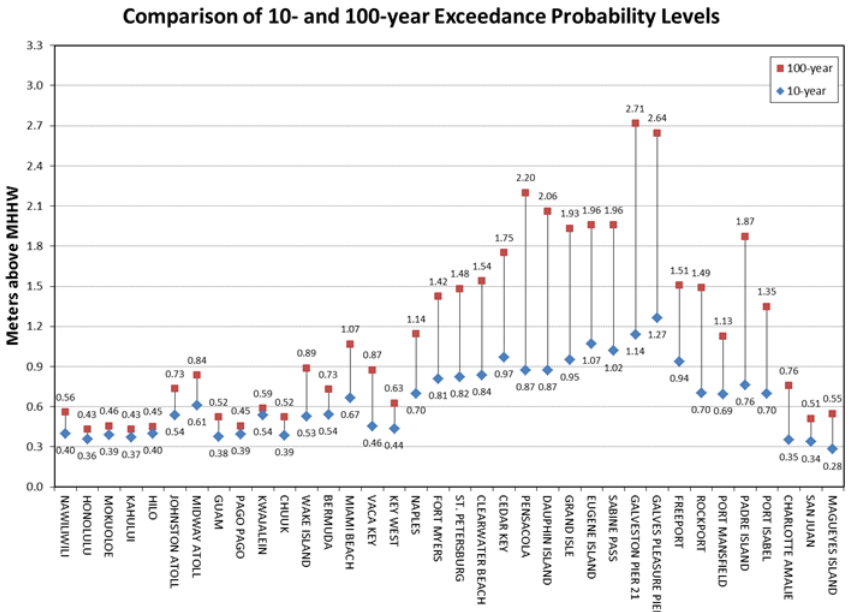
Galveston, Pleasure Pier

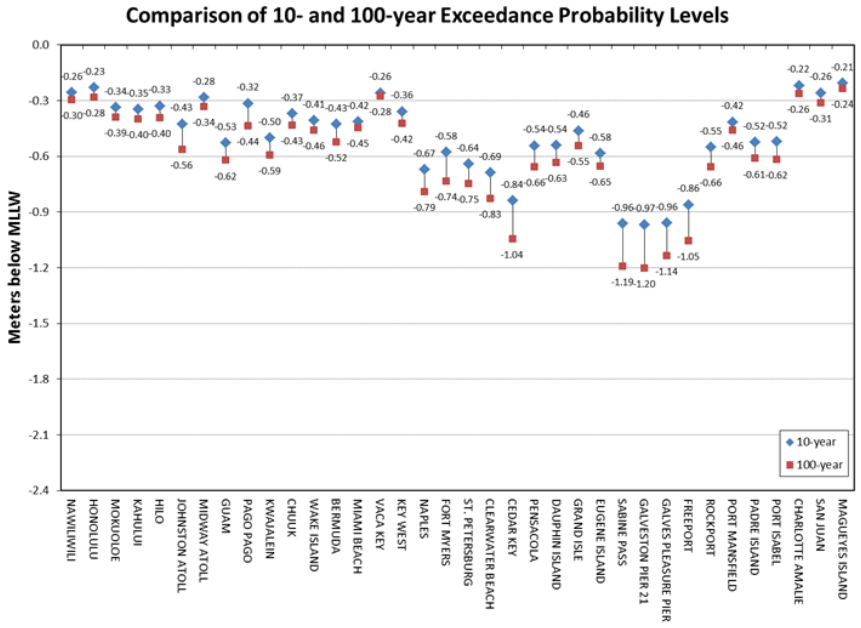


Small differences in the lower bounds of the 90% and 95% confidence intervals

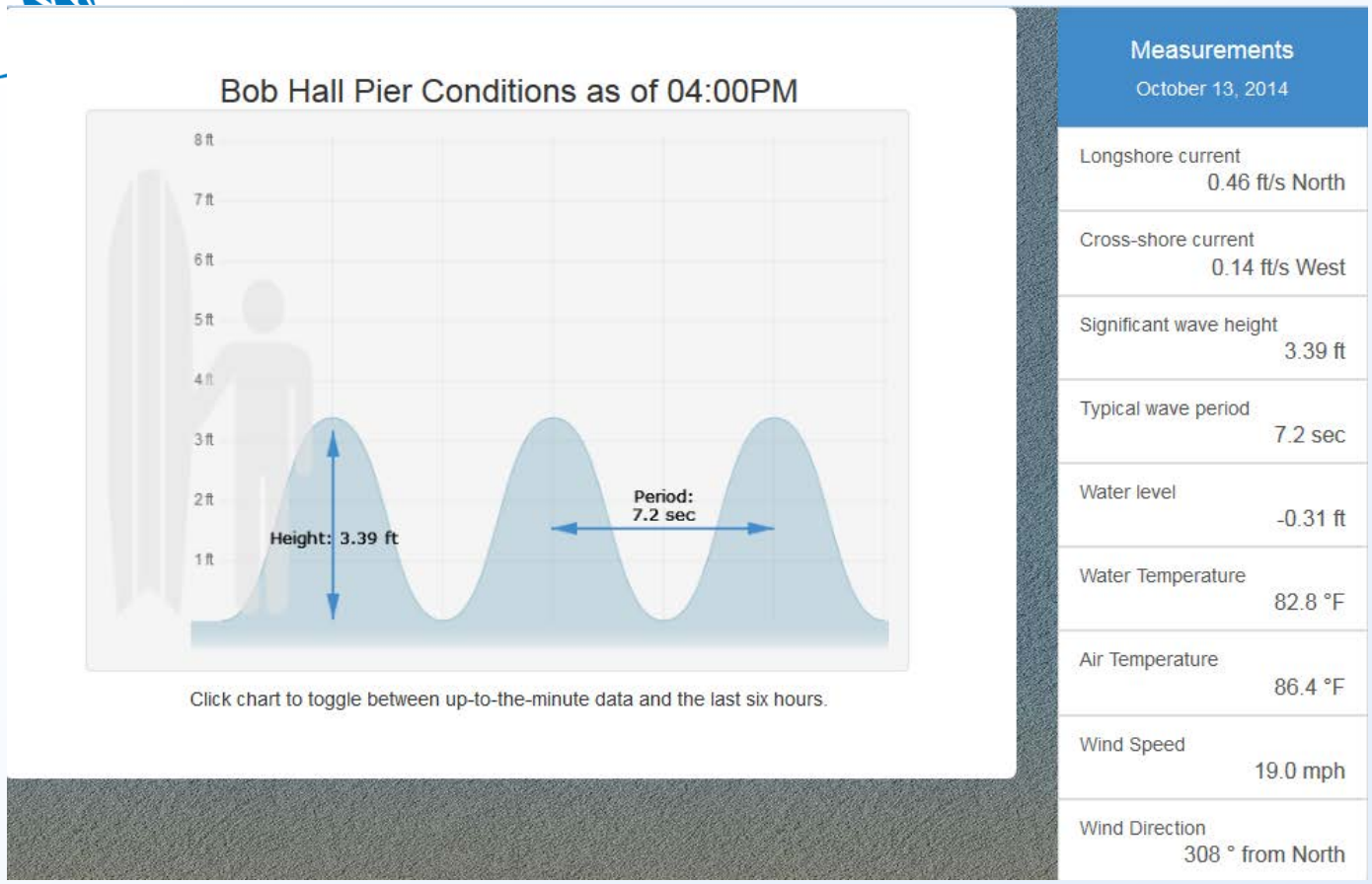
Large uncertainties in the higher bounds of the confidence intervals

NOAA Exceedance Probabilities Comparisons

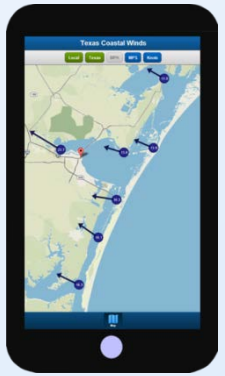


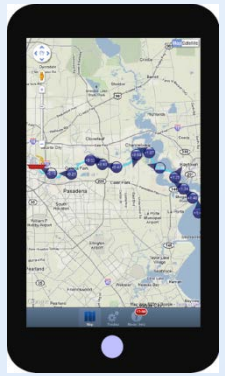


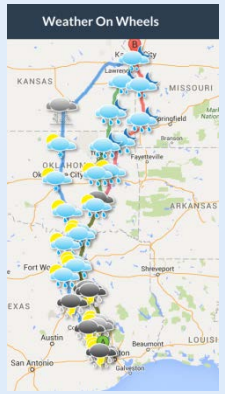
App to Communicate Information



Measurements	October 13, 2014
Longshore current	0.46 ft/s North
Cross-shore current	0.14 ft/s West
Significant wave height	3.39 ft
Typical wave period	7.2 sec
Water level	-0.31 ft
Water Temperature	82.8 °F
Air Temperature	86.4 °F
Wind Speed	19.0 mph
Wind Direction	308 ° from North







- App/website for general users (Near Shore Conditions App) http://cbi-apps.tamucc.edu/bhpwave/