Recent Work and Future Directions in Coastal Surge Modeling and Sea Level Extremes within NOAA

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NOAA National Ocean Service

Panel 7: Extreme Storm Surge for Coastal Areas

Workshop on
Probabilistic Flood Hazard Assessment
(PFHA)
PROGRAM
January 29 - 31, 2013, 8:30 a.m.–6:30 p.m. (EST)
U.S. NRC Headquarters Auditorium
11555 Rockville Pike, Rockville, MD 20852

Storm Surge Modeling at NOAA

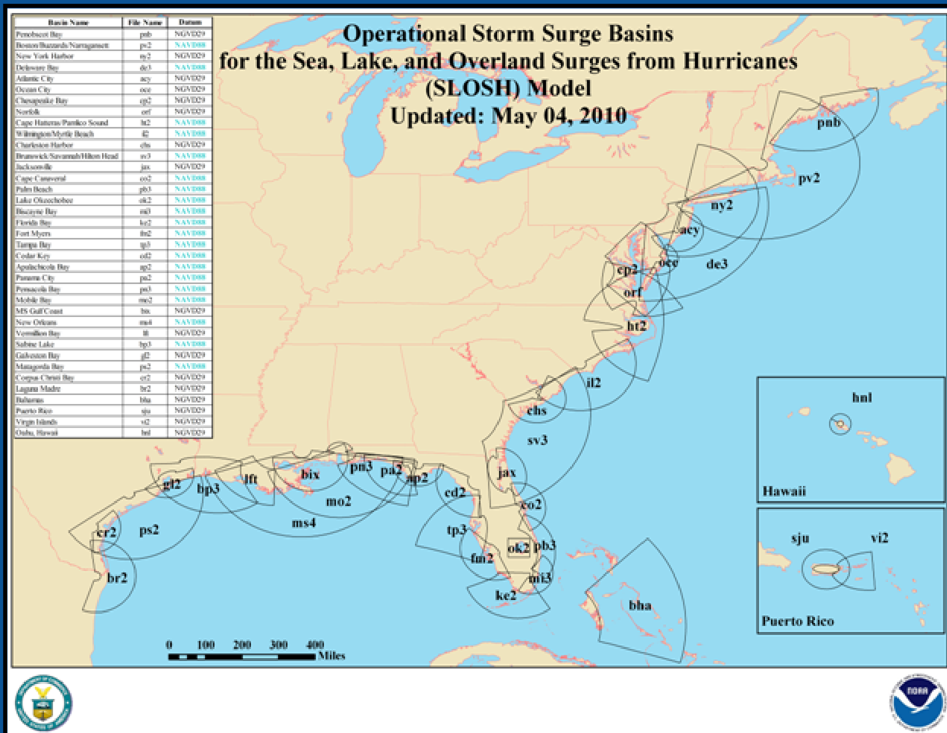
- NOAA uses surge models to predict storms, assess risks, and understand historical events
- Forecast guidance operational requirements are strict
  - Timeliness and robustness are key; leads to bias for efficiency over accuracy
  - Cost-effectiveness also needed for ensemble and probabilistic predictions
  - NOAA predicts storms via efficient SLOSH and ADCIRC implementations
- Highly accurate hindcasts require increased resolution and more complex parameterizations

Sea, Lake, and Overland Surges from Hurricanes (SLOSH): NWS' Operational Surge Model

- The basis for tropical cyclone products
- Uses numerous coastal domains (basins)
  - Structured grids of limited extent and resolution
  - From tens of meters to a few kilometers offshore
  - Sub-grid cell features to model barriers (such as levees or roadways) and waterways
- Simple hurricane model driven by storm track, radius of maximum winds, and central pressure

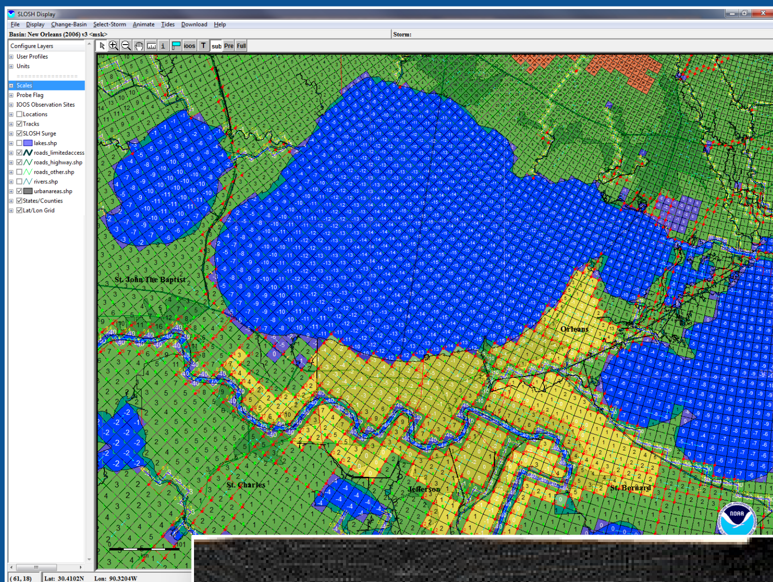
Further info: http://slosh.nws.noaa.gov/sloshPub

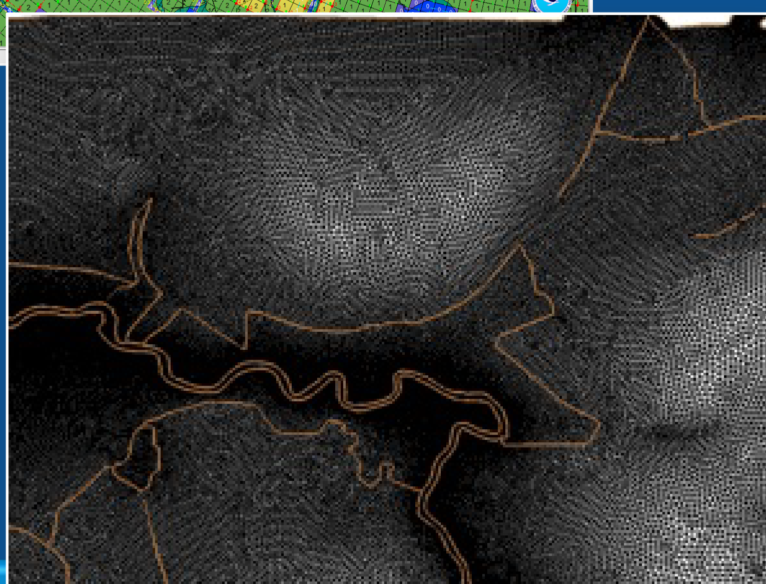
SLOSH's Basins

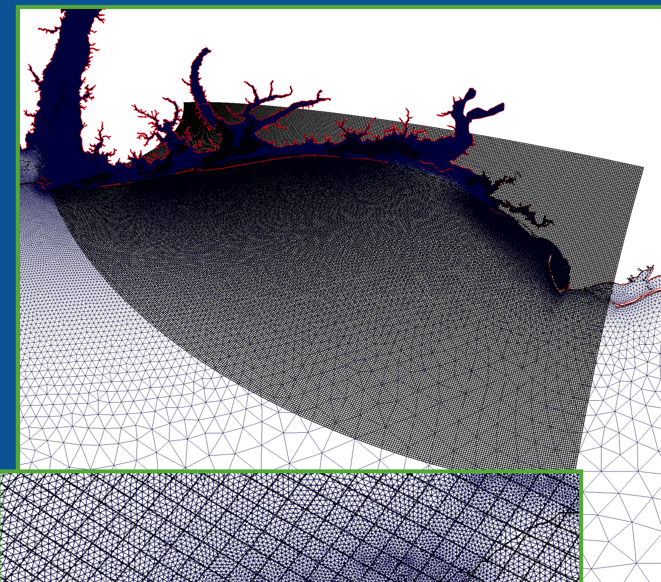


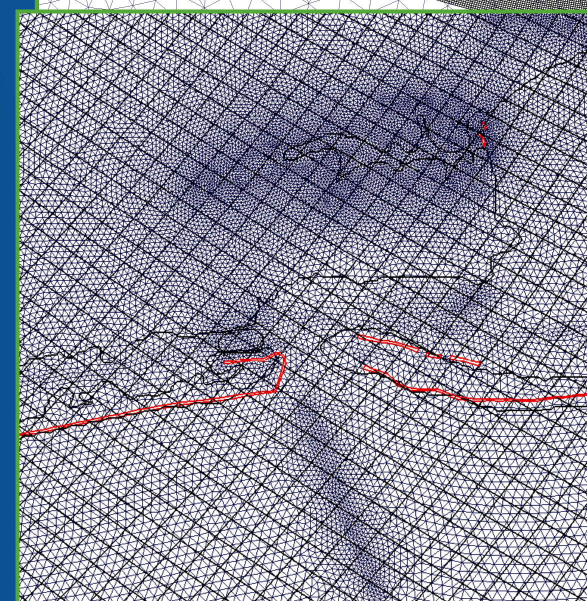
Basins are efficiently sized but can have difficulty capturing larger storms and are limited by size and orientation of structured grid cells

Contrasting Structured and Unstructured Grids – SLOSH and the **<u>AD</u>**VANCED **<u>CIRC</u>**ULATION MODEL FOR OCEANIC,COASTAL AND ESTUARINE WATERS (ADCIRC) (examples for New Orleans, Pensacola)









Computing Surge Hazard Analyses

- SLOSH's primary function is to compute surge hazard analysis for hurricane evacuation studies
  - NHC runs around 15,000 hypothetical storms in each basin to create composites of potential surge
  - Results define surge hazard for evacuation zones

MEOW = Maximum Envelopes of Water

Worst case snapshot for a particular storm category, forward speed, trajectory, and initial tide level, incorporating uncertainty in landfall location

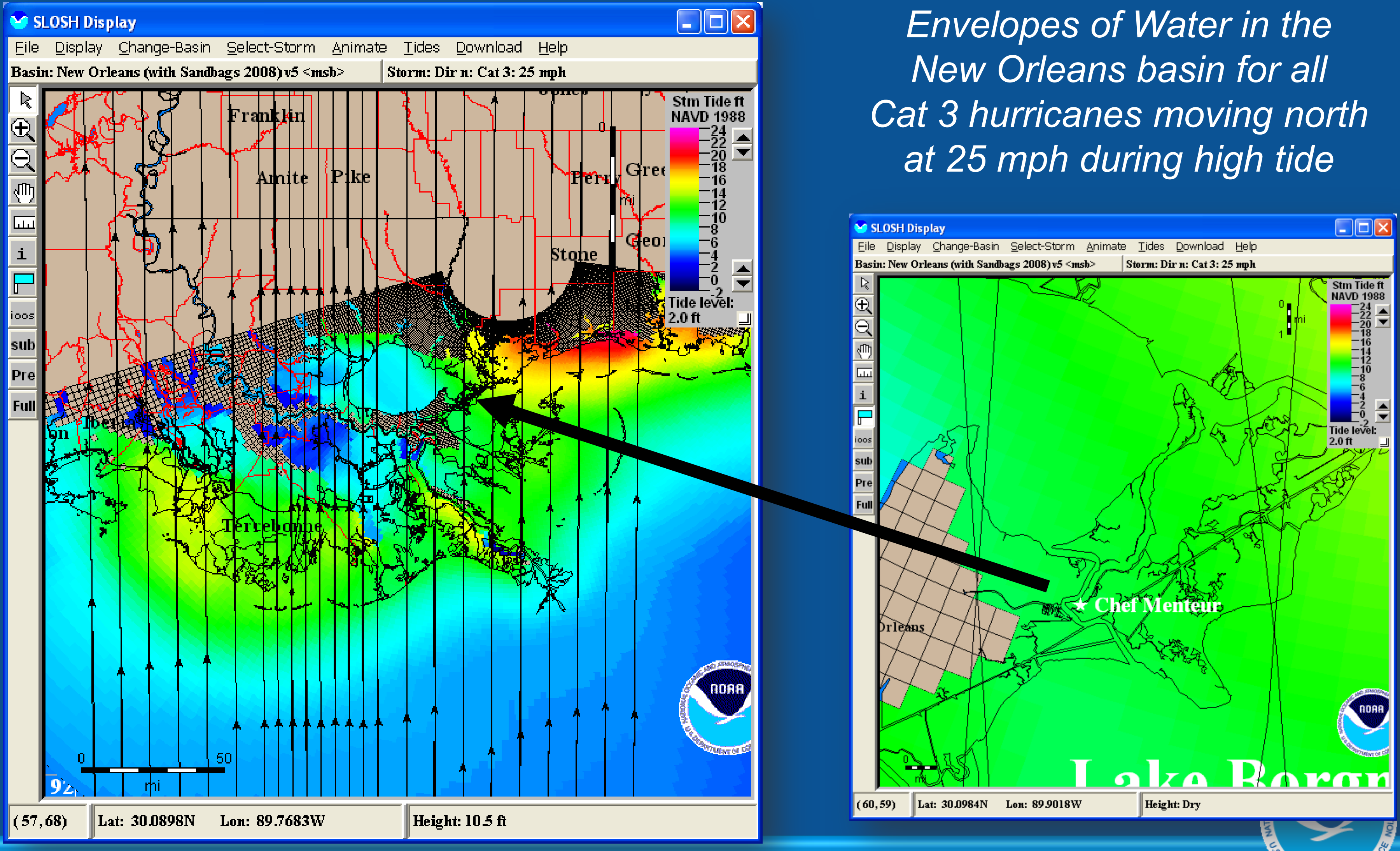
MOM = Maximum of Maximums

Combines all MEOWs for a particular storm category

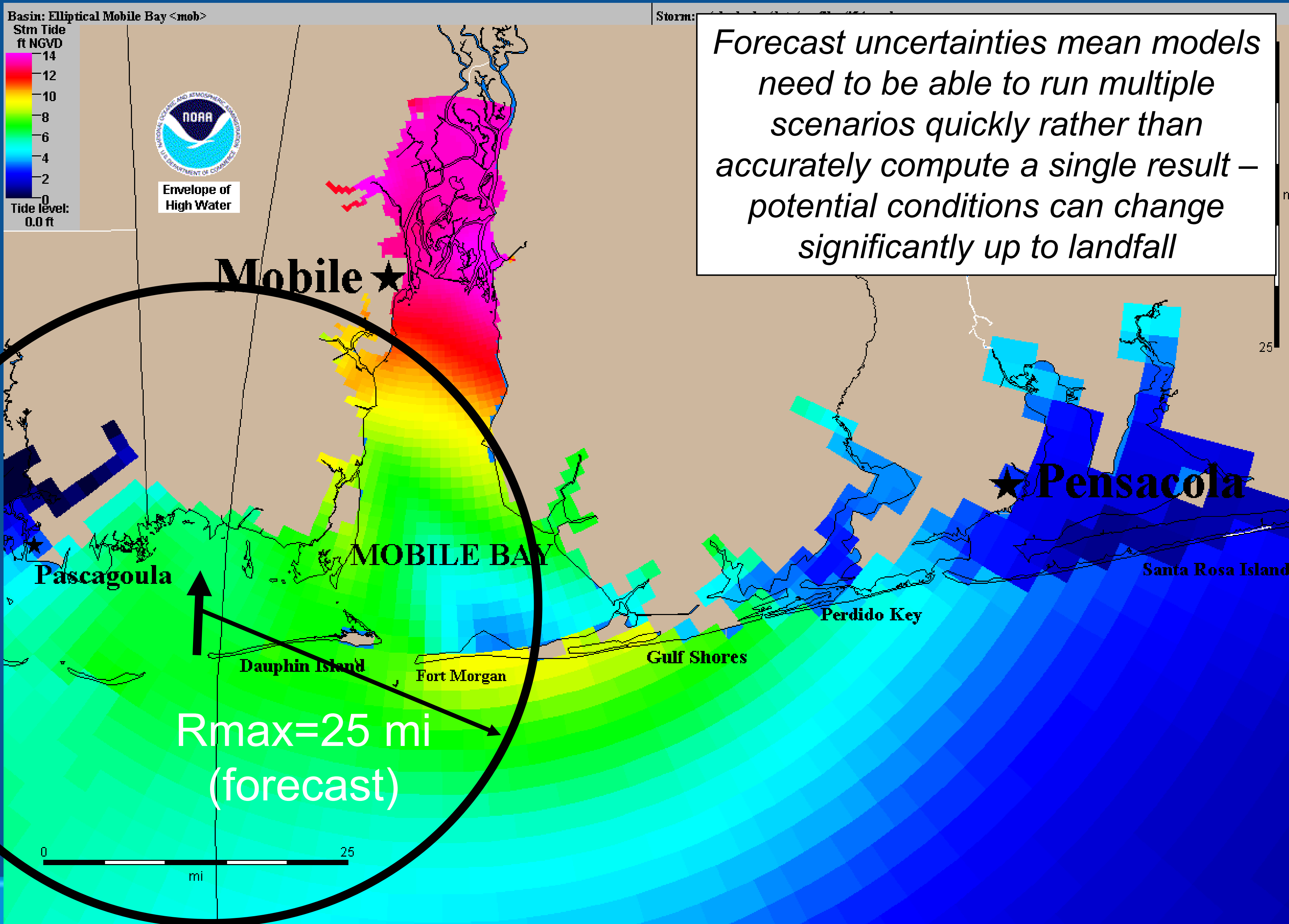
- More info from the National Hurricane Program: http://www.iwr.usace.army.mil/nhp/

Generating a MEOW

Composite of Maximum Envelopes of Water in the New Orleans basin for all Cat 3 hurricanes moving north at 25 mph during high tide

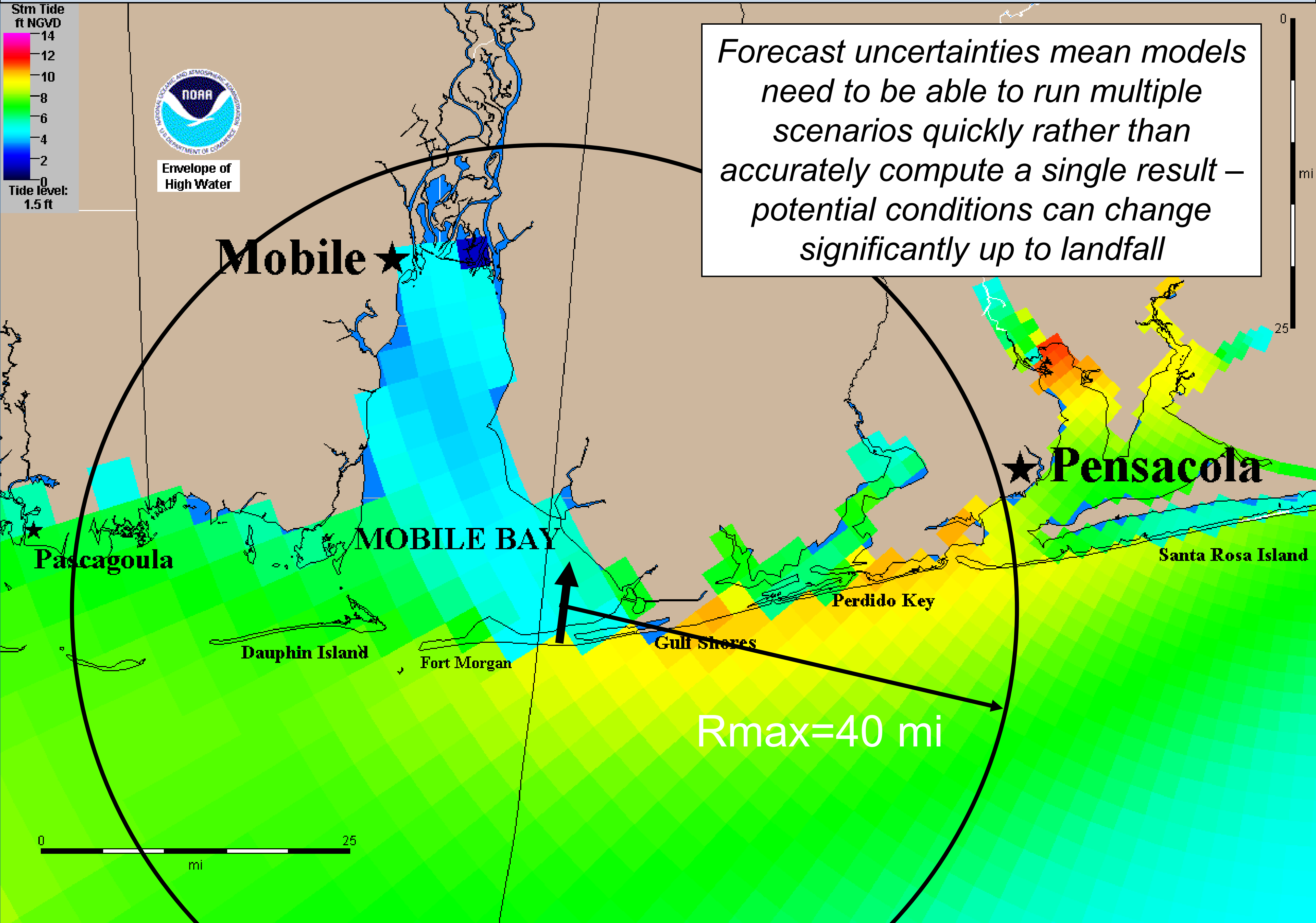


Hurricane Ivan (2004) Surge Based on NHC 12 hr. Advisory



Forecast uncertainties mean models need to be able to run multiple scenarios quickly rather than accurately compute a single result – potential conditions can change significantly up to landfall

Hurricane Ivan (2004) Surge Based on NHC Storm Best Track

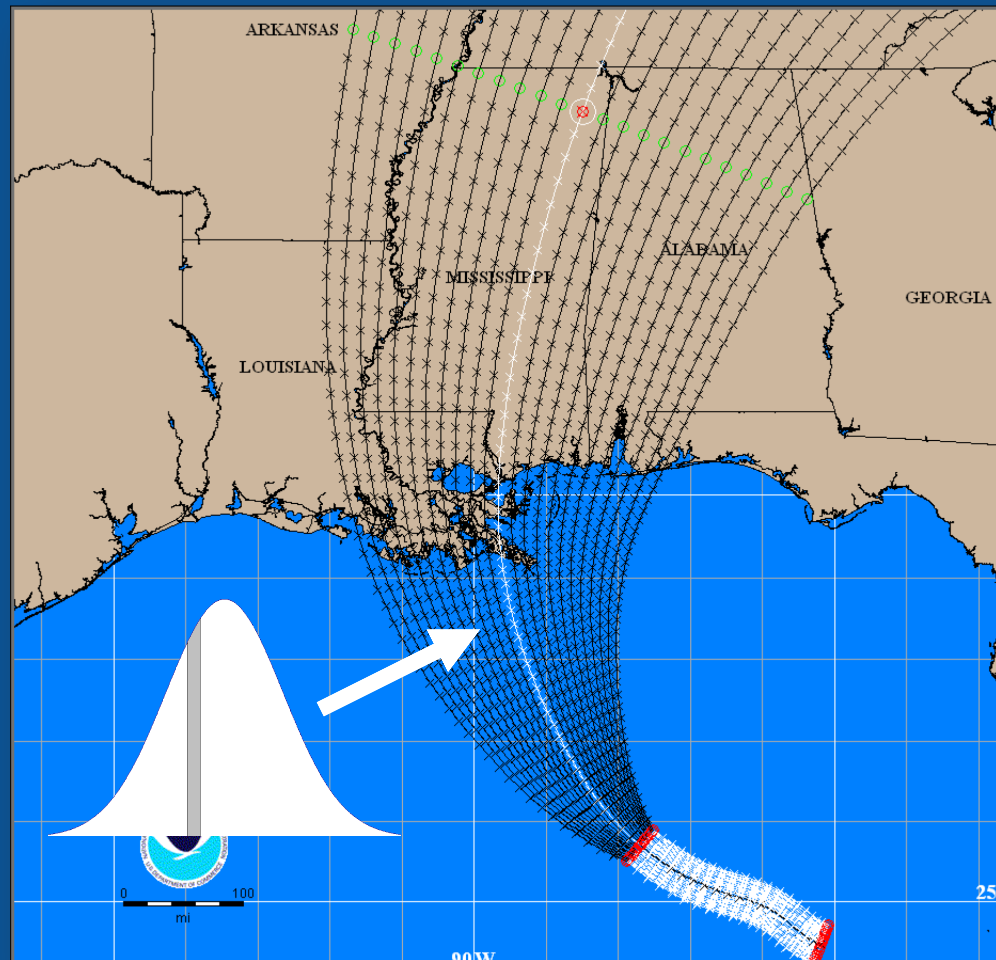


Computing Storm Surge Probabilities

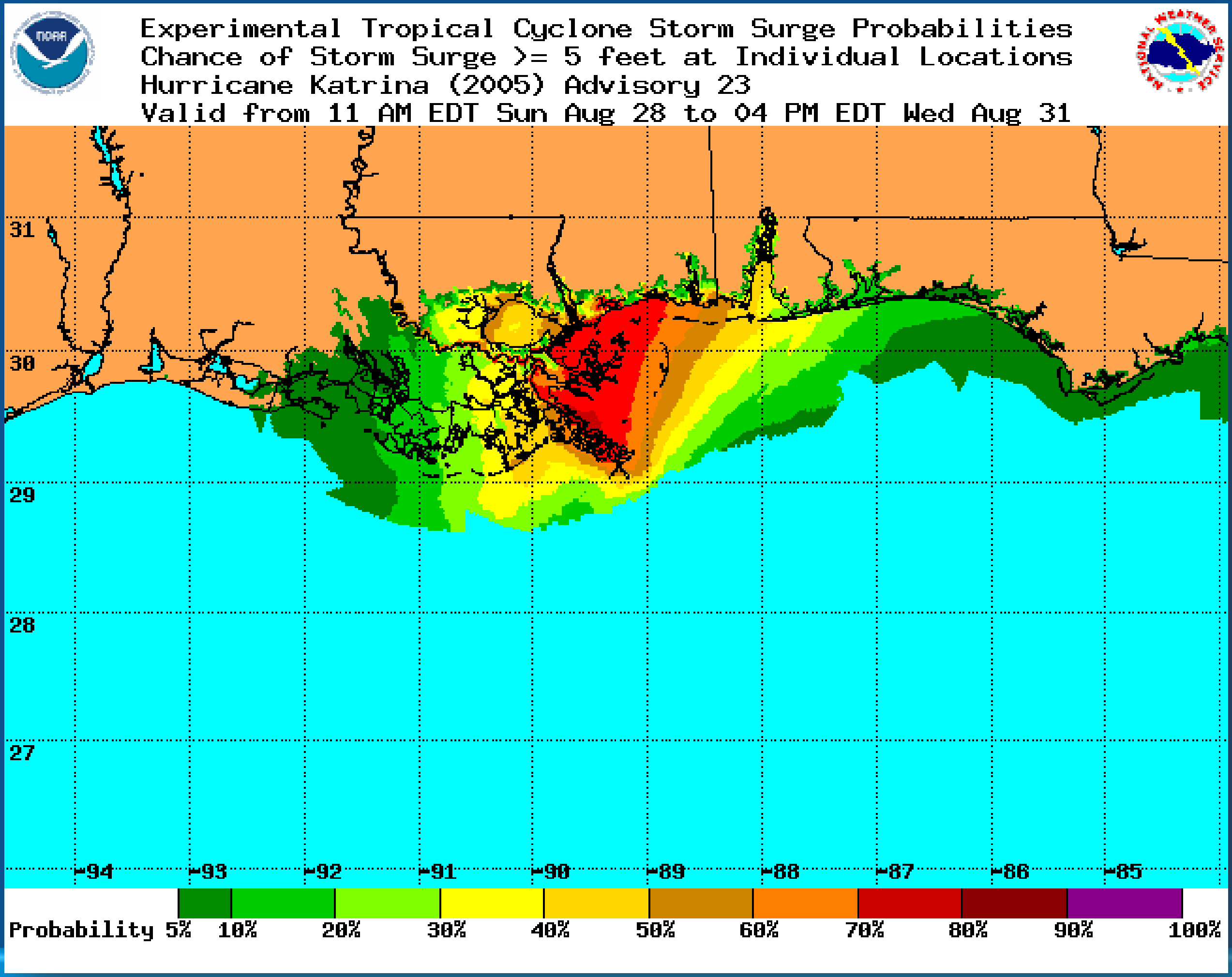
- P-Surge: storm surge ensemble based on NHC forecast advisory
  - Perturbation of cross-track error, along-track error, intensity error, and size error
- Used to calculate probabilities and exceedances
  - "Probability of water exceeding X feet"; available on NHC's website: http://www.nhc.noaa.gov/index.shtml
  - "Height exceeded by X%" of ensemble members; available at MDL: http://www.weather.gov/mdl/psurge/
- Operational time constraint of getting an answer out within 30-minutes of Advisory release time

Perturbing the Hurricane Forecast

- Perturb across 90% of possible track error (roughly 3 times the size of the cone of error)
- Error distributions for cross track, along track and intensity:
  - Assume a normal distribution
  - Use a 5-year "mean absolute error"
- Results in hundreds of storms run through a dozen basins resulting in thousands of simulations

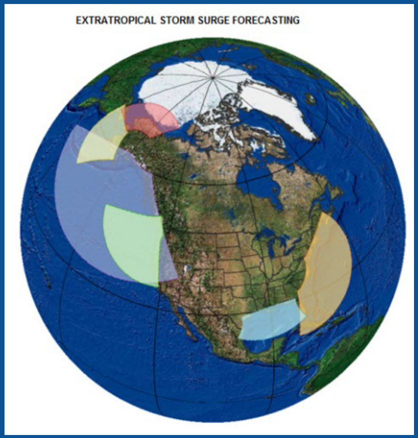


Katrina Advisory 23 - Probability of ≥ 5 feet of Storm Surge



Extra-Tropical Storm Surge

- Extra-Tropical Storm Surge (ETSS)
  - Finite differencing model developed by the Meteorological Development Laboratory
  - Modified SLOSH to predict storm surge heights from extra-tropical storms
  - Global Forecast System for wind forcing
  - Structured grid with finer resolution overland, and coarser offshore
- Does not include
  - Tides, waves, river flow
  - Overland storm surge



Extratropical Storm Surge Website

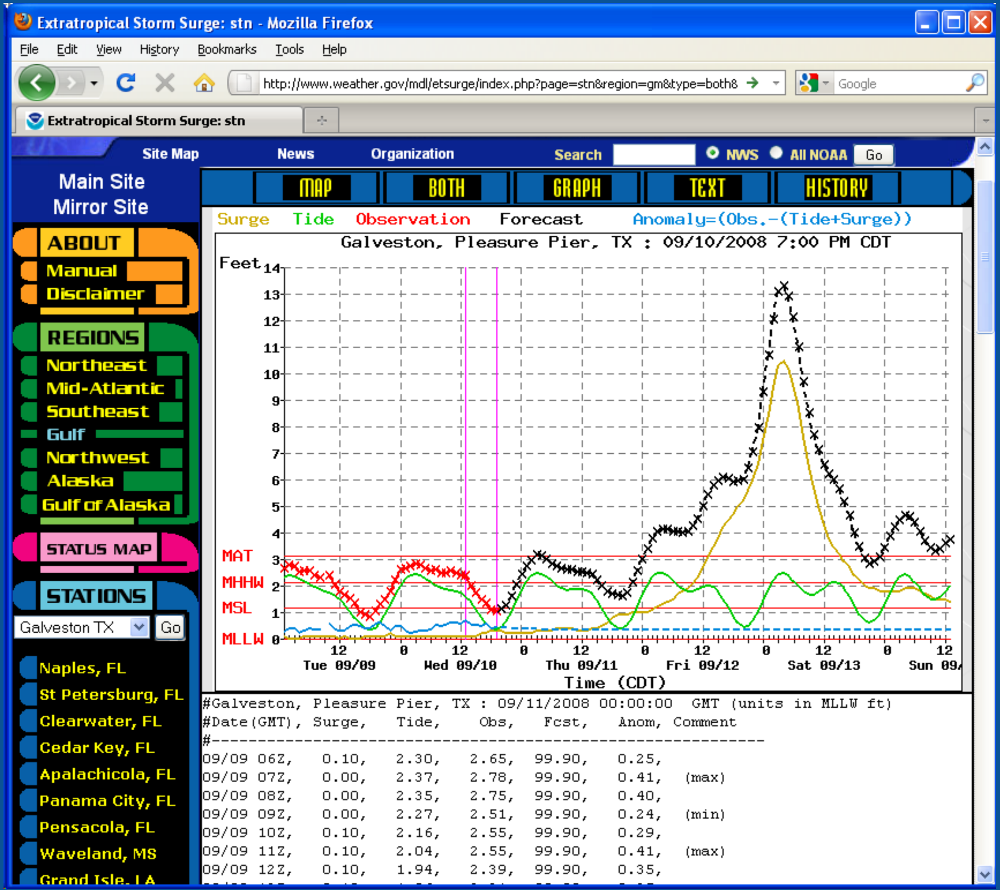
Combine the ETSS output with:

- Observations from NOS / CO-OPs
- Tides computed from constituents provided by NOS/CO-OPS
- Uses a 5 day running average error to improve total water level forecast
- Provides guidance on flooding (when total water level exceeds the HAT)

NOS/OPC also has ETSS model output

- http://www.opc.ncep.noaa.gov/et_surge/et_surge_info.shtml
- Animations of maps of ETSS output with GFS pressure fields

http://www.weather.gov/mdl/etsurge

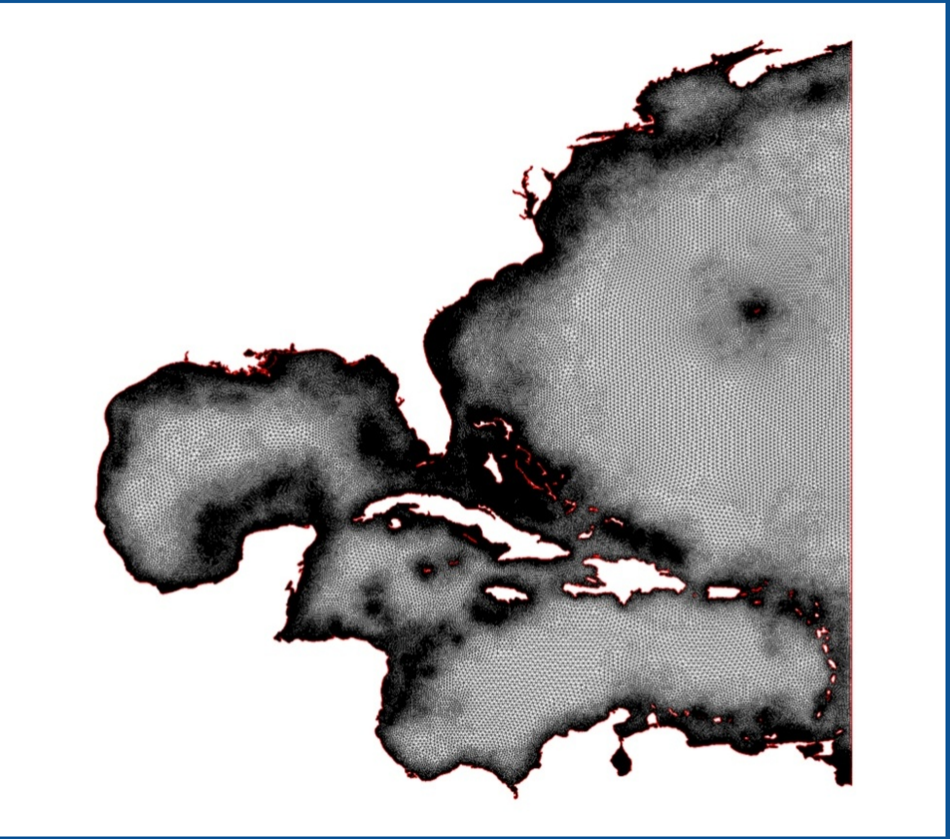


ADCIRC-based Operational Surge Predictions

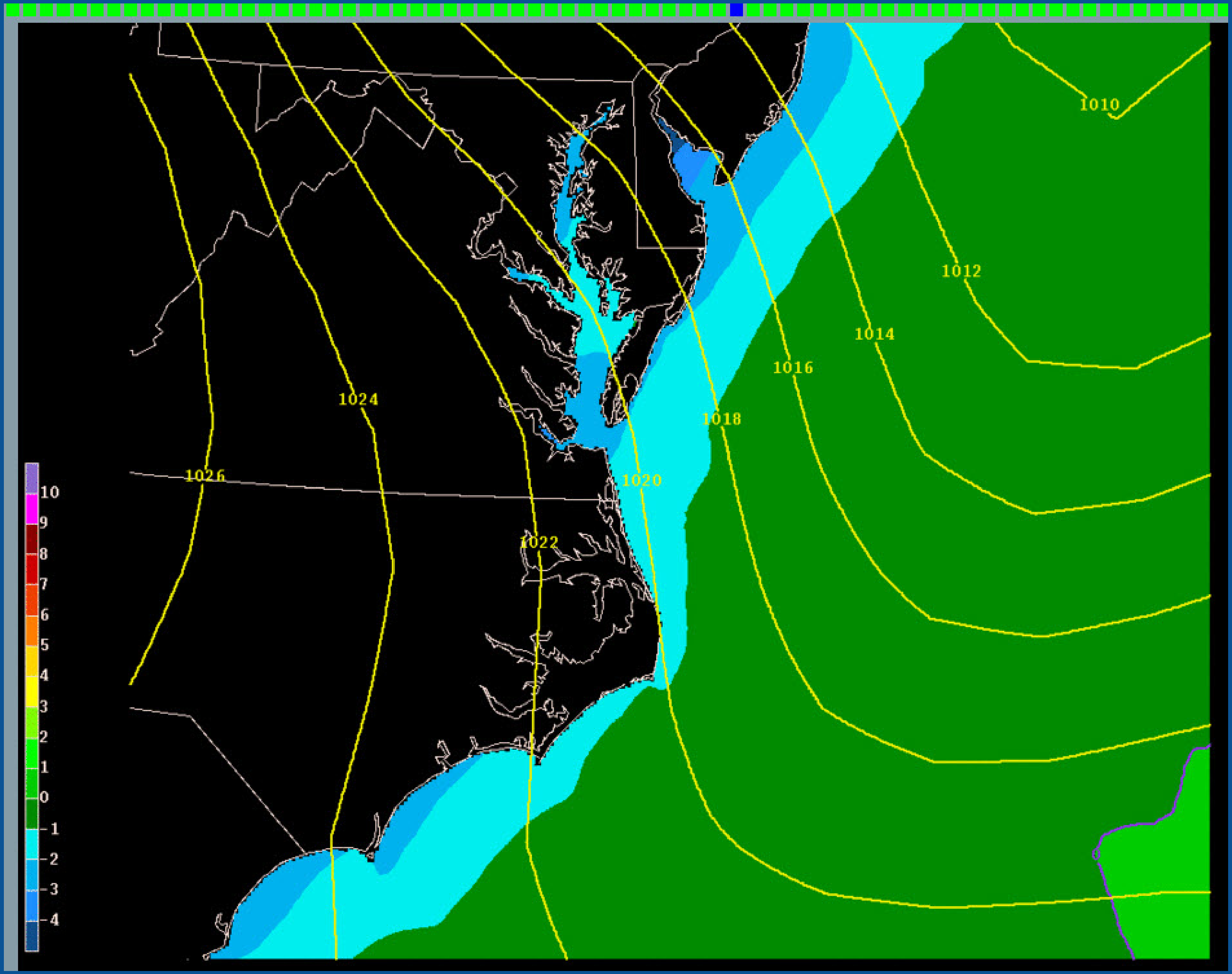
- Extratropical Surge and Tide Operational Forecast System (ESTOFS)
- Operational forecast guidance for extratropical storms in Western North Atlantic basin
  - Computes surge with tides (4X per day)
- Differs from higher resolution hindcast models
  - Insufficient grid resolution at rivers, inlets, and barrier islands
  - No overland grid coverage, waves, or river inflows

ESTOFS-Atlantic

- East Coast 2001 tidal database grid (EC2001)
  - 254,565 nodes
- Coastal resolution of approximately 3 km is not highly precise but efficient for operational forecasting

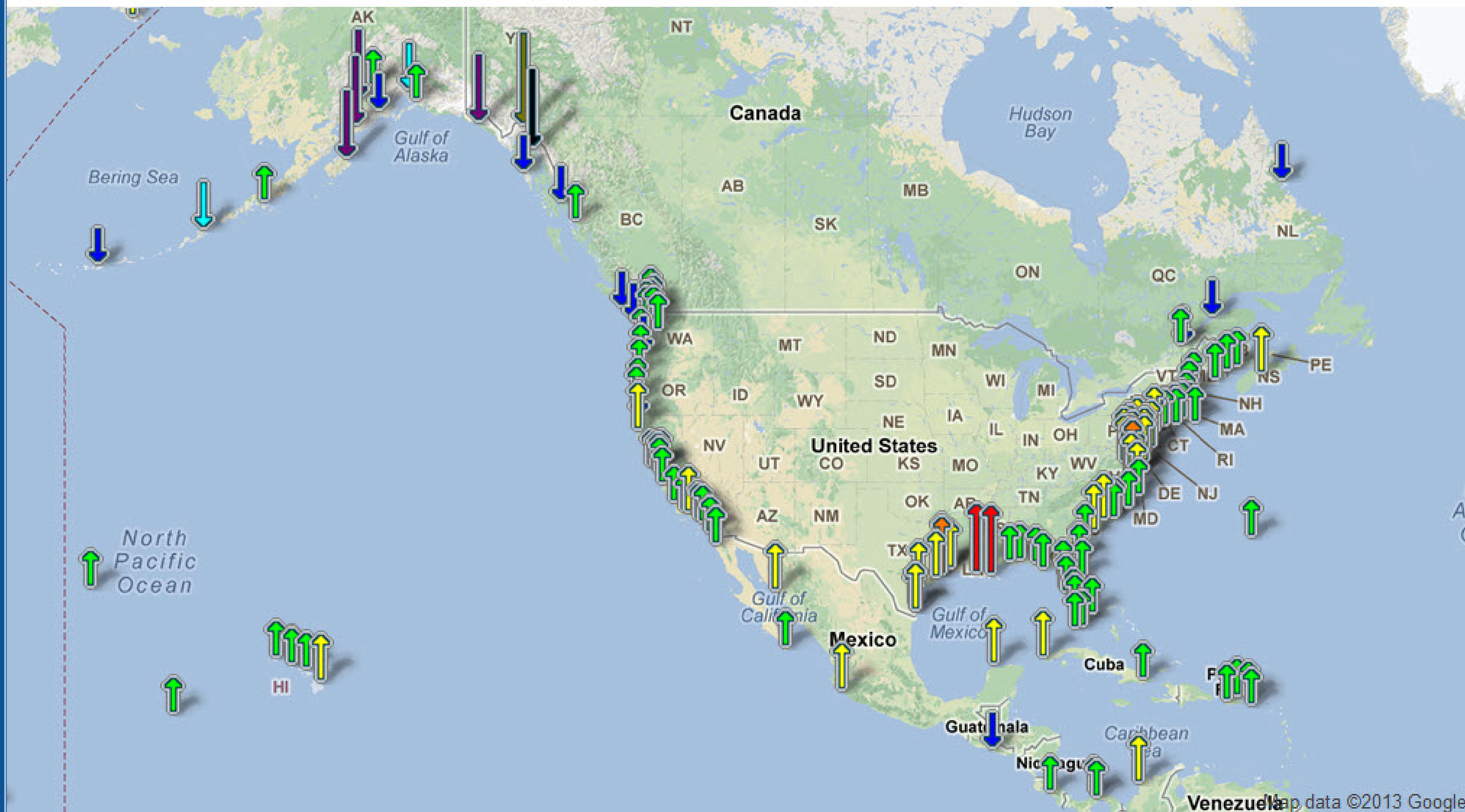


ESTOFS Graphic for February 1, 2013



Recent Work in Sea Level and Extreme Water Levels in NOAA

Relative Sea Level Trends at US Tide Stations



gional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access ac station.

Sea Level Trends

mm/yr (feet/century)

9 to 12 (3 to 4)	3 to 6 (1 to 2)	-3 to 0 (-1 to 0)	-9 to -6 (-3 to -2)	-15 to -12 (-5 to -4)
6 to 9 (2 to 3)	0 to 3 (0 to 1)	-6 to -3 (-2 to -1)	-12 to -9 (-4 to -3)	-18 to -15 (-6 to -5)

http://tidesandcurrents.noaa.gov/sltrends/index.shtml

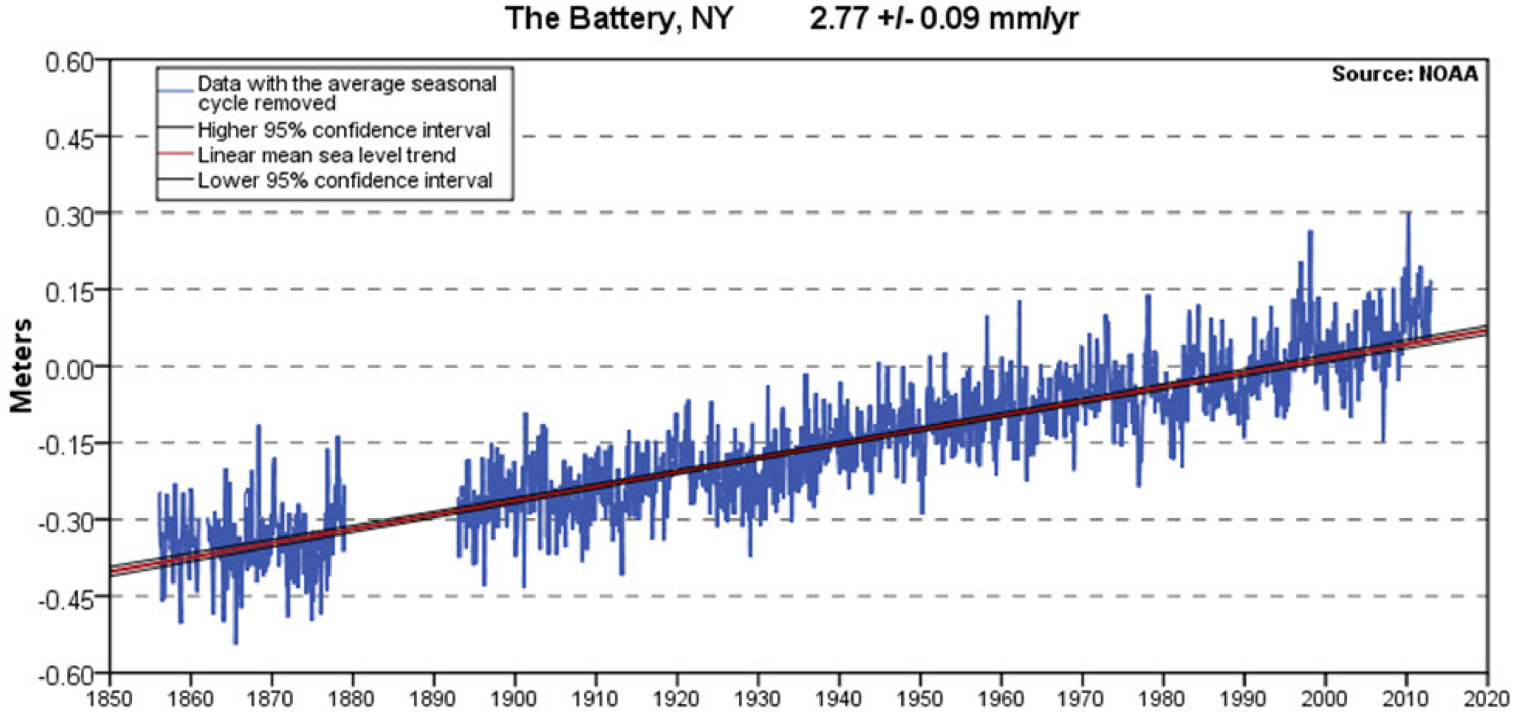
Relative Sea Level Trends and Vertical Land Motion at Tide stations

Regions of significant vertical land subsidence

Tide Station Location	Relative Sea Level Trend	Estimated Vertical land Motion
Colonial Beach, VA	4.8 mm/yr (1.2 mm/yr)	-3.1 mm/yr (0.3 mm/yr)
Lewisetta, VA	5.0 mm/yr (1.0 mm/yr)	-2.4 mm/yr (0.4 mm/yr)
Gloucester Pont, VA	3.8 mm/yr (0.5 mm/yr)	-2.4 mm/yr (0.1 mm/yr)
Sewells Point, VA	4.4 mm/yr (0.3 mm/yr)	-2.6 mm/yr (0.11 mm/yr)
CBBT, VA	6.1 mm/yr (1.1 mm/yr)	-3.3 mm/yr (0.4 mm/yr)
Grand Isle, LA	9.2 mm/yr (0.6 mm/yr)	-7.6 mm/yr (0.2 mm/yr)
Sabine Pass. TX	5.7 mm/yr (1.1 mm/yr)	-3.8 mm/yr (0.5 mm/yr)
Galveston Pier 21, TX	6.4 mm/yr (0.3 mm/yr)	-4.7 mm/yr (0.2 mm/yr)
Galveston PP, TX	6.8 mm/yr (0.8 mm/yr)	-4.9 mm/yr (0.4 mm/yr)
Freeport, TX	4.4 mm/yr (1.1 mm/yr)	-3.6 mm/yr (0.4 mm/yr)
Rockport. TX	5.2 mm/yr (0.7 mm/yr)	-3.6 mm/yr (0.4 mm/yr)
North Spit, Humboilt Bay, CA	4.7 mm/yr (1.6 mm/yr)	-3.4 mm/yr (0.5 mm/yr)
Cordova, AK	5.7 mm/yr (0.9 mm/yr)	-3.4 mm/yr (0.4 mm/yr)

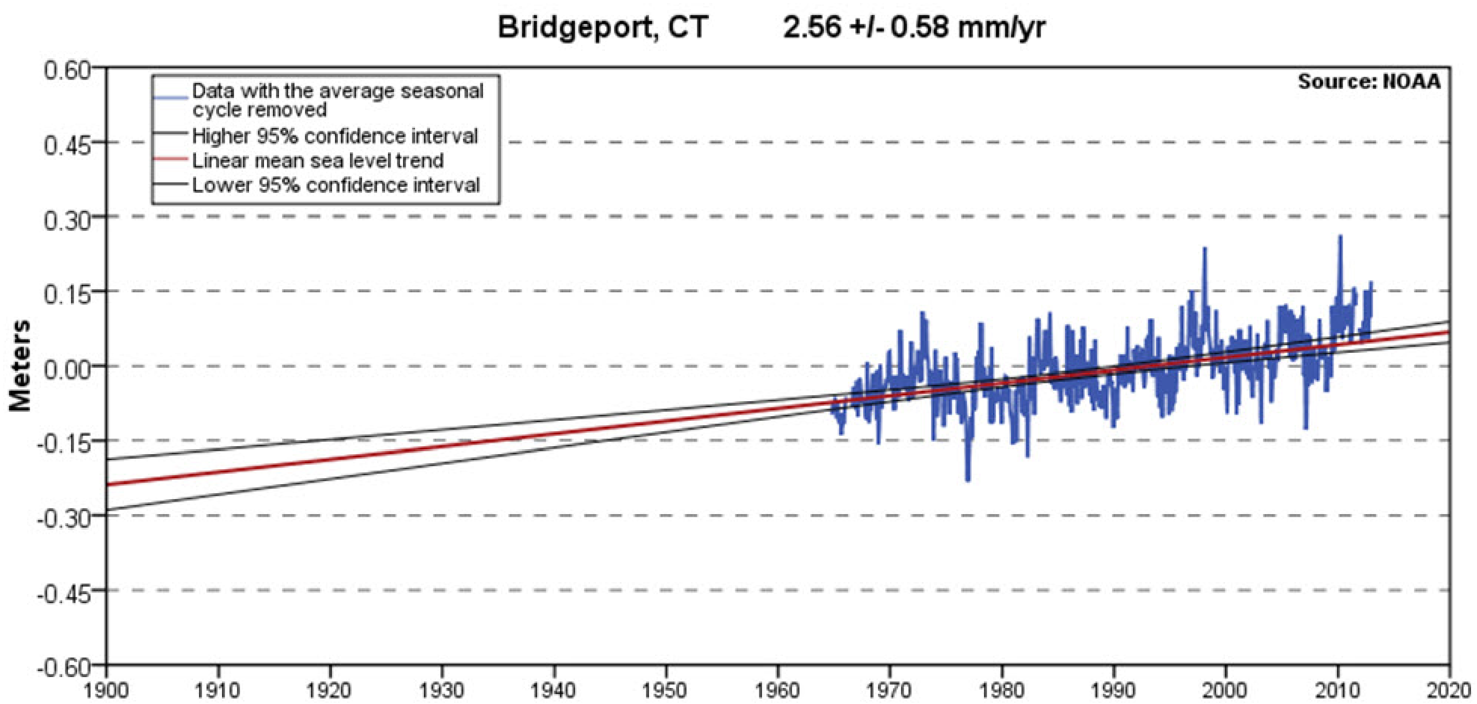
Estimated standard errors of trends given in parentheses

Mean Sea Level Trend
8518750 The Battery, New York



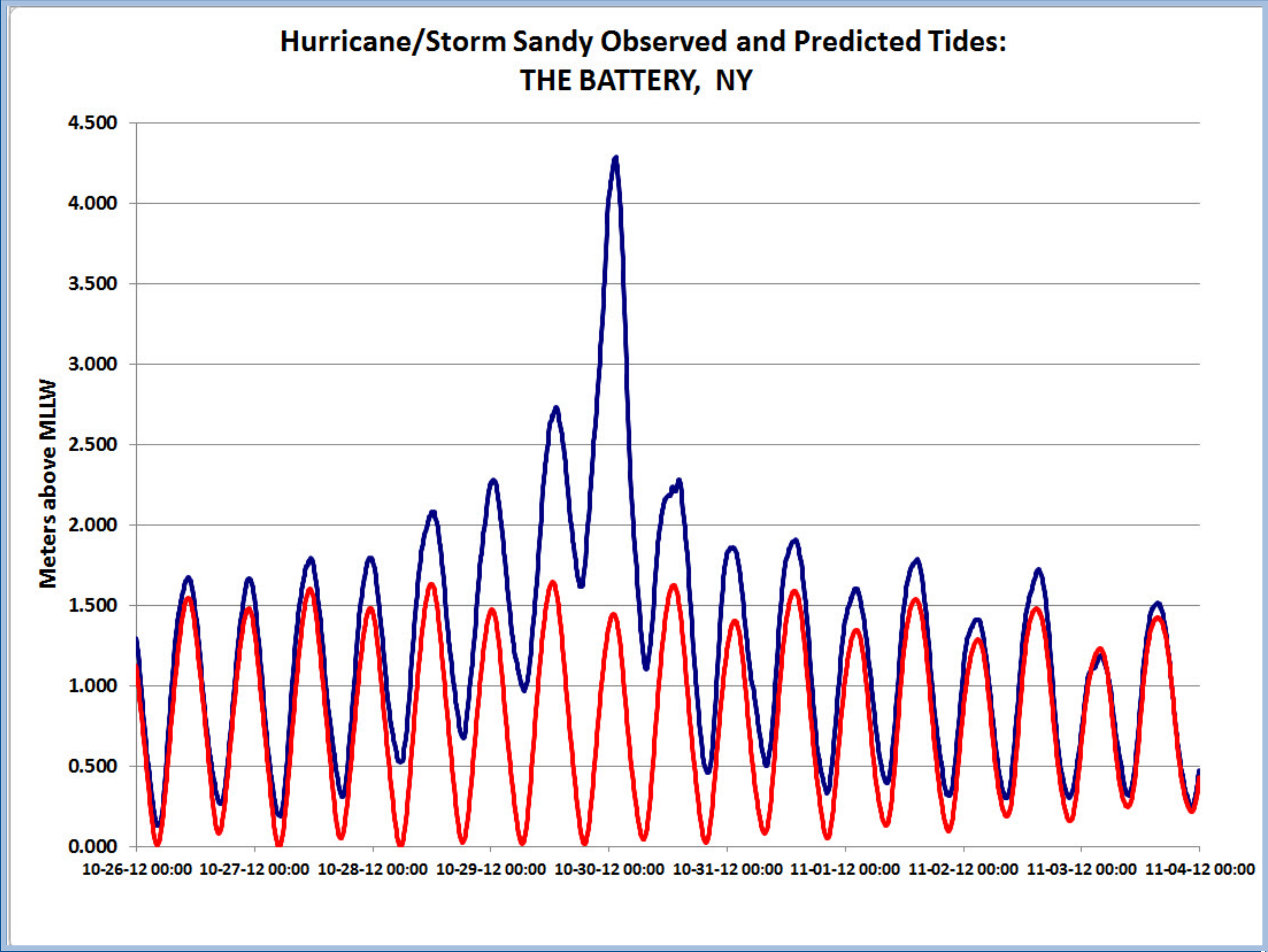
The mean sea level trend is 2.77 millimeters/year with a 95% confidence interval of +/- 0.09 mm/yr based on monthly mean sea level data from 1856 to 2006 which is equivalent to a change of 0.91 feet in 100 years.

Mean Sea Level Trend
8467150 Bridgeport, Connecticut

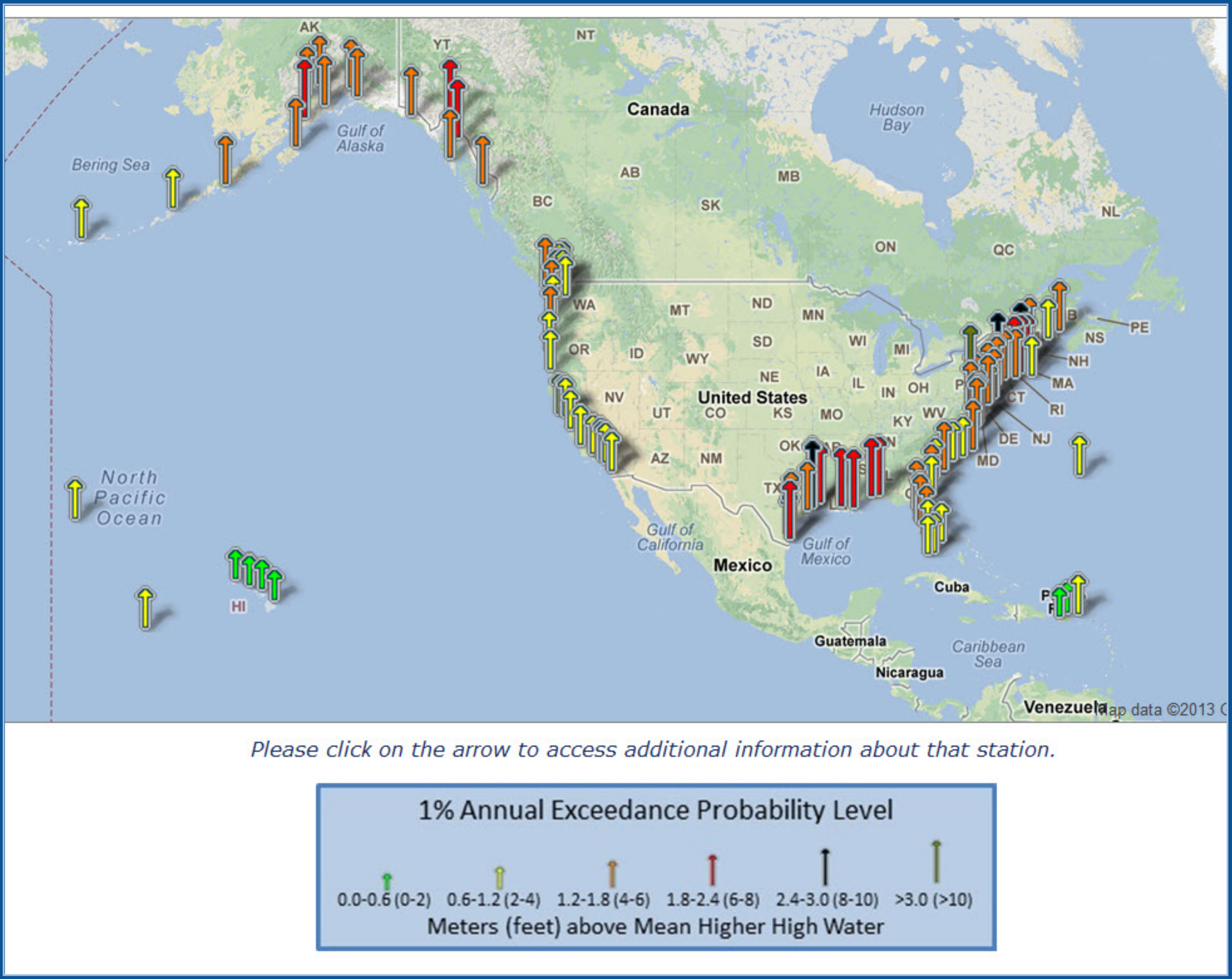


The mean sea level trend is 2.56 millimeters/year with a 95% confidence interval of +/- 0.58 mm/yr based on monthly mean sea level data from 1964 to 2006 which is equivalent to a change of 0.84 feet in 100 years.

Extreme Water Levels

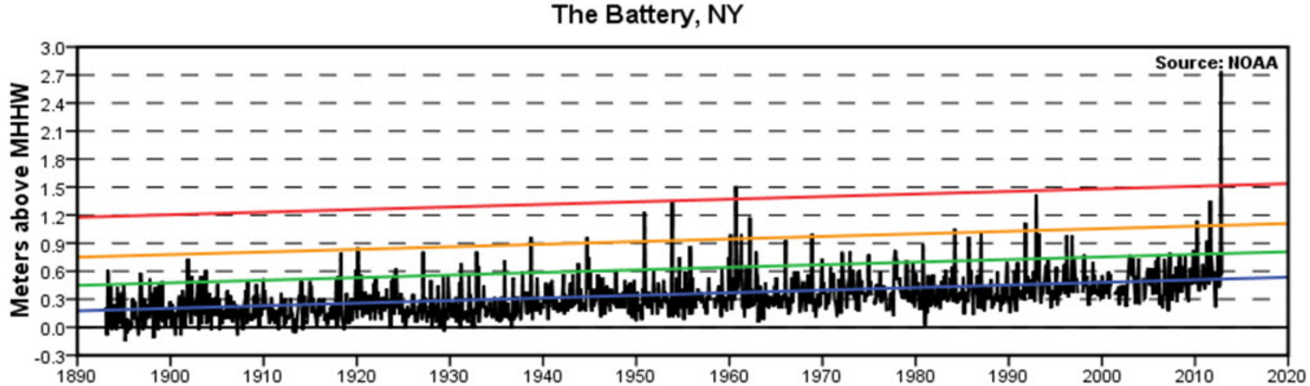


Extreme Water Levels at US Tide Stations



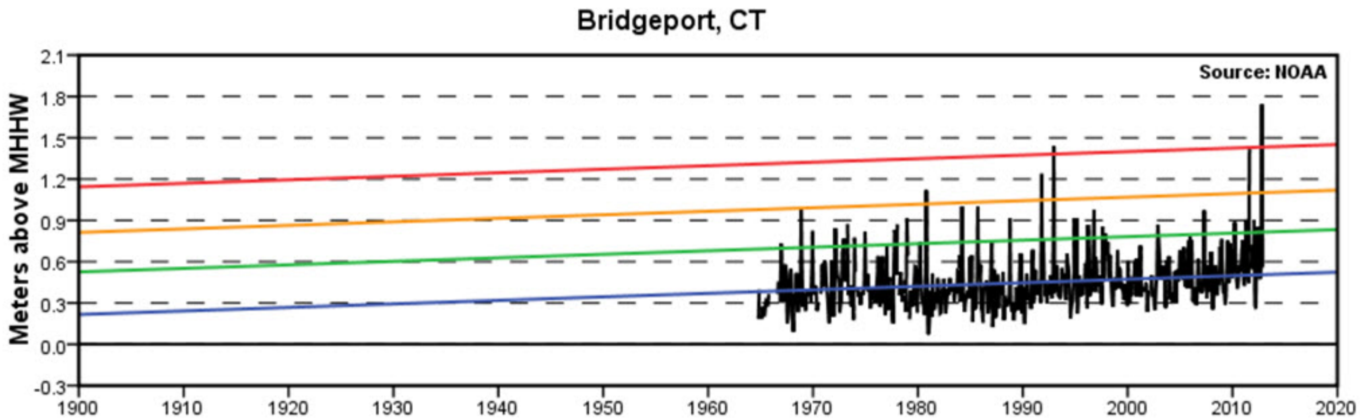
http://tidesandcurrents.noaa.gov/est/

Extreme Water Levels
8518750 The Battery, New York

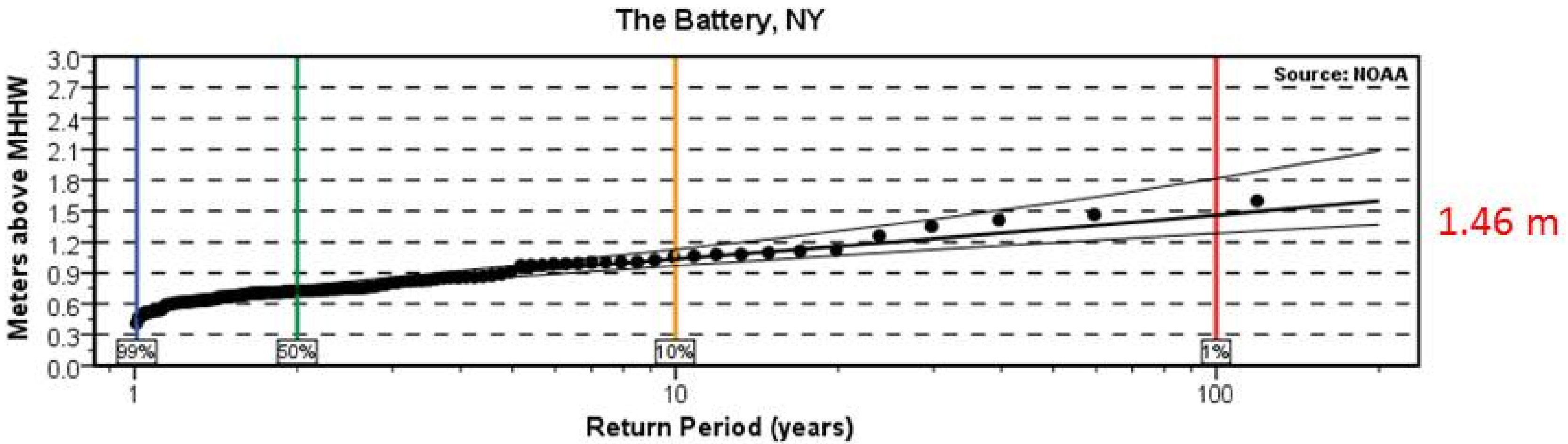


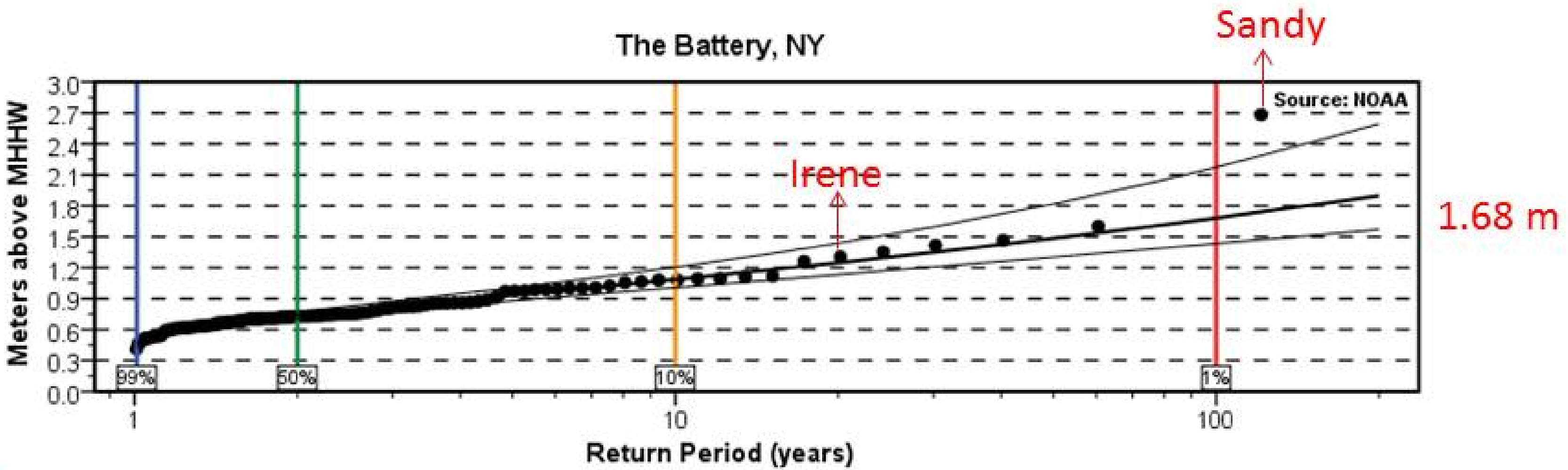
01 year per 100
10 years per 100
50 years per 100
99 years per 100

Extreme Water Levels
8467150 Bridgeport, Connecticut



Effect of Including Hurricanes Irene (2011) and Sandy (2012)





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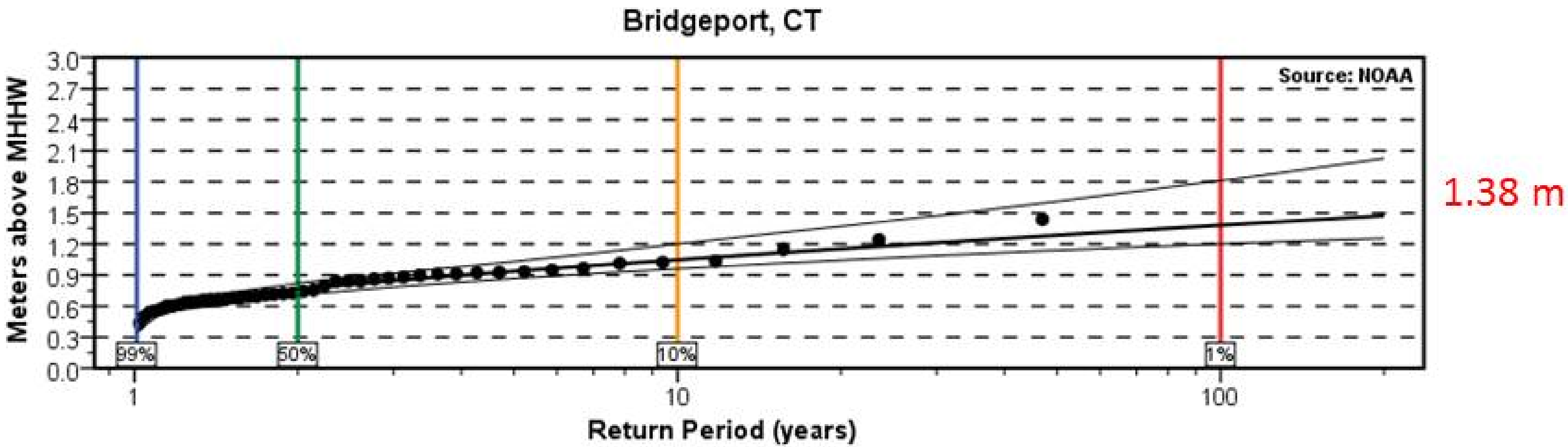
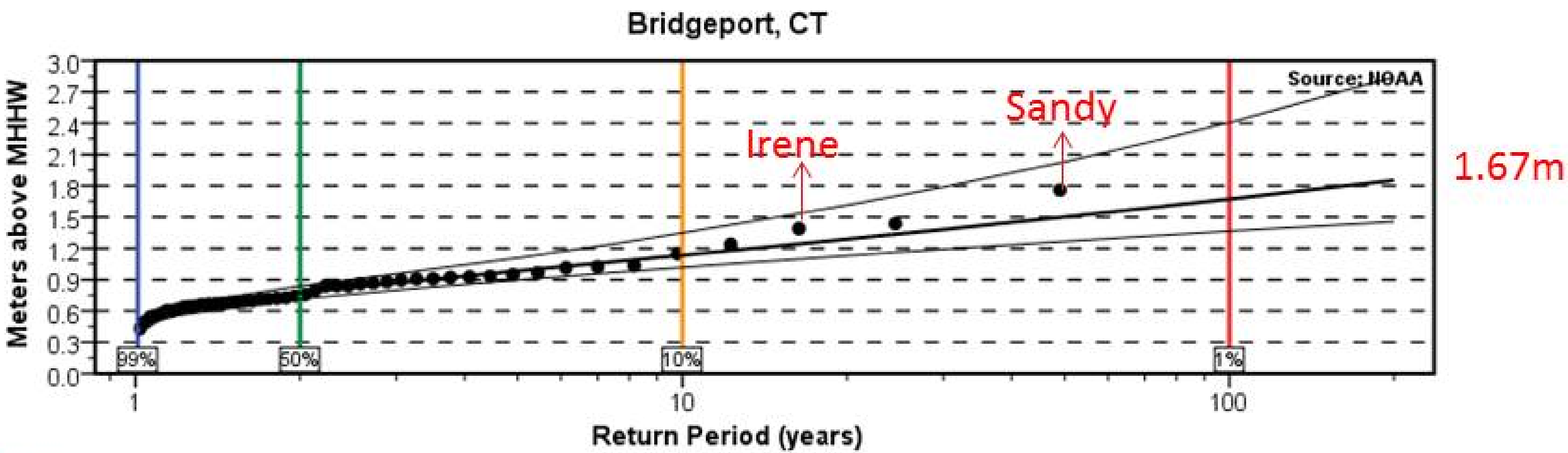


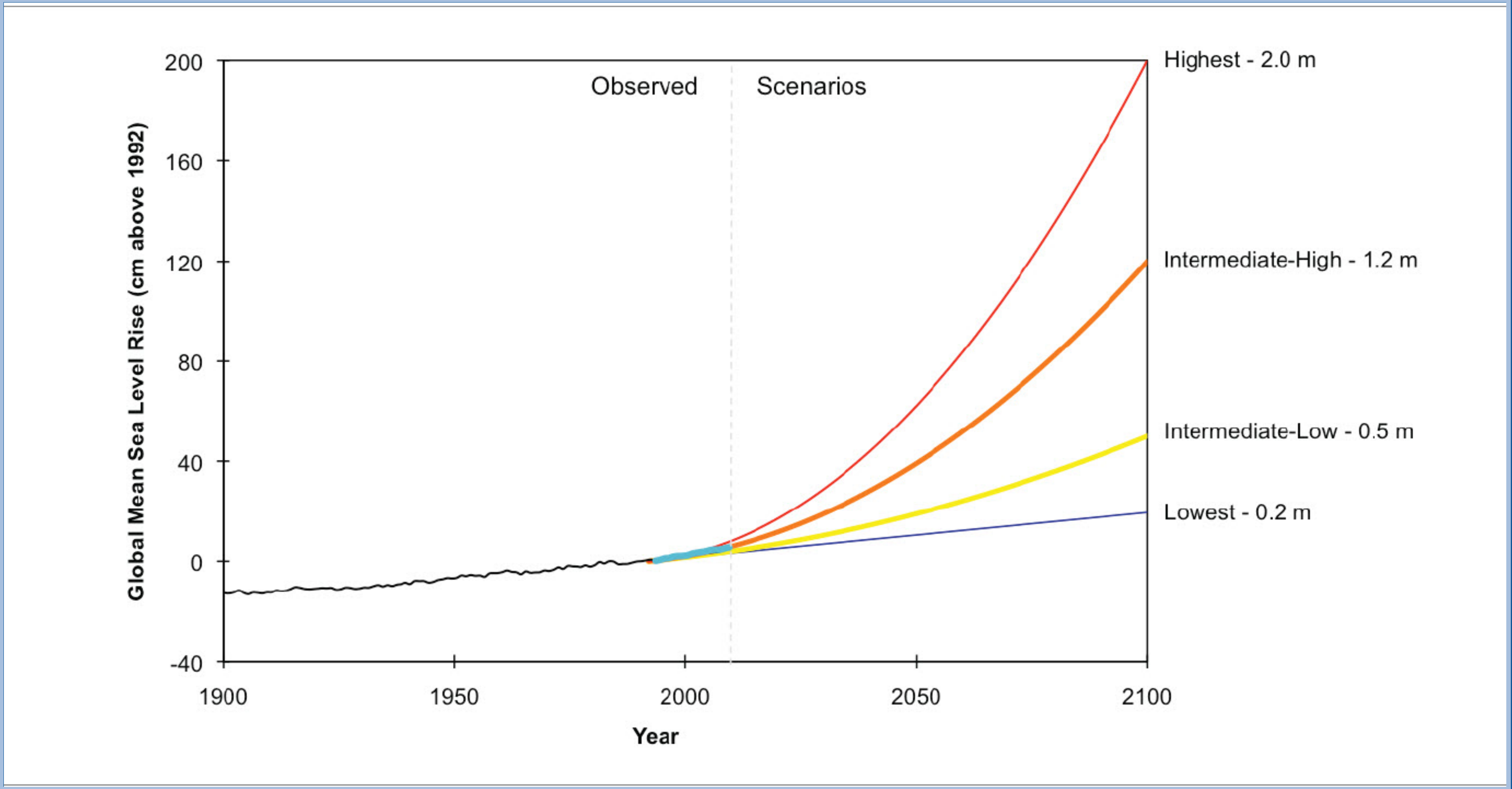


Preliminary Return Periods for Hurricane/Storm Sandy

Bridgeport, CT	120 years (25 - 2100 years)
The Battery, NY	1600 years (230 - 35,000 years)
Sandy Hook NJ	290 years (65 - 4000 years)
Atlantic City, NJ	25 years (12 - 60 years)
Kings Point, NY	23 years (11 - 66 years)

Using NOAA Exceedance Probability Analysis Methodology
http://tidesandcurrents.noaa.gov/est/

Projected Sea level Rise Scenarios up to 2100 in Response to Climate Change



Taken from: Global Sea Level Rise Scenarios for the United States National Climate Assessment, December 6, 2012, NOAA Technical Report OAR CPO-1

Global Sea Level Rise Scenarios for the United States National Climate Assessment, December 6, 2012

- **Global Mean Sea Level Rise Scenarios: Very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100.**

  - Highest Scenario of global SLR by 2100 is derived from a combination of estimated ocean warming from the IPCC AR4 global SLR projections and a calculation of the maximum possible glacier and ice sheet loss by the end of the century.

  - Intermediate-High Scenario is based on an average of the high end of semi-empirical, global SLR projections. Semi-empirical projections utilize statistical relationships between observed global sea level change, including recent ice sheet loss, and air temperature.

  - Intermediate-Low Scenario is based on the upper end of IPCC Fourth Assessment Report (AR4) global SLR projections resulting from climate models using the B1 emissions scenarios.

  - The Lowest Scenario is based on a linear extrapolation of the historical SLR rate derived from tide gauge records beginning in 1900 (1.7 mm/yr).

Potential Impacts of Sea-Level Rise on Extreme Water Level Return Frequencies

- **Subject of active scientific research**
  - **Use long-term tide gauge observations (>40 years)**
  - **Perform extreme value analyses (two methods being investigated current exceedance probabilities**
    - **Annual Maxima Method (AMM) with Generalized Extreme Value (GEV)**
    - **Peak Over Threshold (POT) with Generalized Pareto Distribution (GPD)**
  - **Estimate future extreme exceedance probabilities by using NCA SLR scenarios, vertical land motion estimates**

Example Preliminary Analysis - Draft

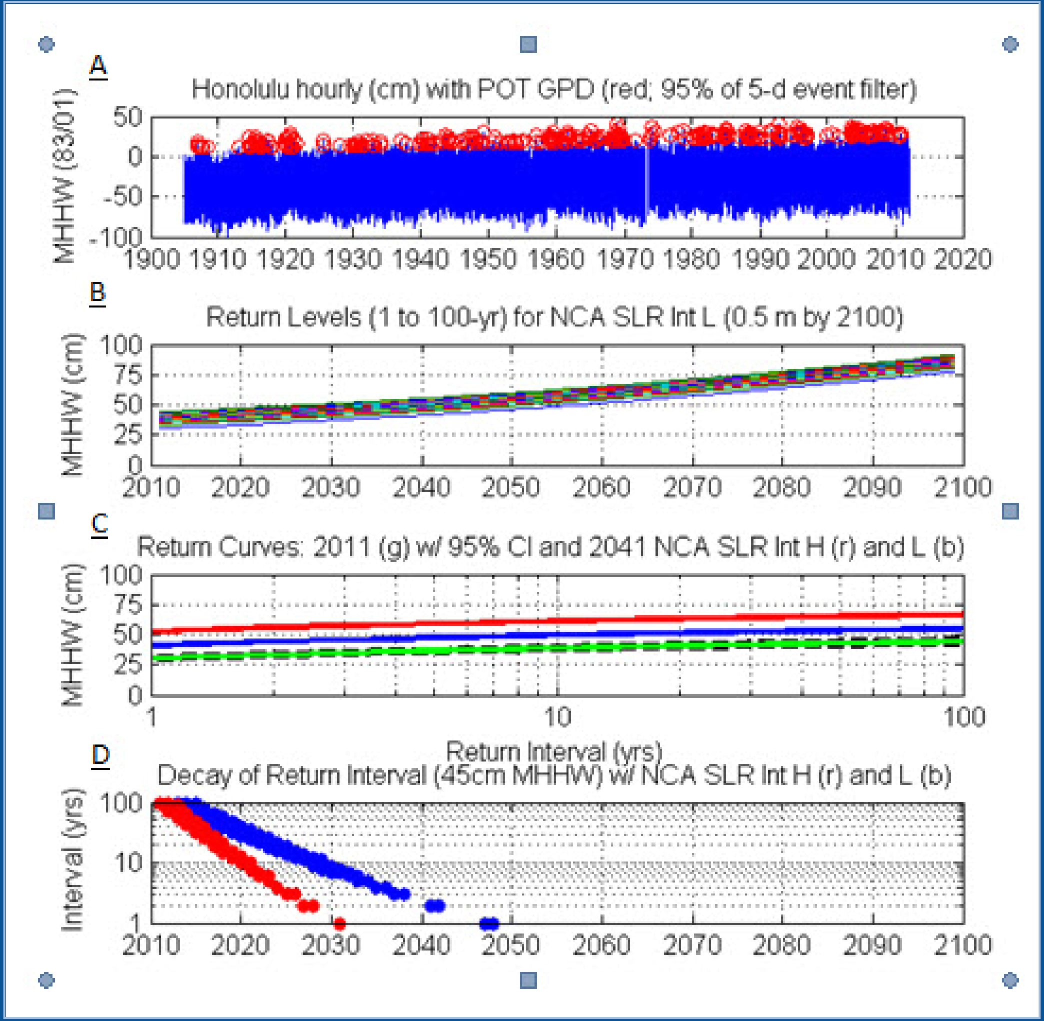


Figure 3. Hourly observations at Honolulu before detrending (A) and GPD-derived plots (B-D) with application of NCA SLR Intermediate High (H) and Low (L) scenarios. (example from Marra and Sweet, NOAA, 2012)

Questions?

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