NACCS - Numerical Modeling and Climate Change Webinar

Statistical Analysis of Extreme Storm Tides

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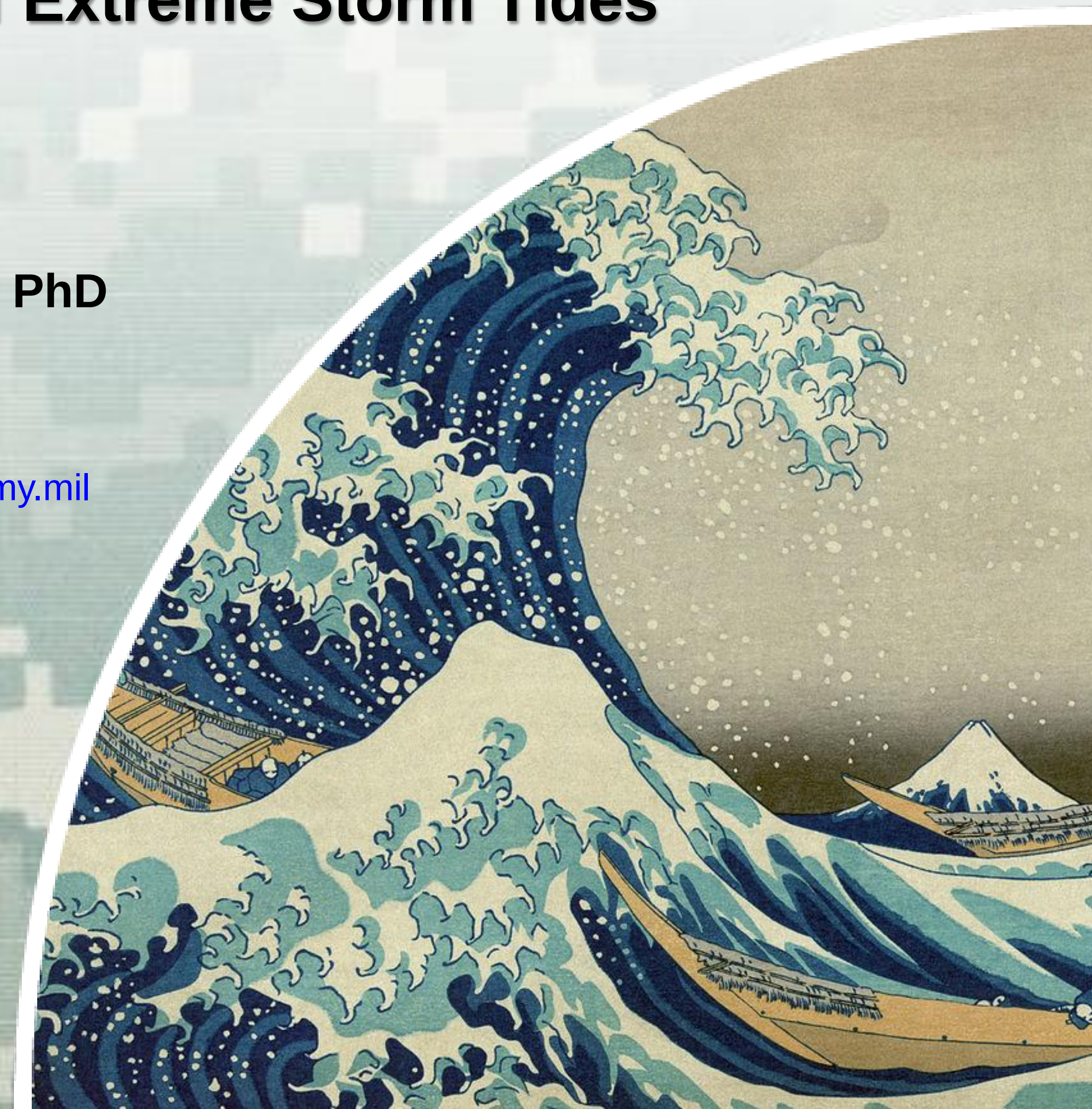


US Army Corps of Engineers

Statistical Analysis of Extreme Storm Tides

Phase I: Extremal Analysis of Storm Tide and Sea Level Change

- Low-fidelity approach (Initial assessment)
  - StormSim software system – extremal analysis and Monte Carlo simulation
  - NOAA verified historical water level measurements (QA/QC, high-water marks)
  - 23 NOAA gage locations
  - 6 USACE/NOAA sea level change (SLC) scenarios
  - Develop storm response benchmark for Phase II validation

Phase II: Joint Probability Analysis of Tropical & Extratropical Storms

- High-fidelity approach
  - Joint Probability Method (JPM) – Bayesian Quadrature Optimal Sampling
  - StormSim – JPA of storm forcing parameters and storm response
  - CSTORM-MS – modeling of storm suite
  - Sea level change and astronomical tide scenarios incorporated in the analysis

Statistical Analysis of Extreme Storm Tides

Phase I: Extremal Analysis of Storm Tide and Sea Level Change

Limitations of low-fidelity approach

- Response-based statistics
  - Analysis limited to gage measurements, high-water marks
  - Limited to historical occurrences (e.g., sparse hurricane landfalls, tracks)
  - Does not incorporate insight from storm-forcing probabilities
- Mixed storm populations
  - Extratropical and tropical storms, and hurricanes considered as single population
  - Hurricane population is statistically underrepresented
- Short record lengths, data gaps, and missing storms

Statistical Analysis of Extreme Storm Tides

StormSim is an extremal statistical analysis and storm simulation software system.

Integrated framework of Matlab® routines

Has been utilized in several recent studies, including:

- **USACE Districts and FEMA coastal risk analysis,**
- **R&D applications,**
- **coastal planning and engineering, and**
- **emergency management.**

Statistical Analysis of Extreme Storm Tides

StormSim – Summary of Capabilities

- Joint probability analysis (JPA) of extratropical and tropical storms / hurricanes.
- Historical data censoring and pre-processing
  - HURDAT2, NOAA-NOS gages, NDBC buoys, others
- Extremal analysis (marginal / conditional distributions)
- Monte Carlo simulation and Bootstrap methods
- Time-dependant, life-cycle analysis
- Simulation of water level and wave climate
  - Sea level change (SLC)

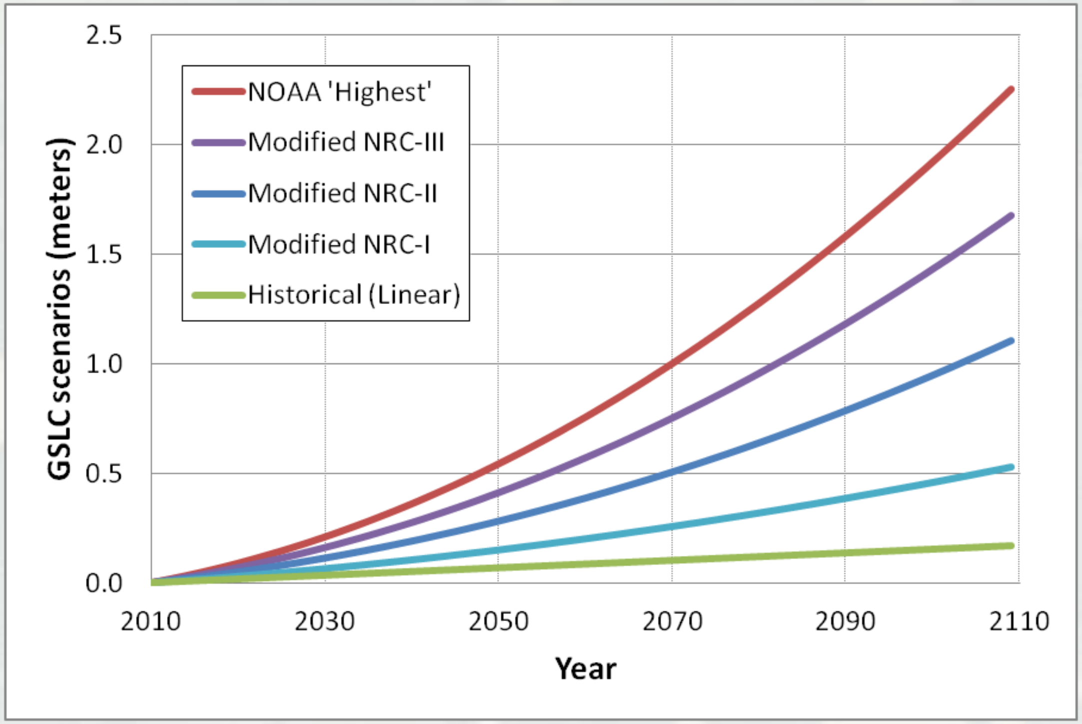
Statistical Analysis of Extreme Storm Tides

NOAA-NOS Water Level Gages (total: 23)

Region I	Region II	Region III
1. Eastport, ME 2. Bar Harbor, ME 3. Portland, ME 4. Boston, MA 5. Woods Hole, MA 6. Nantucket Island, MA 7. Newport, RI 8. Providence, RI 9. New London, CT	10. Montauk Point Light, NY 11. Kings Point, NY 12. The Battery, NY 13. Sandy Hook, NJ 14. Atlantic City, NJ 15. Cape May, NJ	16. Lewes, DE 17. Cambridge, MD 18. Baltimore, MD 19. Annapolis, MD 20. Solomon Island, MD 21. Washington, DC 22. Sewells Point, VA 23. Chesapeake Bay Bridge Tunnel, VA

Statistical Analysis of Extreme Storm Tides

USACE/NOAA Sea Level Change Scenarios



References: USACE 2011: Sea Level Change Considerations for Civil Works Programs
NOAA 2012: Global Sea Level Rise Scenarios for the United States National Climate Assessment

Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

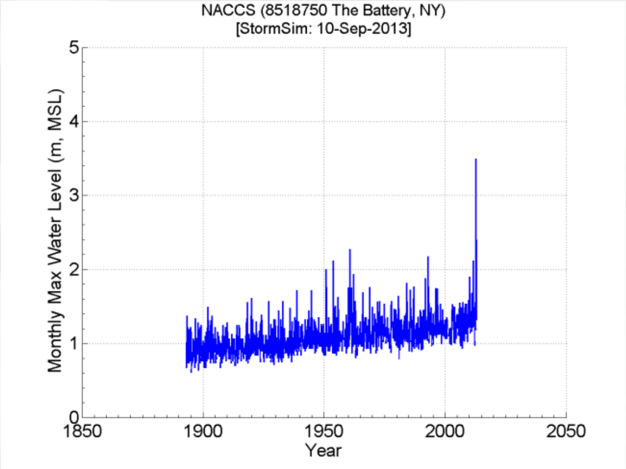
- Extremal analysis of measured water levels
  - Hourly and monthly maximum data (Data gap filling)
  - Generalized Pareto distribution (GPD)
    - Maximum likelihood fitting method (MLM)
  - Bootstrapping – compute mean, confidence limits
- Monte Carlo Life-Cycle Simulation (Double-Loop)
  - Inner loop
    - 100-year life-cycle simulation
    - Storm tide = astronomical tide + storm surge + SLC scenario
  - Outer loop
    - 10,000 simulations of inner loop

Statistical Analysis of Extreme Storm Tides

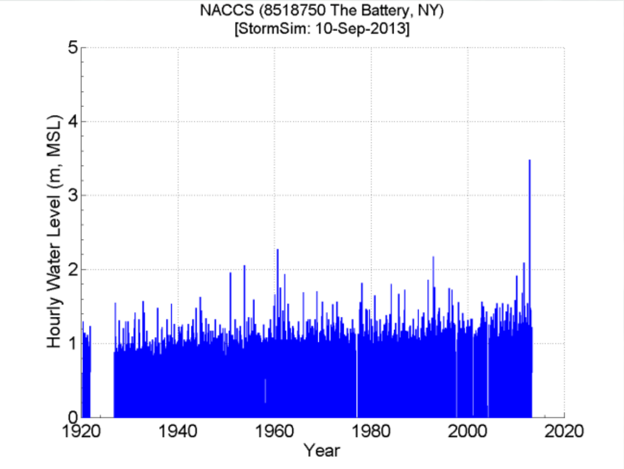
Phase I: General Methodology

- Extremal analysis of measured water levels
  - ► Maximize the use of available data – No extreme storms missing

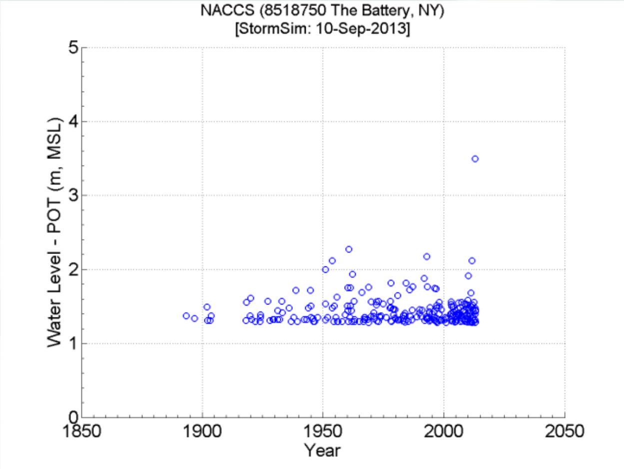
Monthly Max



Hourly Data



Merged POT Data



Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

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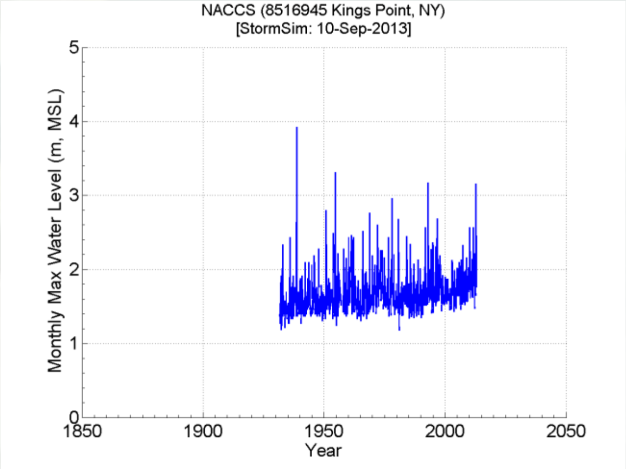
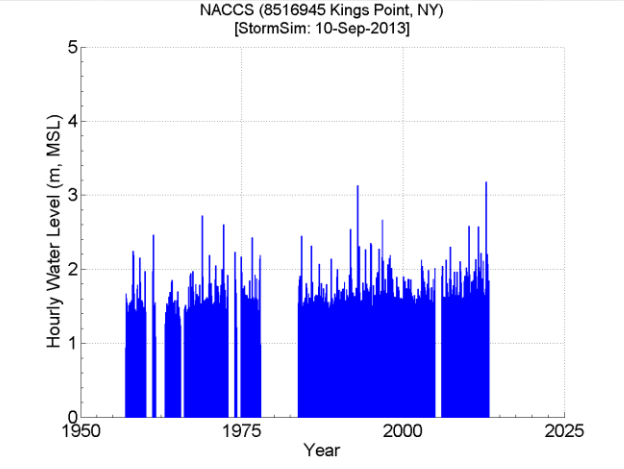
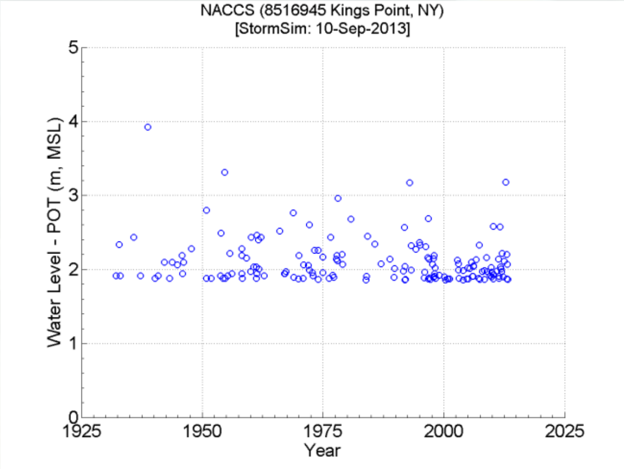


Hourly Data



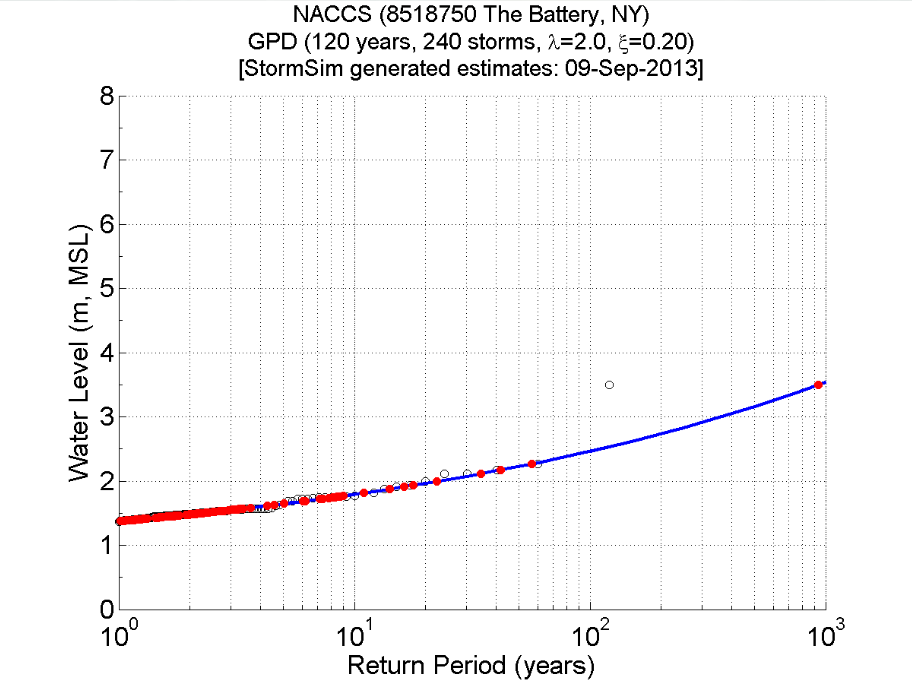
Merged POT Data

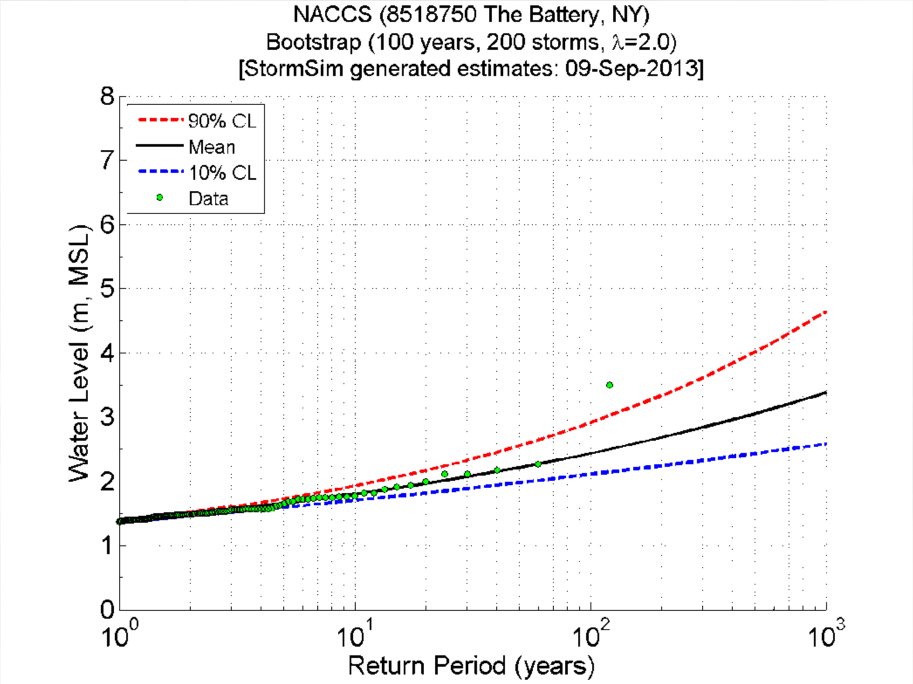


Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

- Extremal analysis of measured water levels
  - Generalized Pareto Distribution – Bootstrapping/MCS





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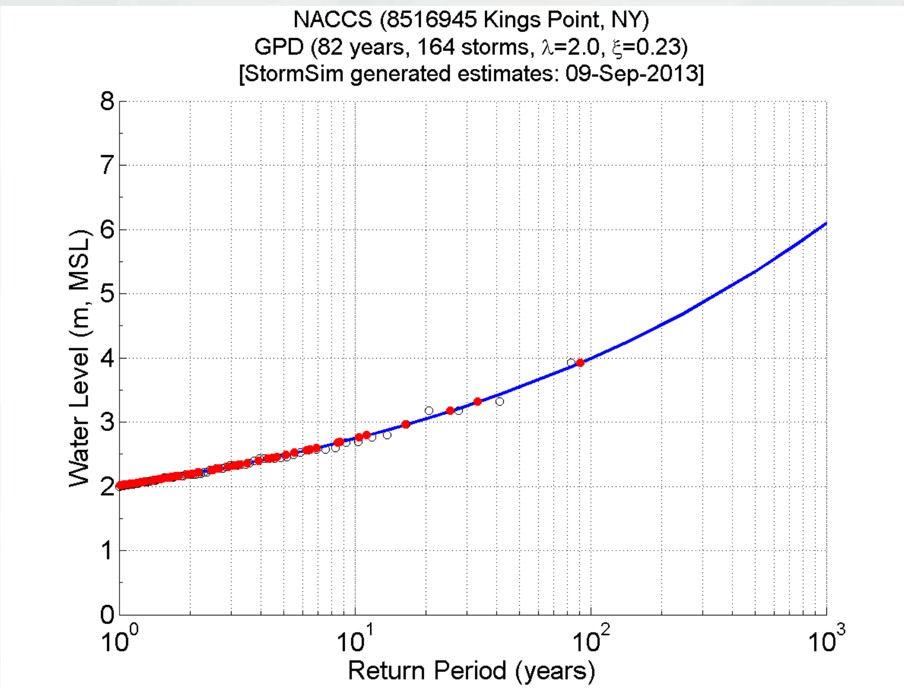
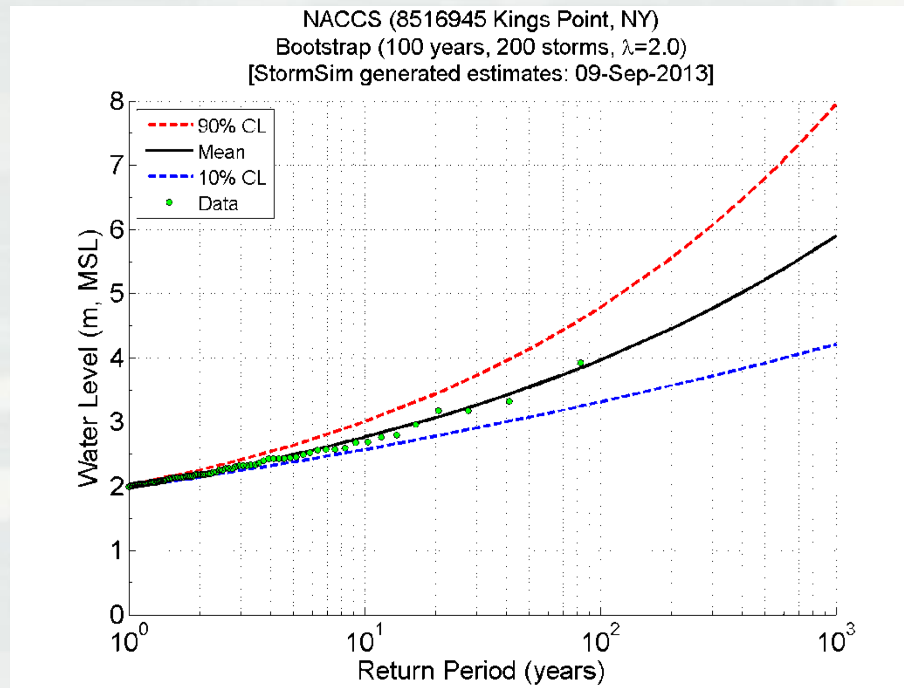
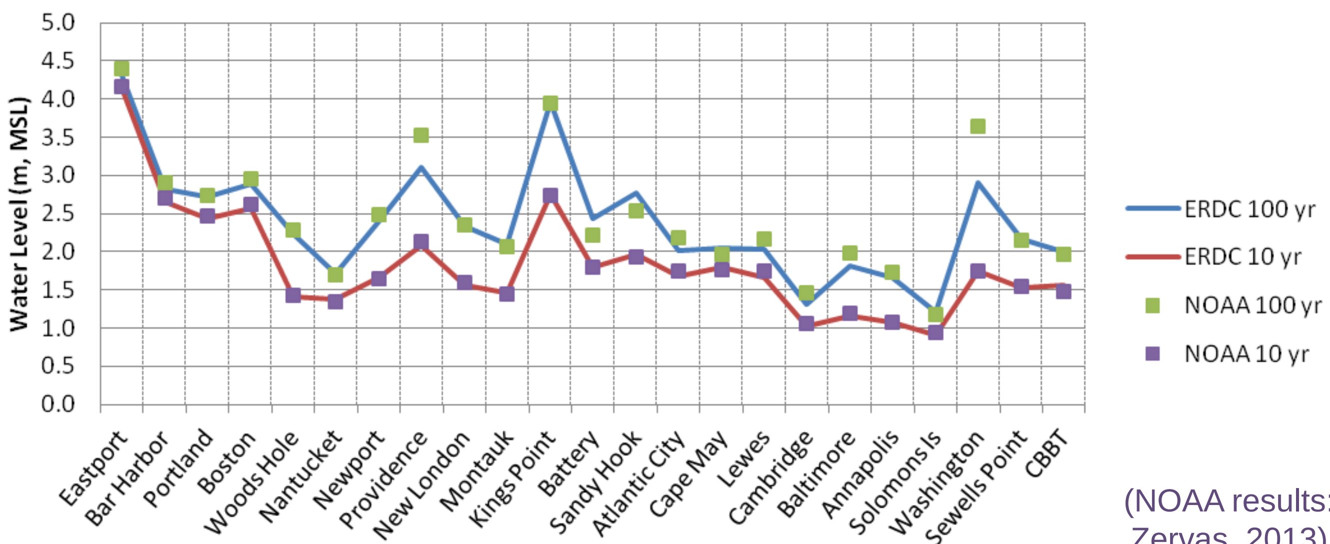




Validation of Extremal Analysis Results

ERDC GPD-MC vs. NOAA GEV results



(NOAA results: Zervas, 2013)

RP = 10 yr

- Differences for all 23 gages < 0.10 m; RSMD = 0.04 m

RP = 100 yr

- Differences for 21 of 23 gages < 0.25 m; RMSD = 0.11 m
- Exceptions: Providence, RI = 0.42 m; Washington, DC = 0.75 m

Statistical Analysis of Extreme Storm Tides

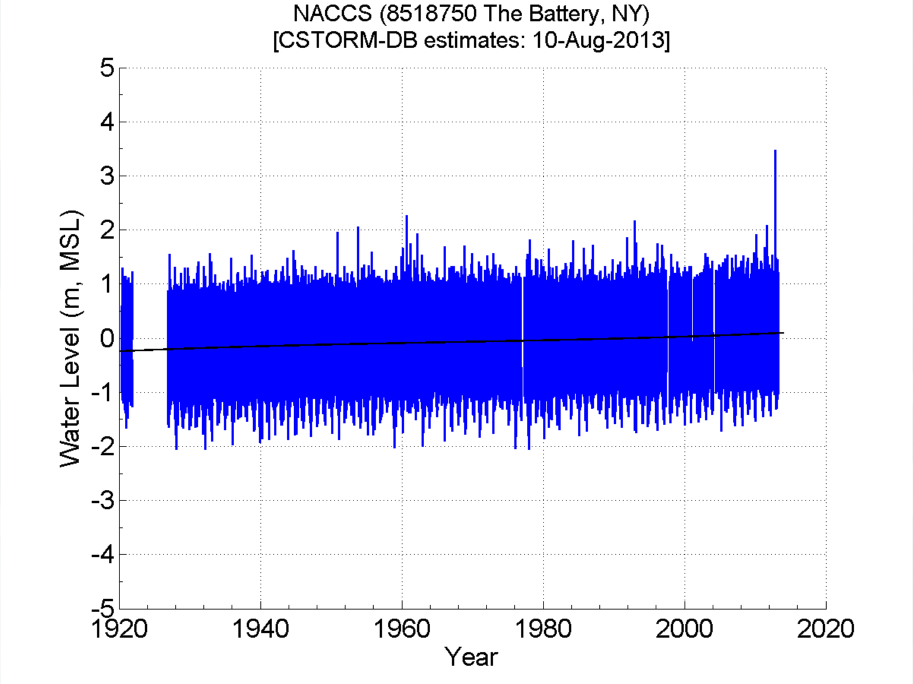
Phase I: General Methodology

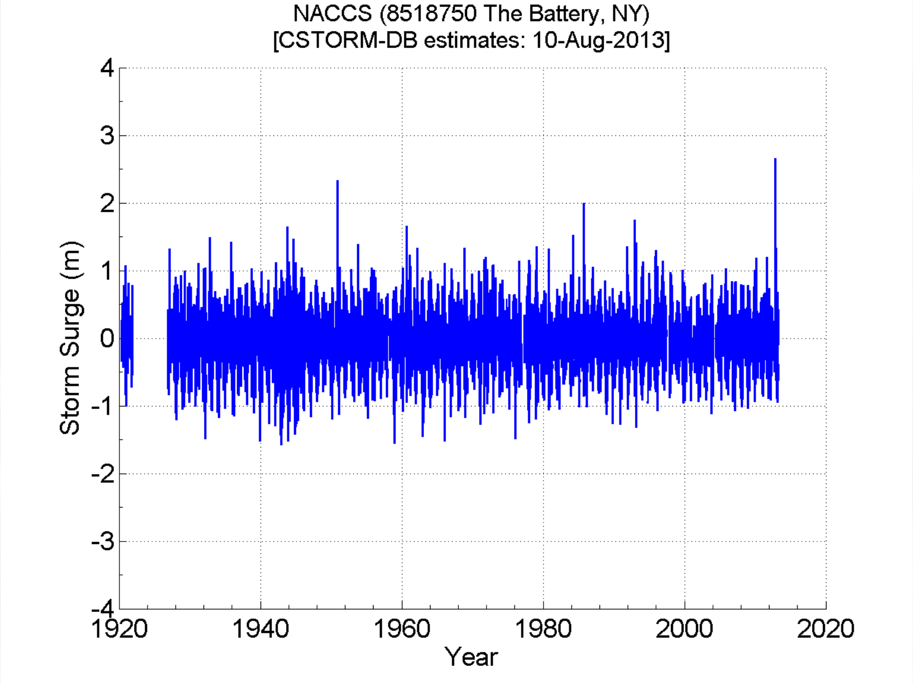
- Monte Carlo Life-Cycle Simulation
  - ▸ Uses only hourly WL, decomposed into:
    - Storm surge/residuals
    - Astronomical tide
    - Sea level change
  - ▸ Inner loop (1^{st}) = 100-year life-cycle
    - WL = random surge + random tide + RSLC(t)
    - $RSLC(t) = (LSLC_{gage} – GSLC_{mean}) + GSLC(t)_{scenario}$
    - Five SLC scenarios
  - ▸ Outer loop (2^{nd}) = 10,000 simulations of the 1^{st} loop

Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Storm Surge/Residuals = Measured WL (detrended) – Predicted WL

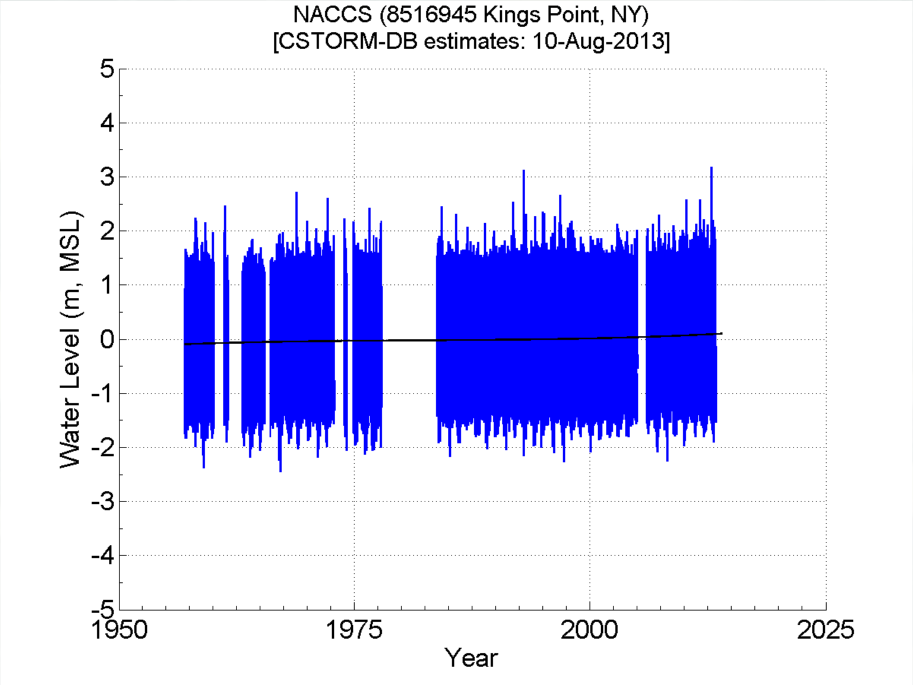


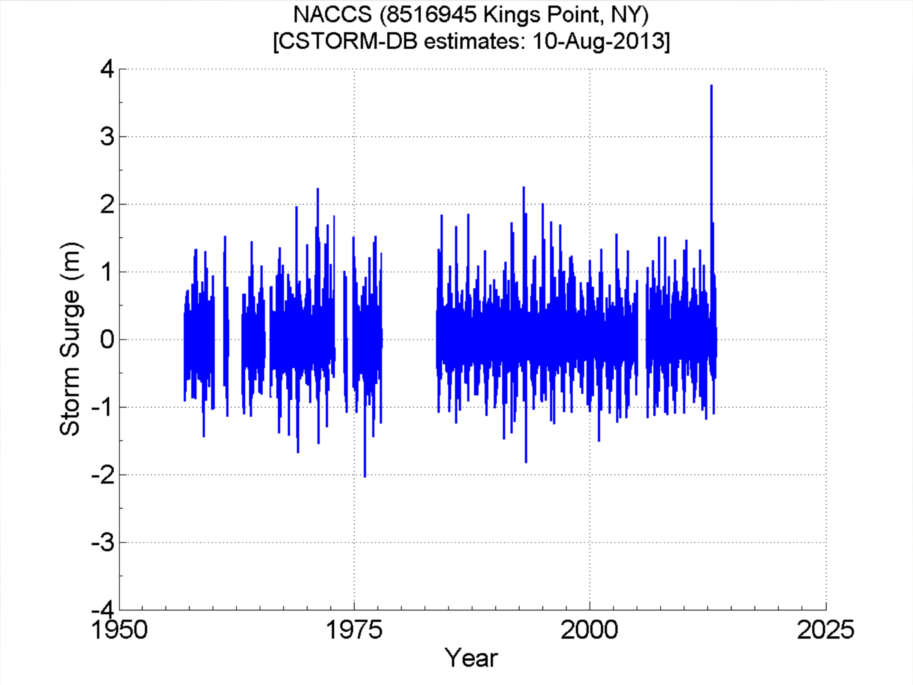


Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Storm Surge/Residuals = Measured WL (detrended) – Predicted WL

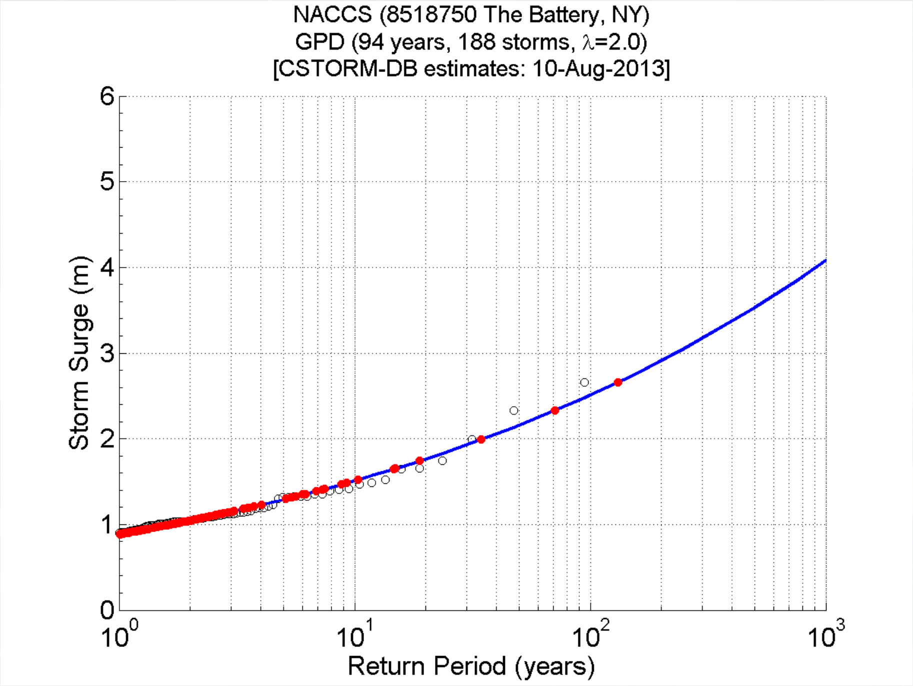


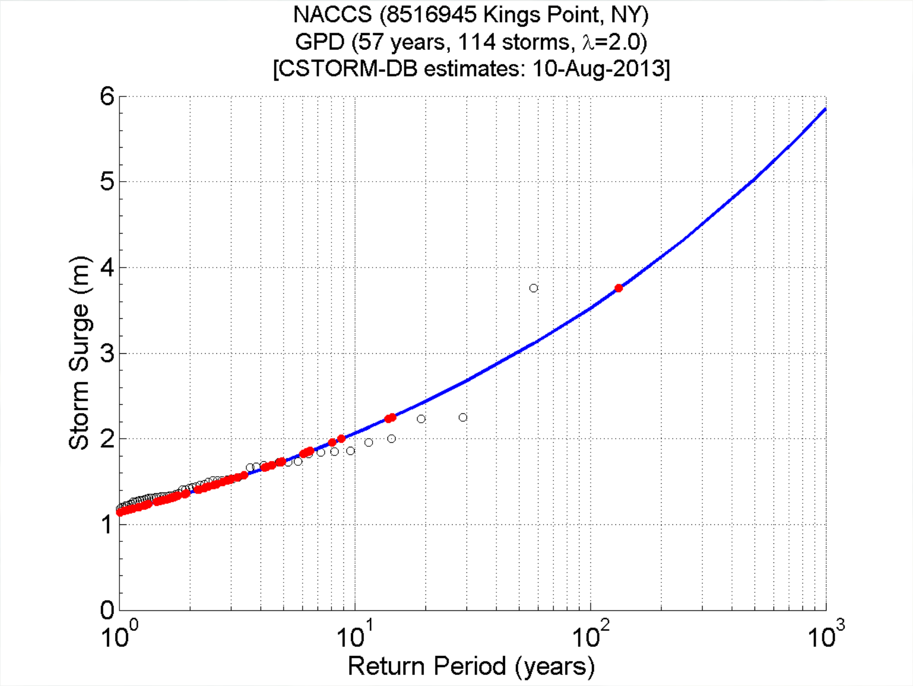


Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Storm Surge – GPD

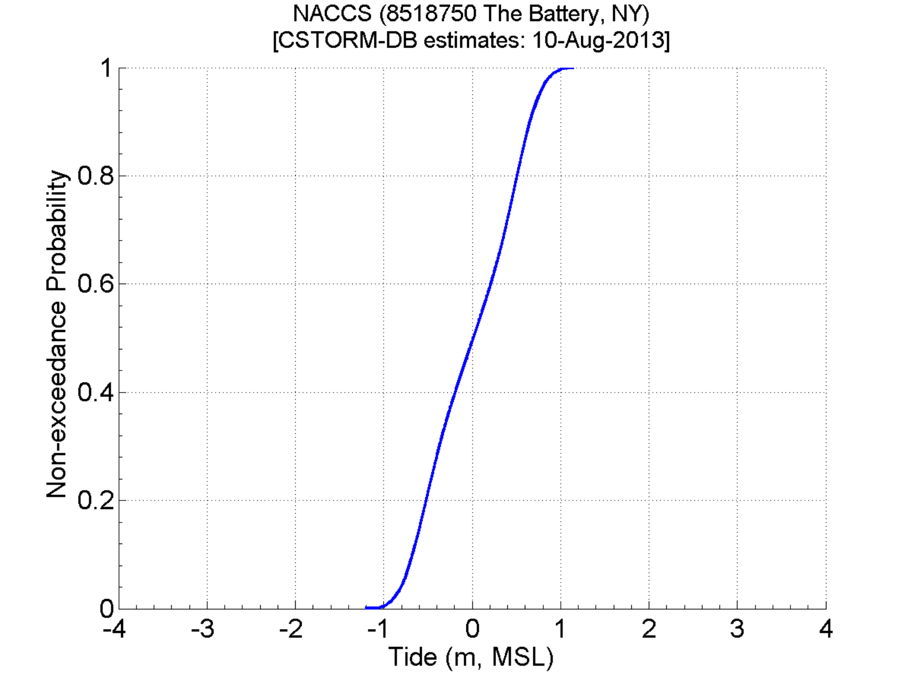


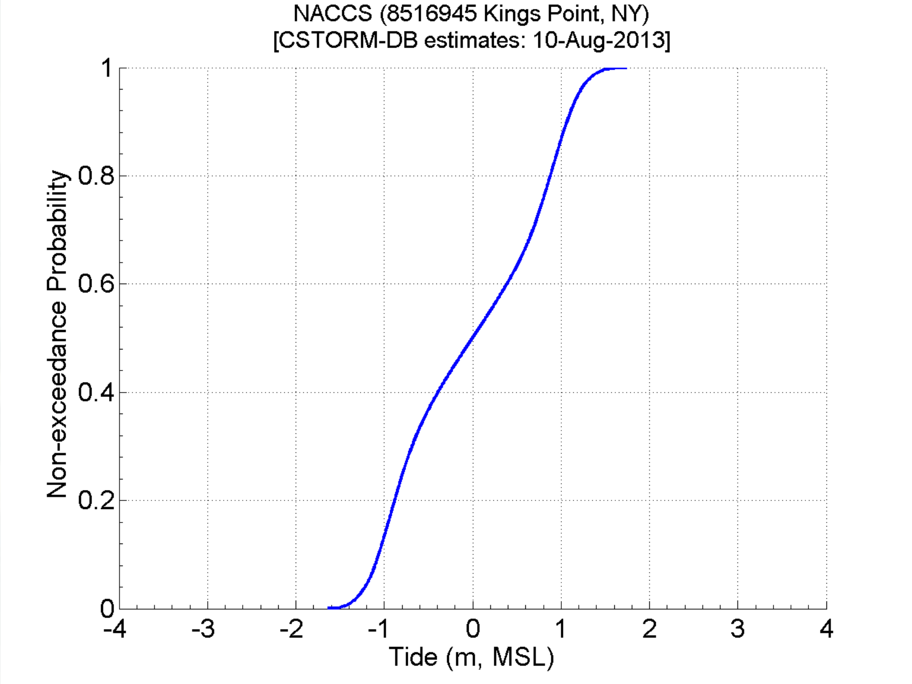


Statistical Analysis of Extreme Storm Tides

Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Astronomical Tide – Empirical CDF





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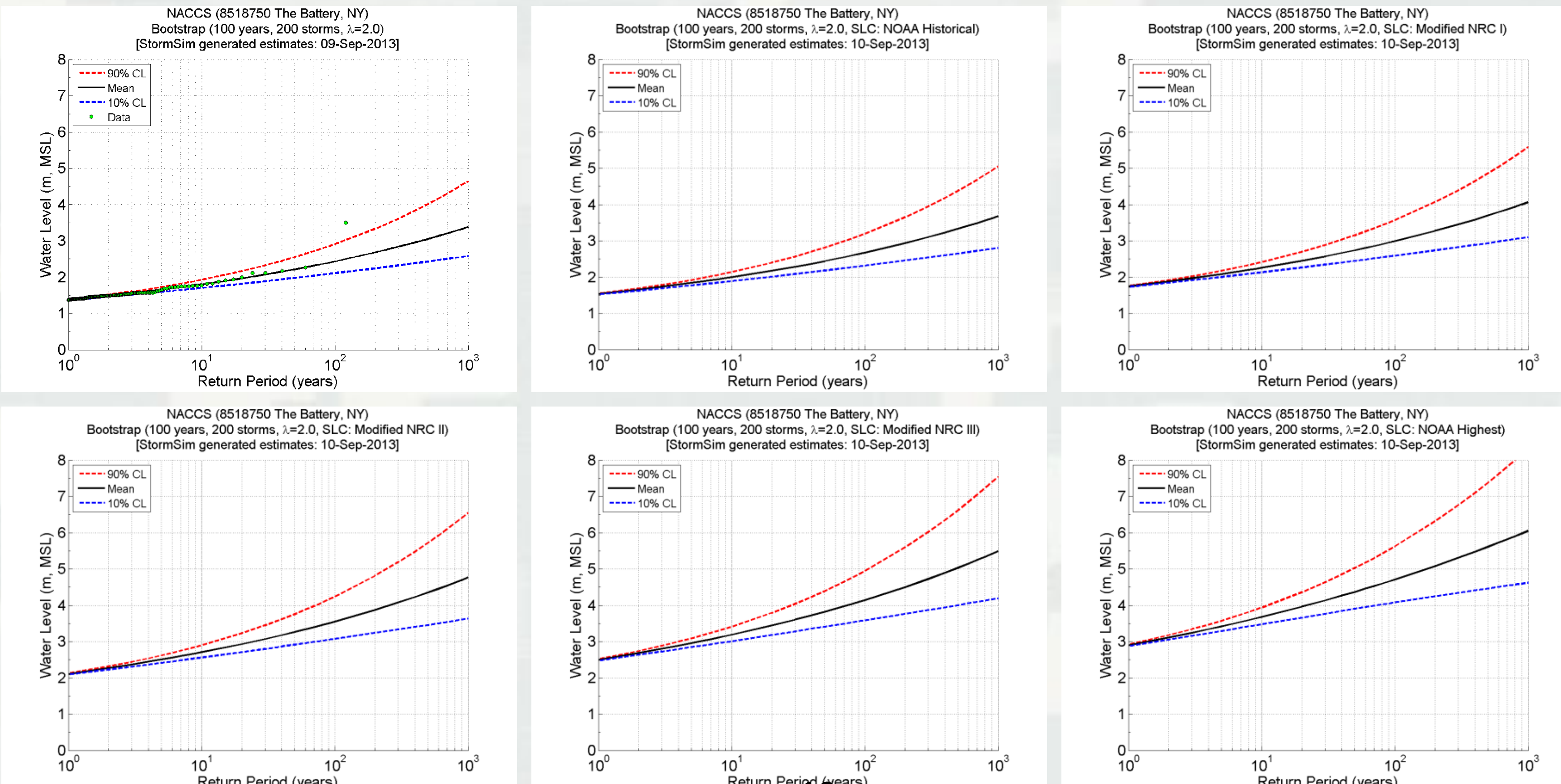
Monte Carlo Life-Cycle Simulation



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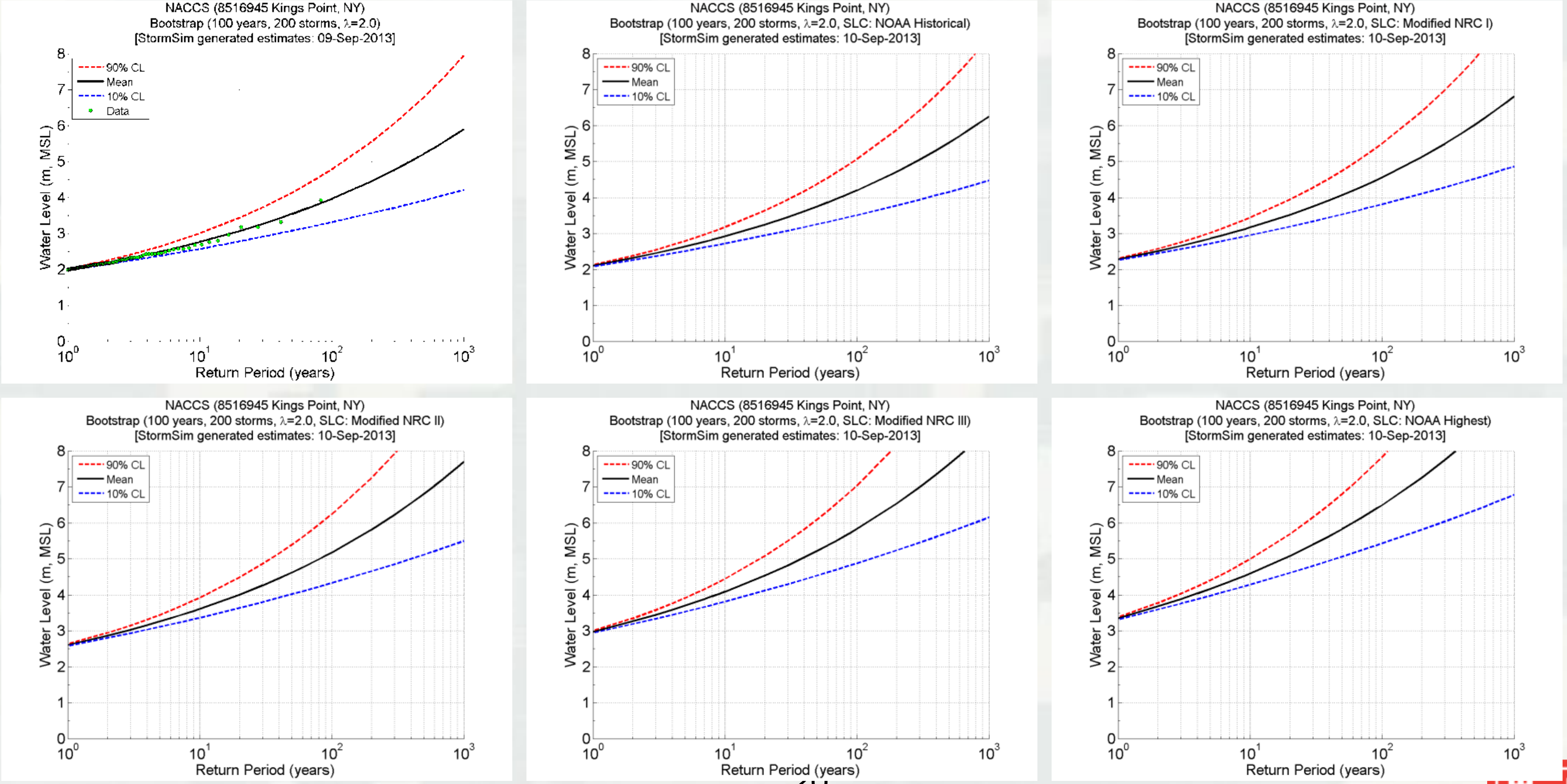
Monte Carlo Life-Cycle Simulation

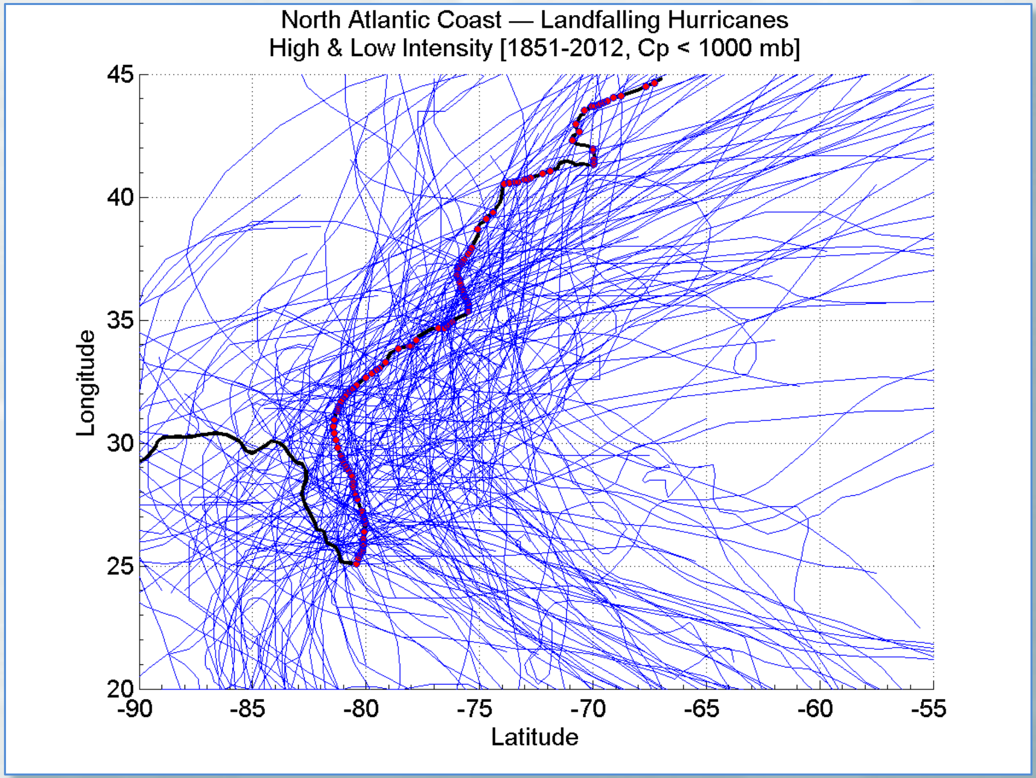


Statistical Analysis of Extreme Storm Tides

Path Forward

- **Phase I**
  - Technical Report - final draft
- **Phase II**
  - Extratropical storms
    - Storm selection process
    - Composite Storm Set (CSS) methodology [Nadal-Caraballo et al. 2012]
  - Hurricanes
    - Marginal distribution of storm forcing parameters
    - Joint probability analysis
    - Definition of synthetic storm suite

Thank you…



North Atlantic Coast — Landfalling Hurricanes
High & Low Intensity [1851-2012, Cp < 1000 mb]
45
40
35
30
25
20
Longitude
-90
-85
-80
-75
-70
-65
-60
-55
Latitude