Probabilistic Assessment of Coastal Storm Hazards

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Probabilistic Coastal Hazard Assessment (PCHA)

- PCHA is a probabilistic framework for the assessment of coastal hazards, including uncertainty quantification.

\[
\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}
\]

\[
\text{Hazard} = \text{Severity} \times \text{Likelihood}
\]

Probable Maximum Hurricane, Standard Project Hurricane ≠ Risk

Bottom line: state-of-the-art risk assessment must be done within a probabilistic context
Probabilistic Coastal Hazard Assessment (PCHA)

- Hazard Curve
  - Annual Exceedance Probability (AEP) of a given coastal hazard e.g., water level, storm surge, wave height, wave run-up, overtopping
### Probabilistic Coastal Hazard Assessment (PCHA)

- Regional Variations

<table>
<thead>
<tr>
<th>Region</th>
<th>Tropical Cyclones</th>
<th>Extratropical Cyclones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Mexico</td>
<td>Tropical Cyclones</td>
<td>Extratropical Cyclones</td>
</tr>
<tr>
<td>Atlantic Coast</td>
<td>Tropical &amp;</td>
<td>Extratropical Cyclones</td>
</tr>
<tr>
<td></td>
<td>Extratropical</td>
<td></td>
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<tr>
<td></td>
<td>Cyclones</td>
<td></td>
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<tr>
<td>Great Lakes</td>
<td></td>
<td></td>
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<tr>
<td>Pacific Coast</td>
<td></td>
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</tbody>
</table>

Type of probabilistic model is region-specific due to different dominant forcing.

(TCs considered for Southern California)
Probabilistic Coastal Hazard Assessment (PCHA)

- **Examples**

  - **USACE’s coastal risk assessment studies**
    - Louisiana Coastal Protection and Restoration, 2009
    - Coastal Texas Storm Surge Studies, 2011 & 2017
    - North Atlantic Coast Comprehensive Study, VA to ME
    - South Atlantic Coast Comprehensive Study*
      - Phase I: NC to South FL, *PR & USVI; Phase II: South FL to MS

  - **FEMA’s National Flood Insurance Program (NFIP)**
    - Risk MAP (Mapping, Assessment & Planning)

  - **U.S. Nuclear Regulatory Commission (NRC)**
    - Probabilistic flood hazard assessment of nuclear power plants
Probabilistic Coastal Hazard Assessment (PCHA)

- Examples: Puerto Rico

**FEMA Coastal Study (2009)**

**Climatology**
- 26 tropical cyclones from 1910 to 2004
- 2 transpositions of Hurricane Betsy’s track

**Probabilistic Model**
- Empirical Simulation Technique (EST)

**Numerical Models**
- PBL (wind and pressure), ADCIRC (storm surge)
Probabilistic Coastal Hazard Assessment (PCHA)

Joint Probability Analysis

vs. historical observations & EST

- **Problem**: Extreme coastal storms are rare, sparse, and not well represented in historical observation records.
ERDC/CHL’s PCHA

- **Approach/Outcome**
  - Develop probabilistic coastal hazard models and efficient synthetic-storm suites to maximize coverage of storm parameter and probability spaces.
  - Simulate storms with high-resolution models.
  - Compute joint probability of storm forcing and responses, including uncertainty.
  - Distribute data and statistical results through simple-to-use web tool.

* Can account for sea level change (SLC) scenarios and future climate changes (e.g., storm frequency and intensity).
ERDC/CHL’s PCHA

**Storm Sampling**
- Characterization of Storm Climate (Forcing)
  - Tropical Cyclones (Synthetic)
  - Extratropical Cyclones (Historical)
- Development of JPM Storm Set
- Development of Composite Storm Set

**Climate and Hydro Modeling**
- PBL Cyclone Model (Wind and Pressure Fields)
- WAM (Regional)
- ADCIRC
  - CSTORM-MS Coupler
  - STWAVE (Nearshore)
- CSTORM

**Response Statistics**
- Combined Joint Probability
- Annual Exceedance Probability Confidence Levels

**CHS**

- Water level (storm surge, astronomical tide, SLC)
- Wind speed, direction, currents
- Wave height, period, direction

- StormSim
ERDC/CHL’s PCHA

- Tropical Cyclones – Parameterization

\[ \text{Response} = f(\hat{x}) = f(x_0, \Delta p, R_{\text{max}}, V_f, \theta) \]
ERDC/CHL’s PCHA

- Synthetic Tropical Cyclone Suite (NACCS Example)

- 130 unique master tracks (MT) from NC to Canada
- Average of 8 TC per MT
- Along-track parameter variations are Latitude-dependent:
  - Δp
  - \( R_{max} \)
  - Holland B

Tropical Cyclones
- 1,050 synthetic

Extratropical Cyclones
- 100 historical

Total Cyclones
- 1,150
**ERDC/CHL’s PCHA**

- **StormSim-GPM (Gaussian Process Metamodell)**

  - **Approach:** augmentation of the synthetic storm suite to refine the discretization of the joint probability distribution.
  - **Increases order of magnitude of synthetic tropical cyclones from 100-1,000 to 10,000-1,000,000**
  - **Reduces AEP uncertainty.**

\[
f(x_0, \Delta p, R_{\text{max}}, V_f, \theta) \Rightarrow [\text{training}] \Rightarrow \text{Response}
\]
ERDC/CHL’s PCHA

### Quantification of Uncertainty

- Meteorological modeling errors + track variation
- Hydrodynamic modeling errors
- Astronomical tide nonlinearity
- SLC nonlinearity

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>FEMA 2008 (m)</th>
<th>USACE 2011 (m)</th>
<th>FEMA 2014 (m)</th>
<th>NACCS (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrodynamic modeling</td>
<td>0.23</td>
<td>0.53 to 0.76</td>
<td>0.39</td>
<td>0.48</td>
</tr>
<tr>
<td>Meteorological modeling</td>
<td>0.36</td>
<td>0.07 to 0.30</td>
<td>0.54</td>
<td>0.38</td>
</tr>
<tr>
<td>Storm track variation</td>
<td>n/a</td>
<td>0.20 × wave setup</td>
<td>n/a</td>
<td>0.25</td>
</tr>
<tr>
<td>Holland B</td>
<td>0.15 × surge elevation</td>
<td>0.15 × surge elevation</td>
<td>n/a</td>
<td>0.15 × surge elevation</td>
</tr>
<tr>
<td>Astronomical tide</td>
<td>0.20</td>
<td>n/a</td>
<td>n/a</td>
<td>variable</td>
</tr>
</tbody>
</table>
Probabilistic Coastal Hazard Assessment (PCHA) Products

- **Coastal Hazards System (CHS)** [https://chs.erdc.dren.mil](https://chs.erdc.dren.mil)
  - National coastal storm hazard data resource, spanning practical probability and forcing-parameter spaces.
  - Contains numerical and probabilistic modeling results including storm surge, astronomical tide, waves, currents, and wind.

- **StormSim** – stochastic storm simulation system
  - Used for joint probability analysis of coastal storm hazards.
  - GUI in development for select statistical tools.

- **CSTORM** system (POC: Dr. Chris Massey, Ms. Mary Cialone)
  - Standardizes application of high-resolution, highly skilled numerical models.
  - Consists of WAM for deep water waves, and tightly two-way coupled ADCIRC and STWAVE for storm surge and nearshore waves.
Probabilistic Coastal Hazard Assessment (PCHA) Studies

- **North Atlantic Coast Comprehensive Study (NACCS)**
  - Virginia to Maine
  - Statistical reanalysis (v.2) to be completed in 2017

- **Coastal Texas Study**
  - To be completed in summer of 2017

- **South Atlantic Coast Comprehensive Study (SACCS)**
  - Phase I (2018), Phase II (2019)
  - South Florida to North Carolina
    - including Puerto Rico and USVI
  - Mississippi to South Florida
Contact Information

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Questions?