14th International Workshop on Wave Hindcasting and Forecasting – Key West

ERDC
Engineer Research and Development Center

NACCS: Joint Probability Analysis of Coastal Storm Hazards

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Overview

Storm Selection

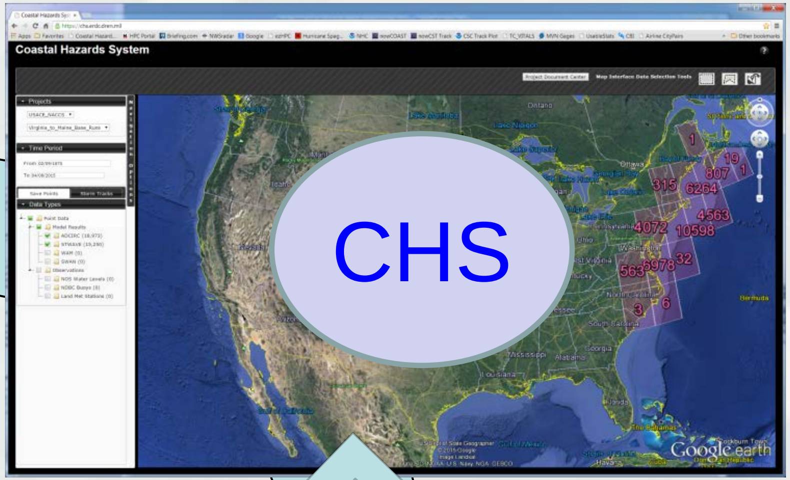
Characterization of Storm Climate (Forcing)

Tropical Cyclones (Synthetic)

Extra-tropical 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

Coupler

STWAVE (Nearshore)

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

Response Statistics

Combined Joint Probability

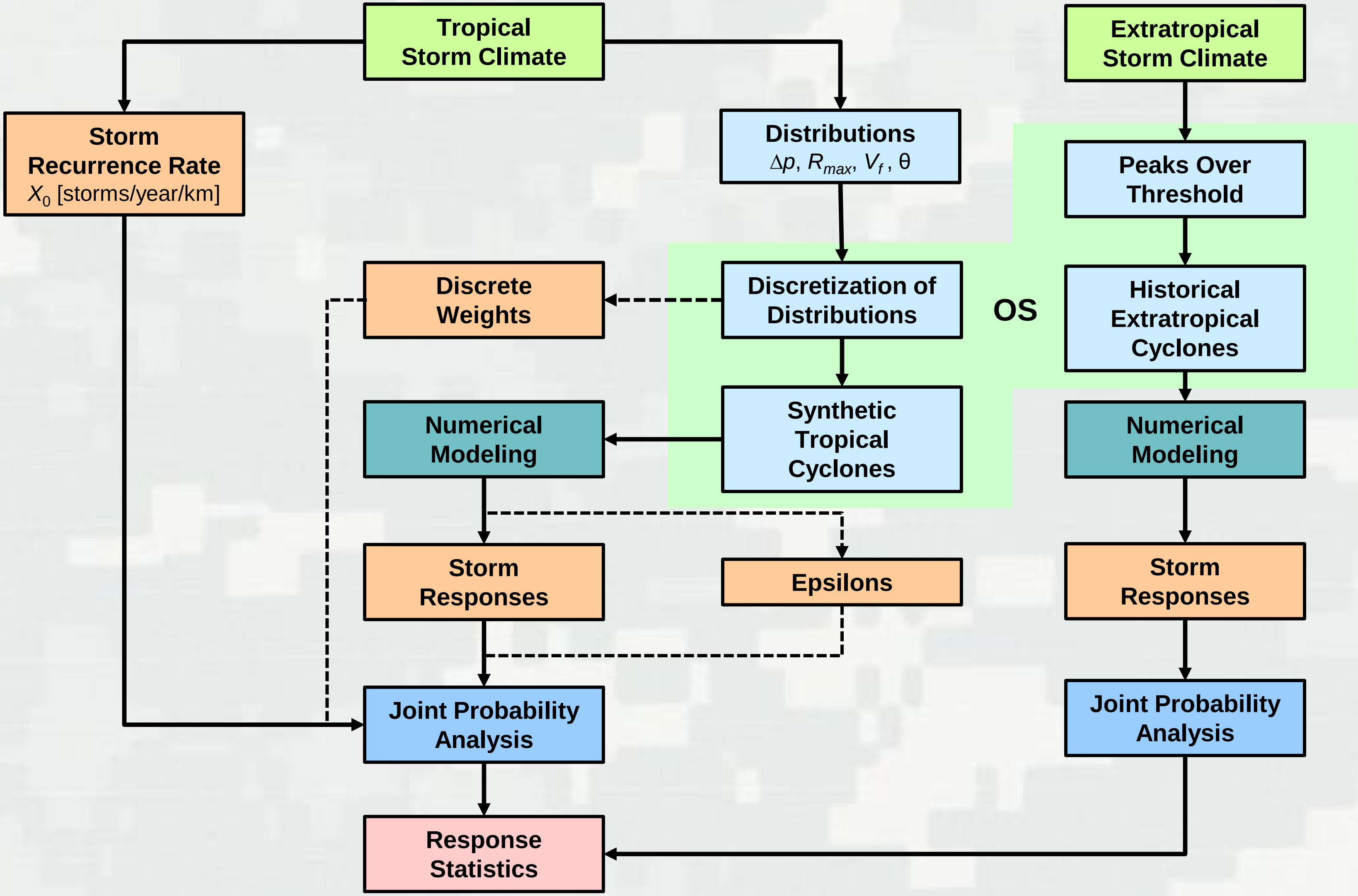
Annual Exceedance Probability
Average Recurrence Interval
Confidence Levels

Overview

Joint Probability Method

- Joint Probability Method with Optimal Sampling (JPM-OS) is standard-of-practice for quantifying flooding hazards of hurricane-prone coastal regions
- Overcomes main limitation of underrepresentation of TCs in historical water level observations
- Some JPM studies performed post-Katrina
  - Resio et al. - IPET/LACPR (2007/2009)
  - FEMA Mississippi Coastal Analysis Project (2008)
  - North Carolina Coastal Flood Analysis System (2008)
  - USACE/FEMA Texas Coastal Study (2011)
  - USACE/FEMA Region III Storm Surge Study (2013)
  - FEMA Region II JPA (2014)
  - USACE North Atlantic Coast Comprehensive Study (2015)

Joint Probability Analysis



Joint Probability Analysis

Tropical Storms (Resio et al. 2009)

JPM integral $$\lambda_{r(\hat{x})>r} = \lambda \int P[r(\hat{x}) > r|\hat{x}]\, f_{\hat{x}}(\hat{x})d\hat{x} \approx \sum_{i}^{n} \lambda_i\, P[r(\hat{x}) > r|\hat{x}]$$

$\lambda_{r(\hat{x})>r}$ = AEP of storm response r for forcing vector $\hat{x}$
$P[r(\hat{x}) > r|\hat{x}]$ = conditional probability that storm i with parameters $\hat{x}_i$ generates a response larger than r .
λ_i = mean annual storm rate. $f_{\hat{x}}(\hat{x})$ = joint pdf of $\hat{x}$

Forcing vector $\hat{x}_i$ includes:

- Track location (x_o)
- Heading direction (θ)
- Central pressure deficit (ΔP)
- Radius of maximum winds (R_{max})
- Translational speed (V_t)

Extratropical Storms (Nadal-Caraballo, Melby and Ebersole 2012)

Fit POT values with GPD using MLM and high frequency cutoff using Q-Q optimization

Storm Climatology

Historical Tropical Cyclones (TC)

- Sampling from NOAA HURDAT database
- 1938 – 2013 period
- TC intensities equal or greater than ΔP = 25 hPa (988 hPa)
- 90 TCs affecting the North Atlantic Coast region
- Subset of 45 TCs (landfalling and bypassing within 300 km)

Historical Extra-tropical Cyclones (XC)

- Sampling from NOAA CO-OPS non-tidal residuals (NTD)
- 1938 – 2013 period
- Data from 23 gages with 30+ years of hourly observations
- Statistical analysis is done separate from TCs; probabilities are combined in the end

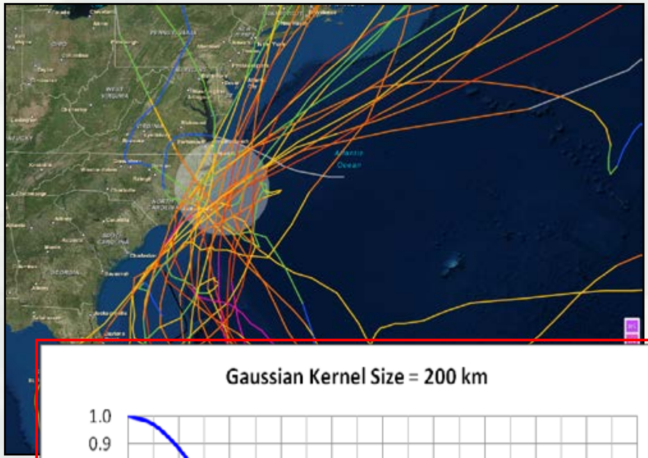
Storm Recurrence Rate

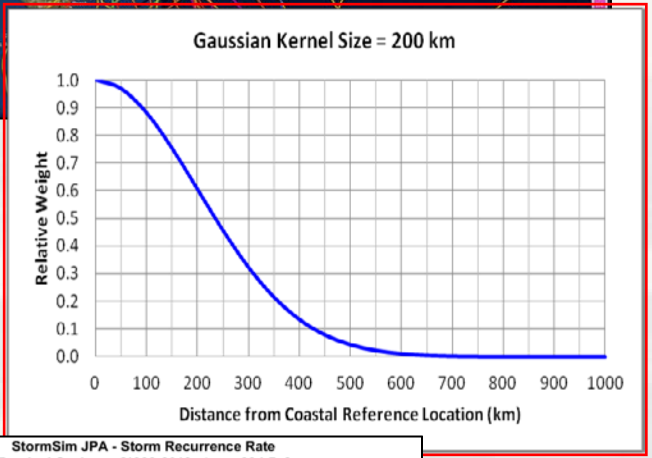
Storm Recurrence Rate (SRR)

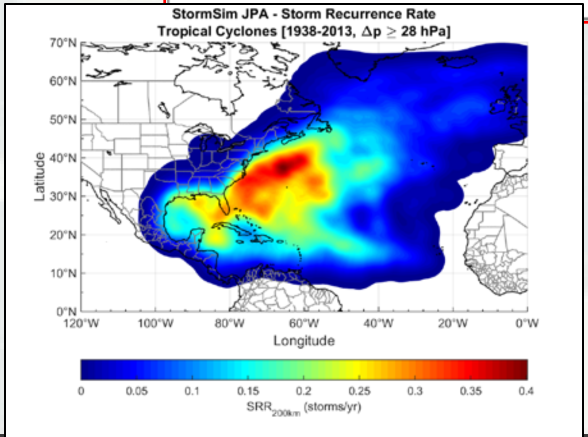
- # storms/year/km
- High intensity TCs: $\Delta P \geq 48$ hPa
- Low intensity TCs: $28 \leq \Delta P < 48$ hPa

Gaussian Kernel Function

- Chouinard and Liu (1997)
- Distance-weighted properties
  - ▸ Distance 0 km weight = 1.0
  - ▸ Distance 200 km weight = 0.6
  - ▸ Distance 800 km weight ~ 0.0



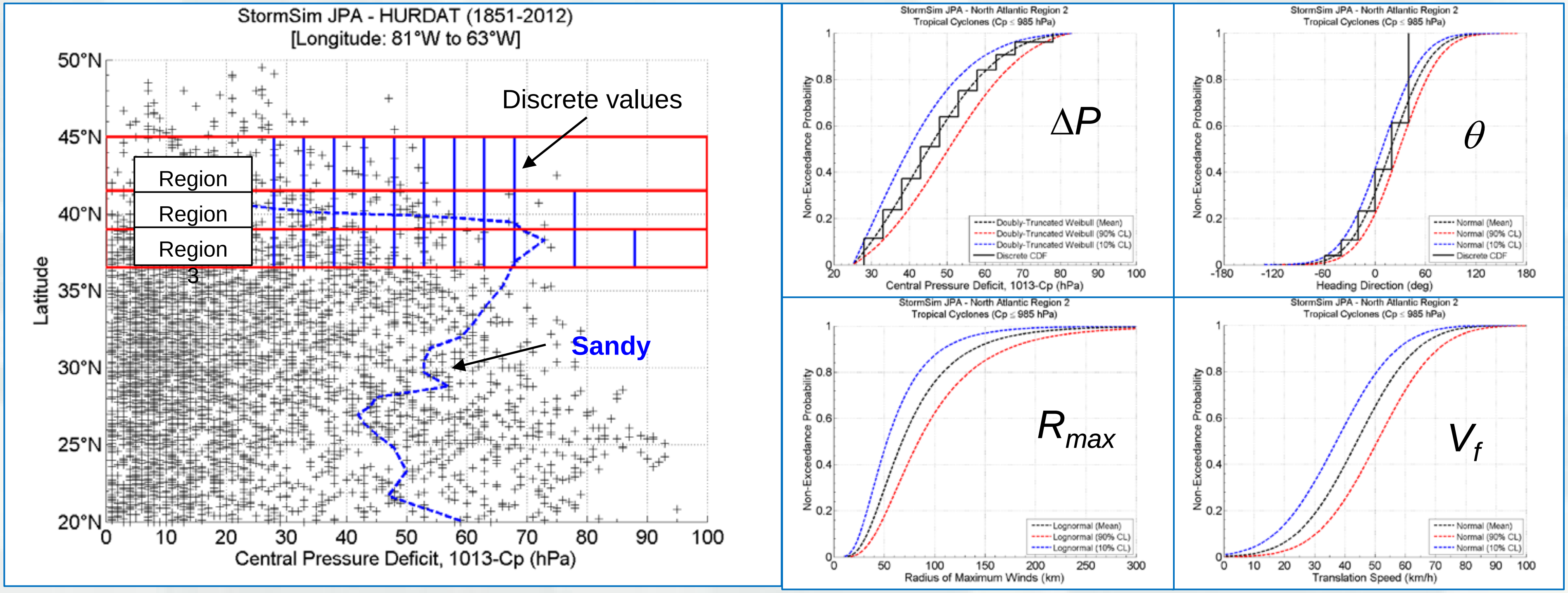




Parameterization of Tropical Cyclones

Non-Exceedance Probability Distributions

$$\text{Response} = f(\hat{x}) = f(X_0, \Delta P, R_{max}, V_f, \theta)$$



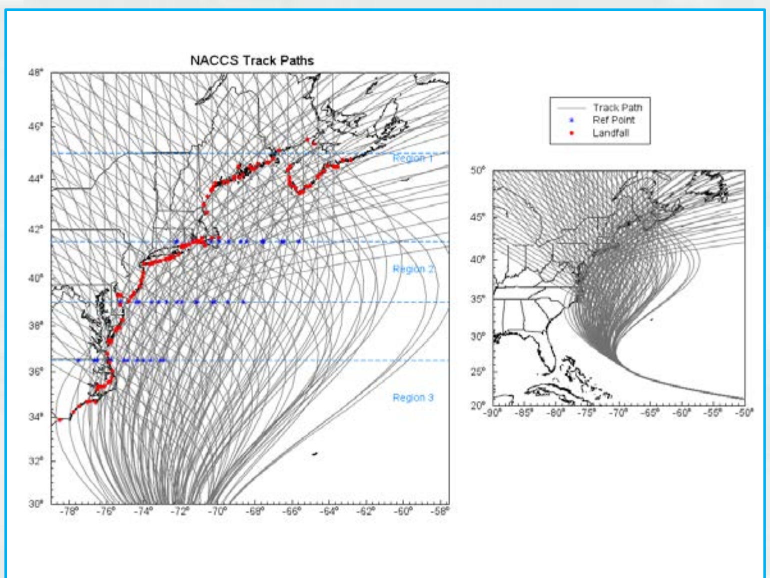
Hybrid Discretization: **Uniform: θ, ΔP ; Bayesian Quadrature: R_{max} , V_f**

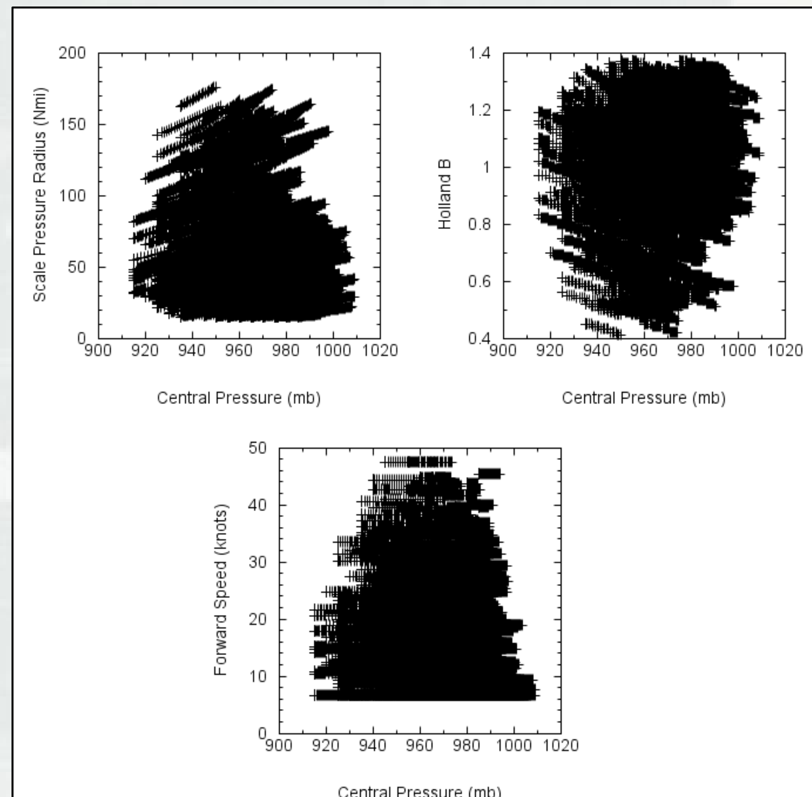
Final Storm Definition

- 1050 Synthetic Tropical Storms
- 130 unique master tracks, average 8 storms/track
- Latitude-dependent along-track parameter variations: ΔP, R_{max}, Holland B
- Within or near historical parameter space (e.g. min ΔP = 98 mb

for Isabel with 915 mb)

C_p: 915 – 985 mb, V_f: 12 – 88 km/hr
R_{max}: 25 – 174 km

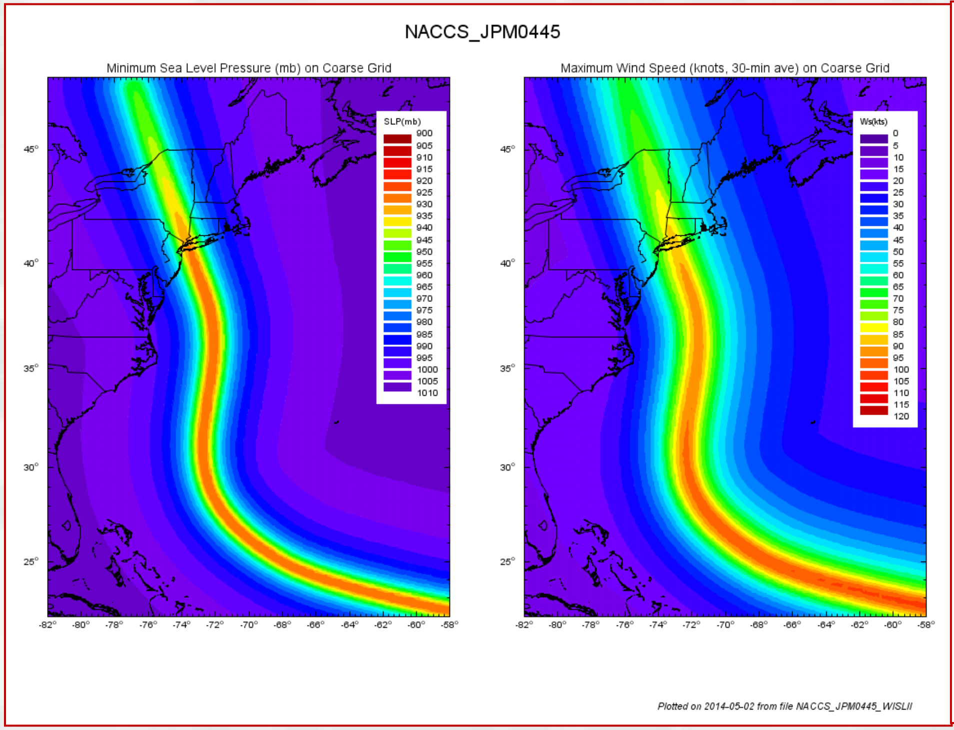


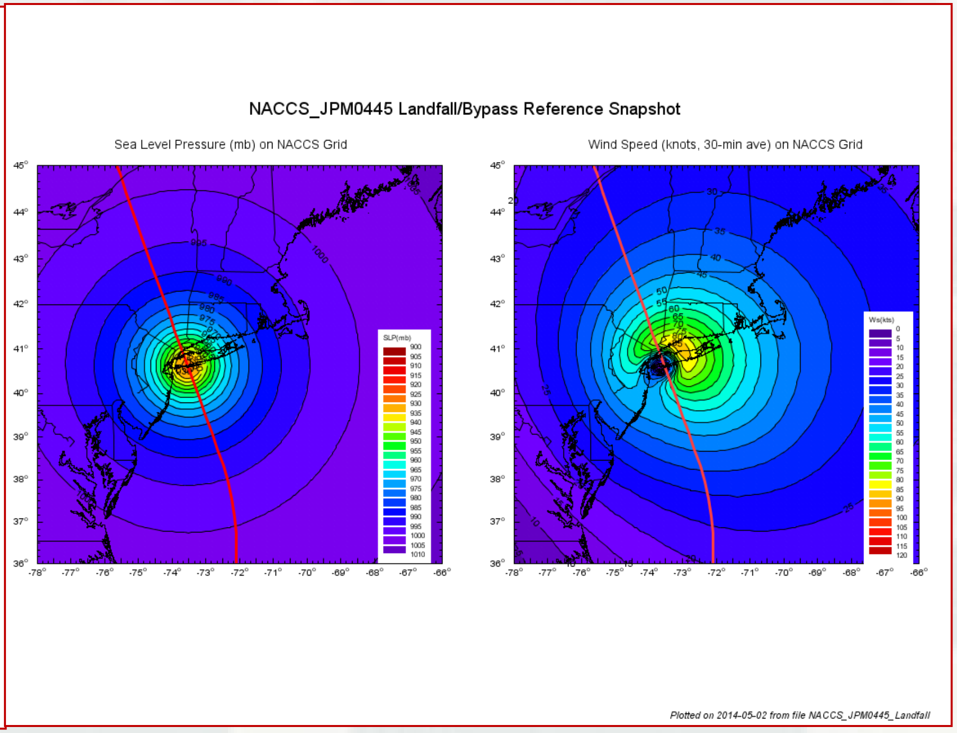


Numerical Simulation

Meteorological modeling of synthetic TCs

Wind and Pressure Fields (OWI 2014)





CSTORM-MS (WAM, ADCIRC-STWAVE)

Numerical Simulation

100 Historical Extratropical Storms
1050 Synthetic Tropical Storms
1150 Total Storm Population

Model Simulations: 1150 Storms x 3 conditions:

- Surge and wave only (base)
  - Expectation is linear superposition with uncertainty
  - Also modeled 96 random tide realizations
  - Computed statistics of total water level
- Surge and wave and tide
- Surge and wave and tide and sea level change

Total Storms simulated: 3450

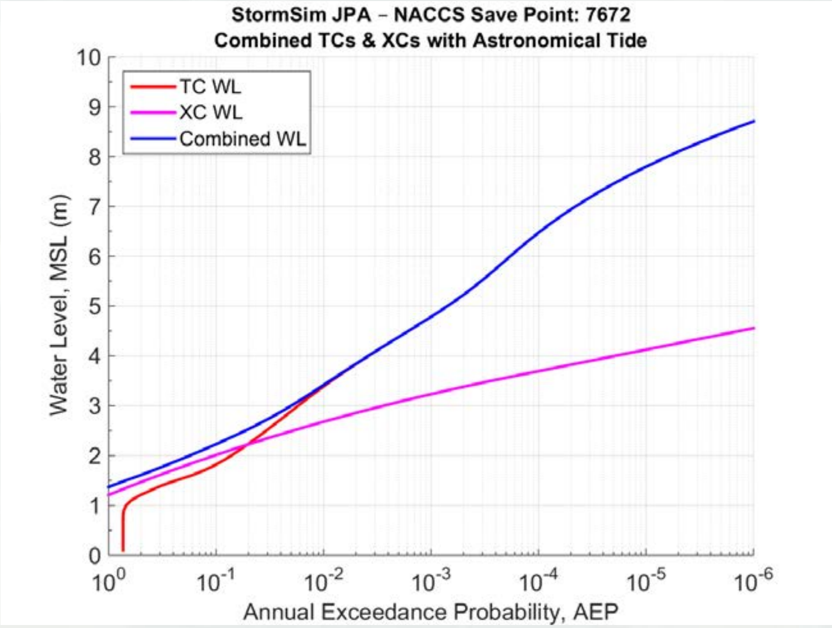
JP of Storm Responses

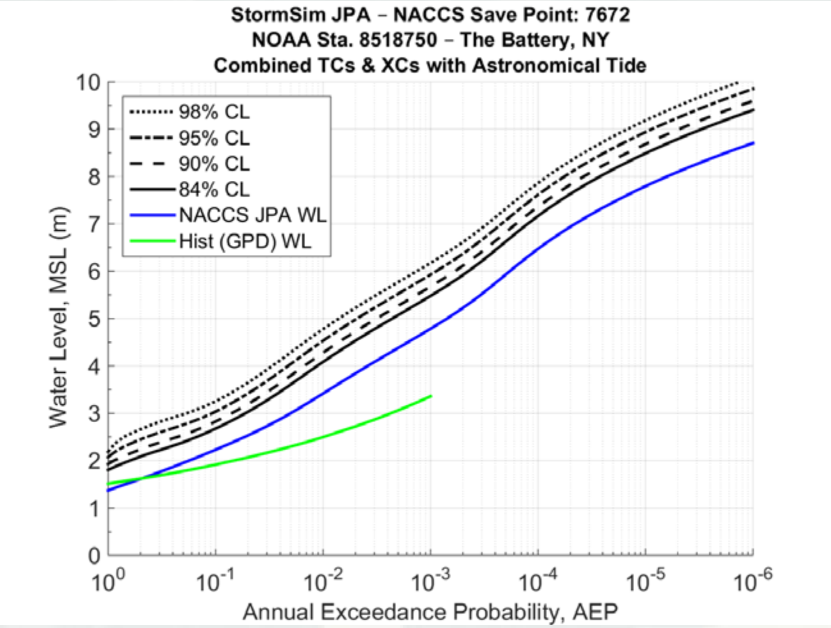
Response Probabilities

Storm probability mass = *f*(SRR, $f_{\hat{x}}(\hat{x})$,track spacing)

Discrete integration of CCDF is computed for a given response bin by summing storm probability masses for storms that produced a larger response

Combined Probabilities $P(CC) = P(TC) + P(XC)$





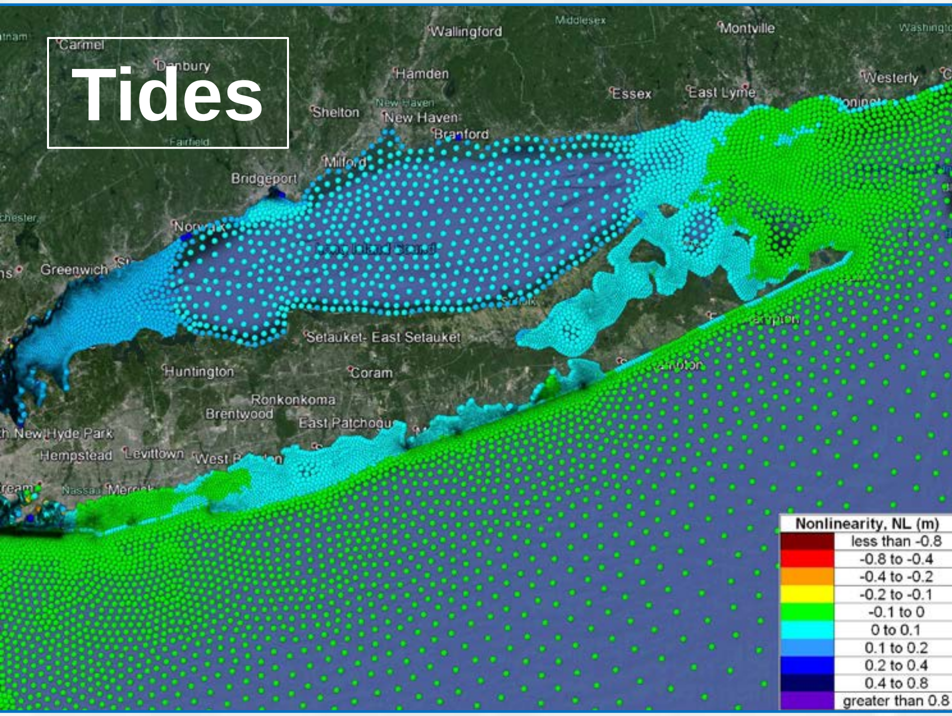
Uncertainty

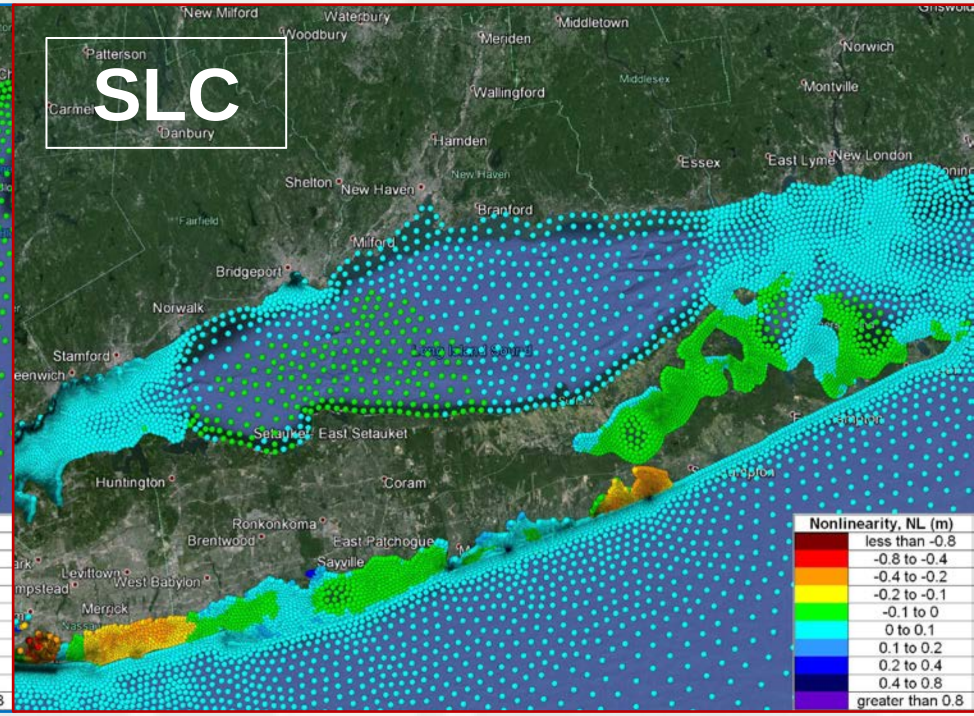
- Epistemic uncertainty of response (σ_r)
  - Expressed as confidence limits (e.g., NACCS approach):
    - $CL = \mu_r + z\sigma_r$, where CL = confidence limits, μ_r = mean value of a given TC response, and z = Z-score.

$$\sigma_\varepsilon = \sqrt{\sum_i^n \sigma_i^2}$$

Uncertainty	FEMA 2008 (m)	USACE 2011 (m)	FEMA 2014 (m)	NACCS (m)
Hydrodynamic modeling	0.23	0.53 to 0.76	0.39	0.48
Meteorological modeling	0.36	0.07 to 0.30	0.54	0.38
Storm track variation	n/a	0.20* × wave setup	n/a	0.25
Holland B	0.15* × surge elevation	0.15* × surge elevation	n/a	0.15* × surge elevation
Astronomical tide	0.20	n/a	n/a	variable

Nonlinear Residuals (NLR) due to Tides and SLC

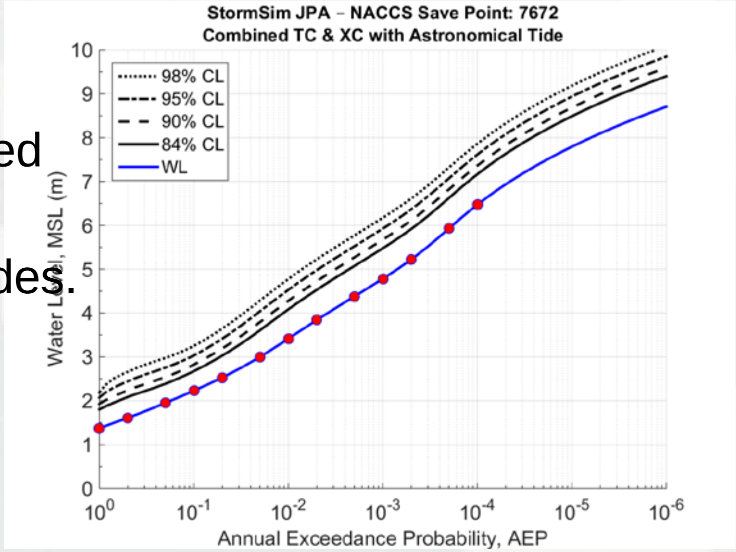


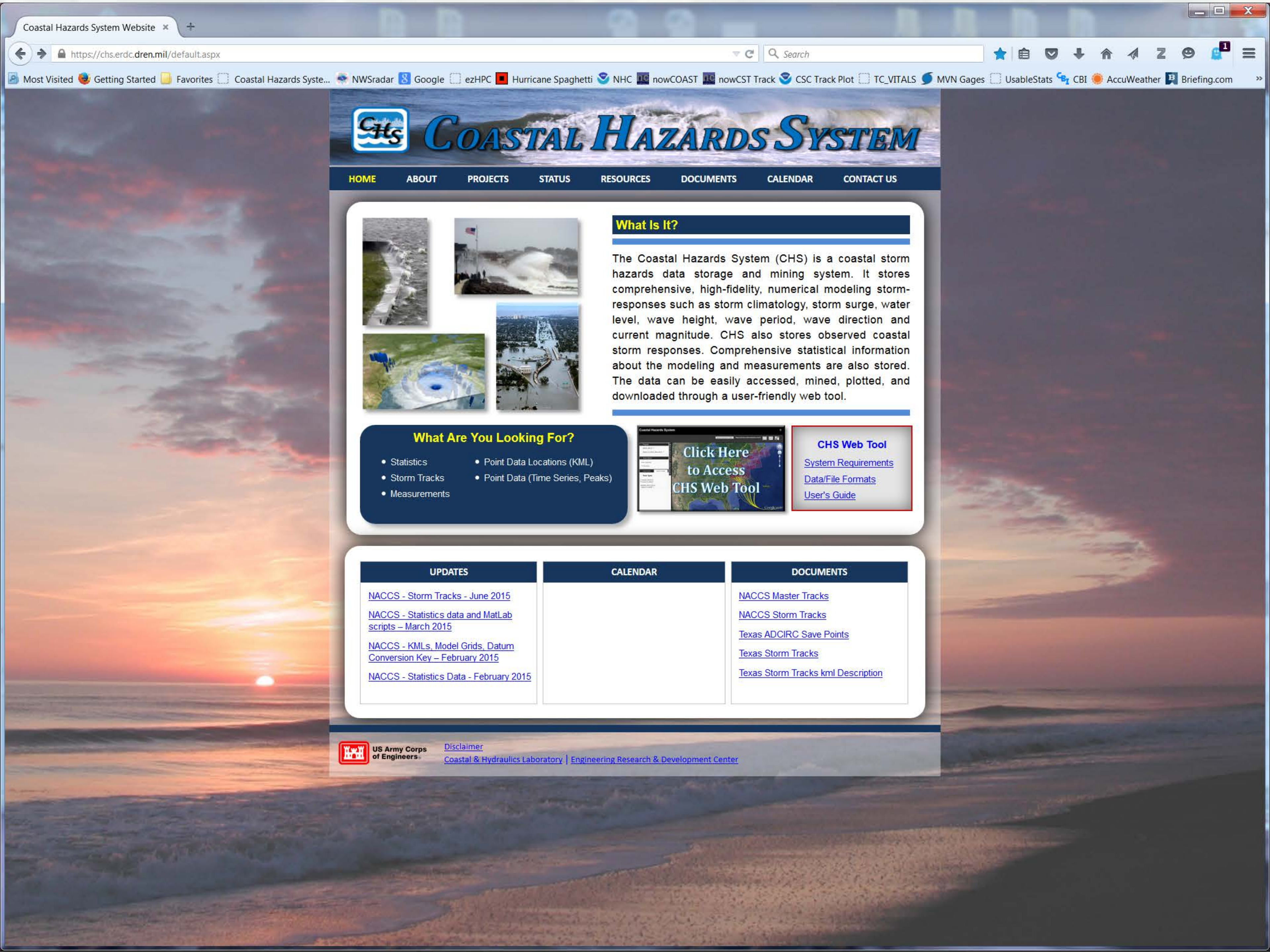


JP of Storm Responses

Final Product

- Approximately 19,000 output locations
- Peaks and time series files for all storms in HDF5 format
- Thirteen (13) Average Recurrence Interval (ARI) values:
  1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000, 10000 yrs
- Associated Annual Exceedance Probability
- Confidence Limits : 84%, 90%, 95%, 98%
- Nonlinear residuals
- Storm relative probabilities
- Measurements for storms and associated GPD ARI
- Grids, model inputs, reports, Matlab codes.




Coastal Hazards System Website
https://chs.erdc.dren.mil/default.aspx
Most Visited Getting Started Favorites Coastal Hazards Syste... NWSradar Google ezHPC Hurricane Spaghetti NHC nowCOAST nowCST Track CSC Track Plot TC_VITALS MVN Gages UsableStats CBI AccuWeather Briefing.com
COASTAL HAZARDS SYSTEM
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What Is It?
The Coastal Hazards System (CHS) is a coastal storm hazards data storage and mining system. It stores comprehensive, high-fidelity, numerical modeling storm-responses such as storm climatology, storm surge, water level, wave height, wave period, wave direction and current magnitude. CHS also stores observed coastal storm responses. Comprehensive statistical information about the modeling and measurements are also stored. The data can be easily accessed, mined, plotted, and downloaded through a user-friendly web tool.
What Are You Looking For?
Statistics
Storm Tracks
Measurements
Point Data Locations (KML)
Point Data (Time Series, Peaks)
Click Here to Access CHS Web Tool
CHS Web Tool
System Requirements
Data/File Formats
User's Guide
UPDATES
NACCS - Storm Tracks - June 2015
NACCS - Statistics data and MatLab scripts – March 2015
NACCS - KMLs, Model Grids, Datum Conversion Key – February 2015
NACCS - Statistics Data - February 2015
CALENDAR
DOCUMENTS
NACCS Master Tracks
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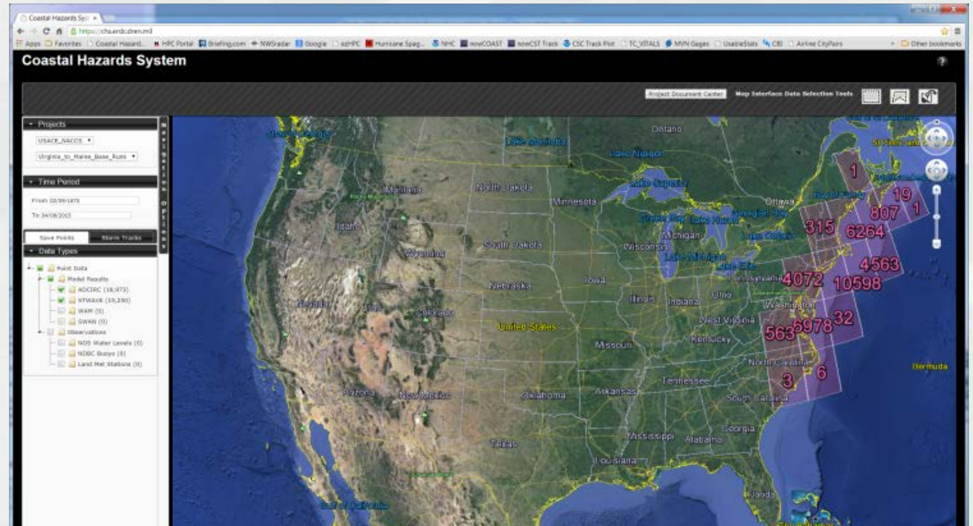
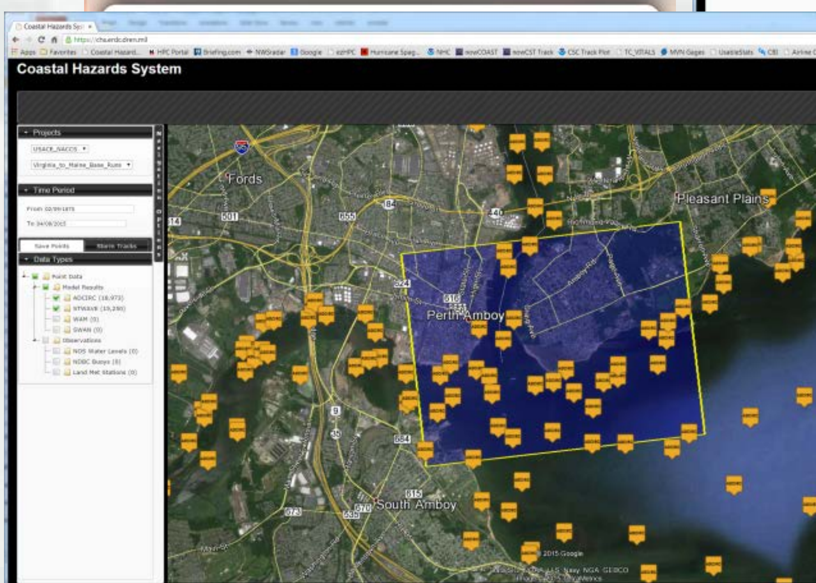
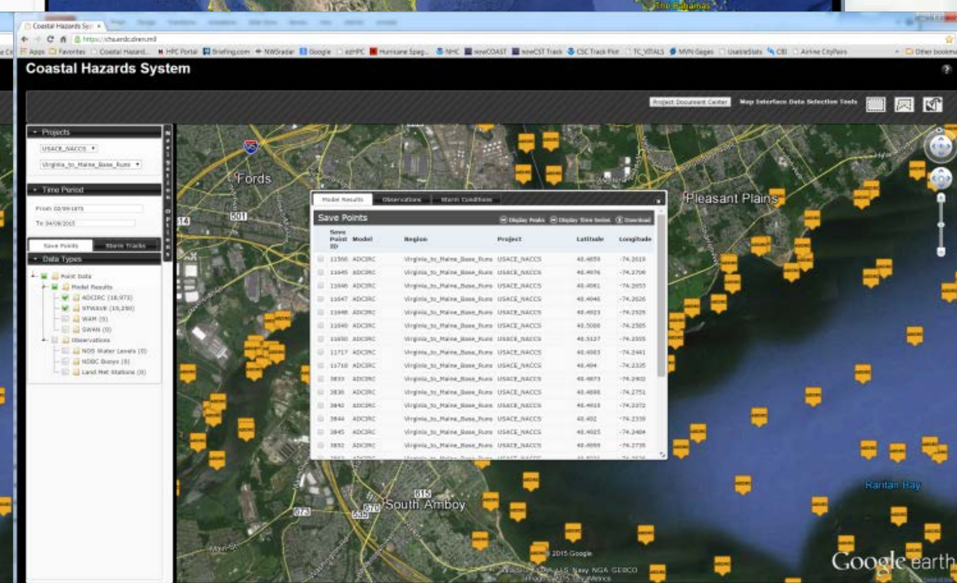
Coastal Hazards System

https://chs.erdc.dren.mil

Select “CHS Web Tool”

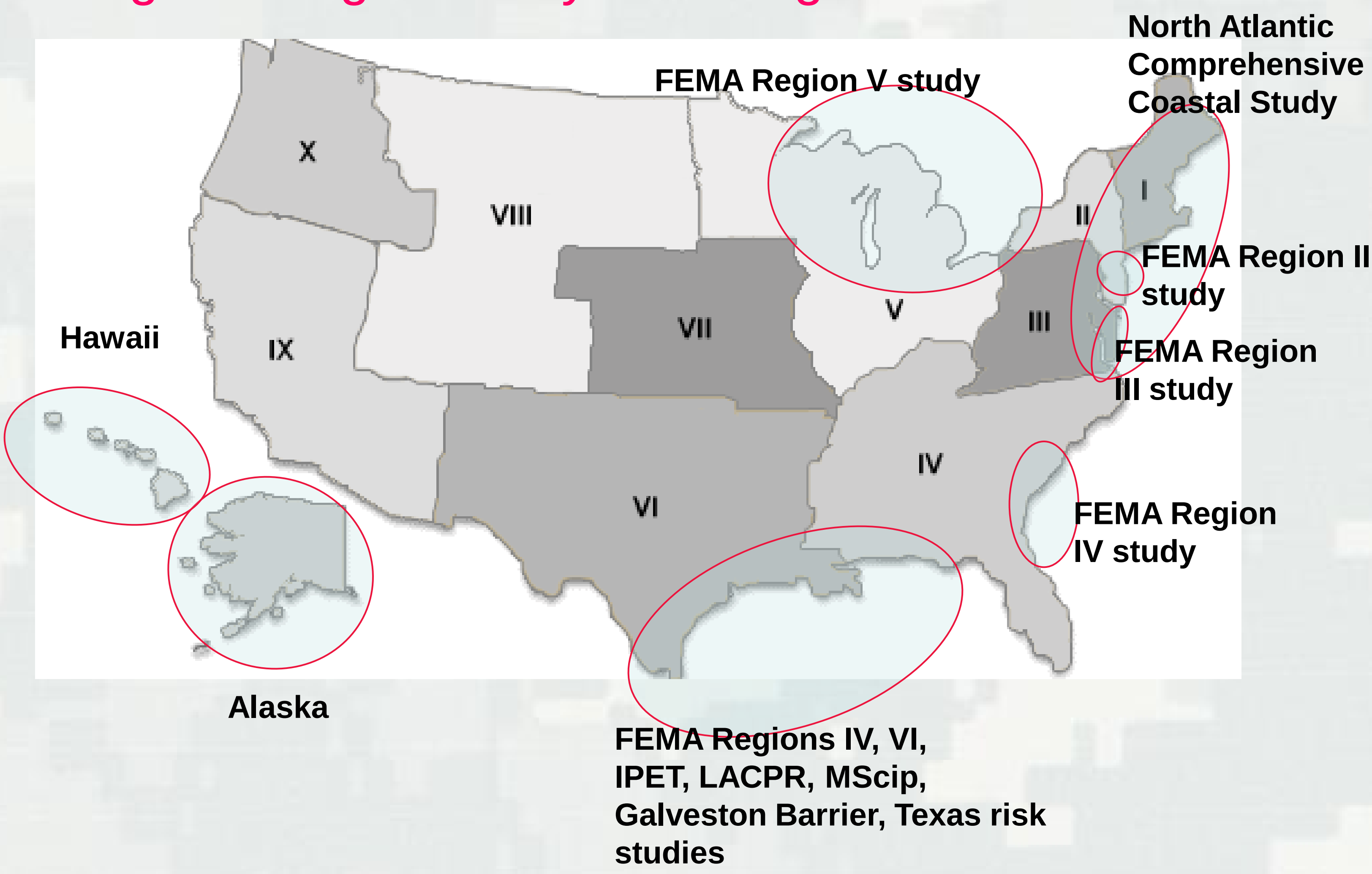






Coastal Hazards System

Regional High-Fidelity Modeling Studies



Summary

- NACCS approach was built around probabilistic modeling with high-fidelity numerical simulation
- Selected tropical storms using JPM-OS-BQ method
- Selected extratropical storms using POT from observations
- Computed joint probability of responses
- Computed epistemic uncertainties as confidence limits
- Stored and distributing peaks, time series, statistics in Coastal Hazards System

Thanks for listening…Questions?