Statistical Analysis of Extreme Storm Tides

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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
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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.
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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)

<table>
<thead>
<tr>
<th>Region I</th>
<th>Region II</th>
<th>Region III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Eastport, ME</td>
<td>10. Montauk Point Light, NY</td>
<td>16. Lewes, DE</td>
</tr>
<tr>
<td>7. Newport, RI</td>
<td>15. Cape May, NJ</td>
<td>22. Sewells Point, VA</td>
</tr>
<tr>
<td>8. Providence, RI</td>
<td></td>
<td>23. Chesapeake Bay Bridge Tunnel, VA</td>
</tr>
<tr>
<td>9. New London, CT</td>
<td></td>
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</tbody>
</table>
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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
### 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
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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
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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**

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

(NOAA results: Zervas, 2013)
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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\textsuperscript{st}) = 100-year life-cycle
    - WL = random surge + random tide + RSLC(t)
    - RSLC(t) = \((\text{LSLC}_{gage} - \text{GSLC}_{mean}) + \text{GSLC}(t)_{scenario}\)
    - Five SLC scenarios
  - Outer loop (2\textsuperscript{nd}) = 10,000 simulations of the 1\textsuperscript{st} loop
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Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Storm Surge/Residuals = Measured WL (detrended) – Predicted WL
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Phase I: General Methodology

- Monte Carlo Life-Cycle Simulation
  - Storm Surge/Residuals = Measured WL (detrended) – Predicted WL
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Phase I: General Methodology

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

![Graphs showing storm surge vs return period for two locations with GPD analysis.](image)
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Phase I: General Methodology

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

![Graphs showing non-exceedance probability vs tide](image-url)
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Monte Carlo Life-Cycle Simulation
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Monte Carlo Life-Cycle Simulation

[Graphs showing water level versus return period for different scenarios]
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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...