Probabilistic Flood Hazard Assessment Using the Joint Probability Method for Hurricane Storm Surge

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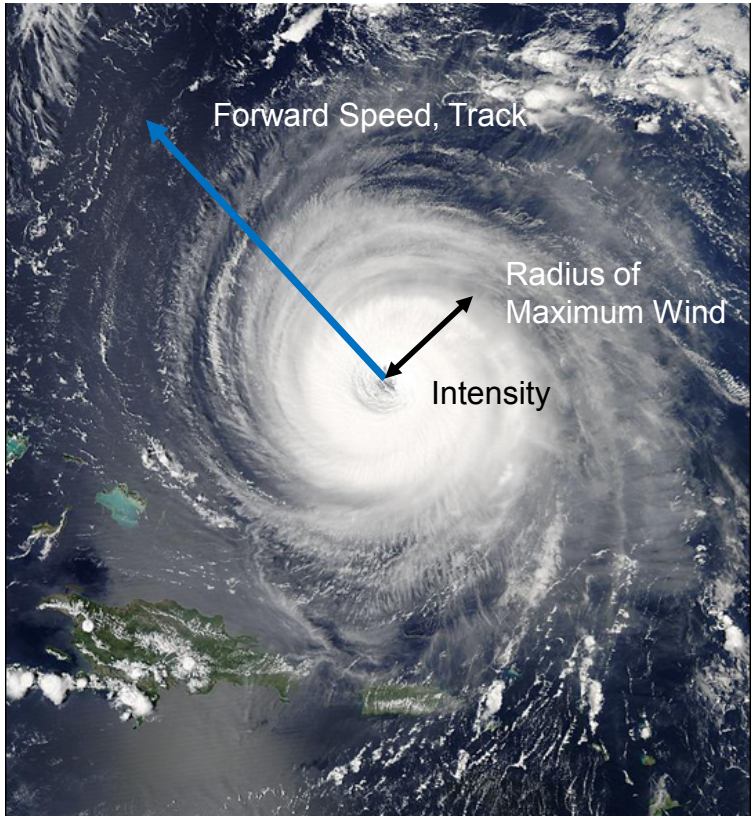
Objective

- To provide guidance on the estimation of annual exceedance probability (AEP) surge levels generated by tropical cyclones
- Support both a probabilistic flood hazard assessment for a coastal site as well as the siting and design of nuclear power plants in coastal environments
- Example AEP range: 10^{-5} to 10^{-7} (100,000- to 10,000,000-yr return period)

Storm Surge (Hazard)-JPM

- EPRI conducted research into the use of the joint probability method (JPM) to simulate hurricanes and establish flood hazard curve
- Hurricanes are simulated using stochastic model of storm parameters
  - Proximity of the landfall
  - Track angle of the storm
  - Storm intensity (central pressure)
  - Storm size (radius of maximum wind)
  - Storm forward speed

Storm Meteorological Parameters



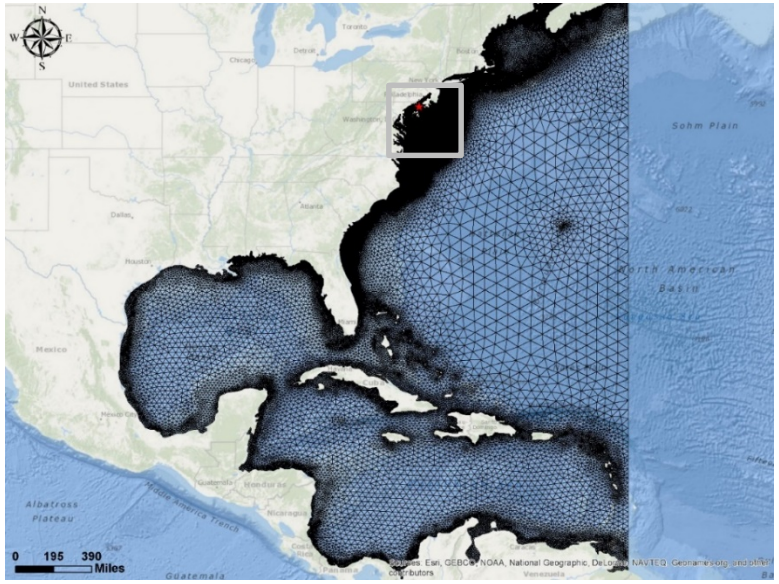
Source: NASA Earth Observatory Image

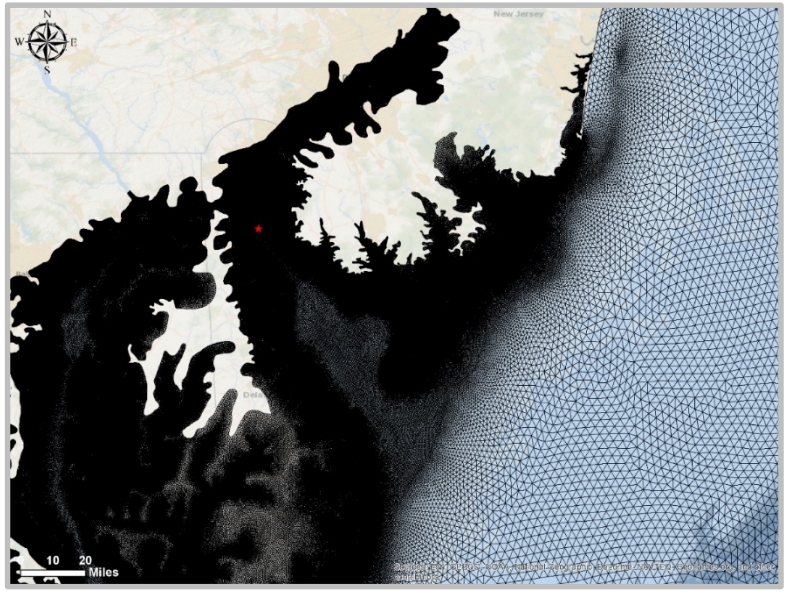
JPM Steps

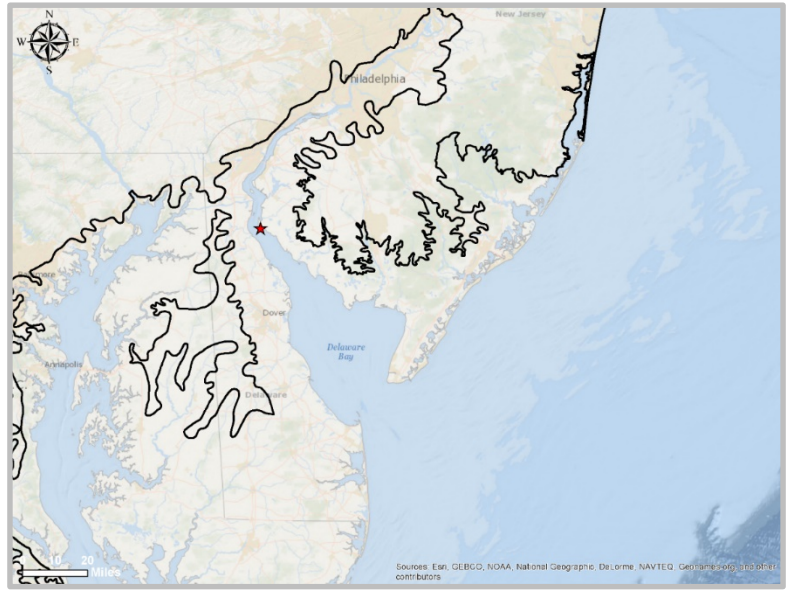
1. Develop/validate storm surge model
2. Determine range of storm parameters
3. Develop wind fields for hypothetical storm events
4. Simulate surge and wave fields for each storm event
5. Estimate surge response functions
6. Estimate storm parameter and uncertainty distributions
7. Estimate surge cumulative distribution function including effects of uncertainty

Storm Surge Model Development

- Model selection
- Mesh/grid development
- Calibration
- Validation
- Application

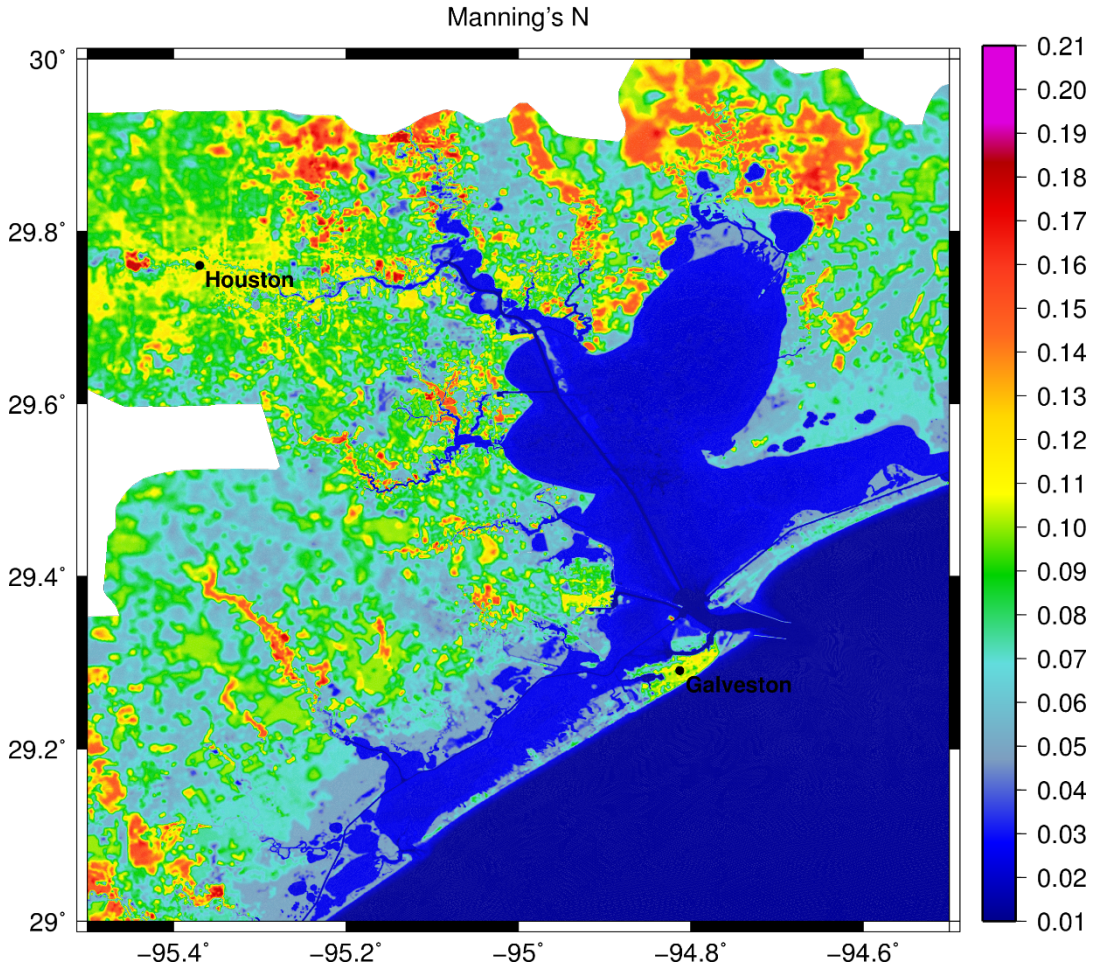






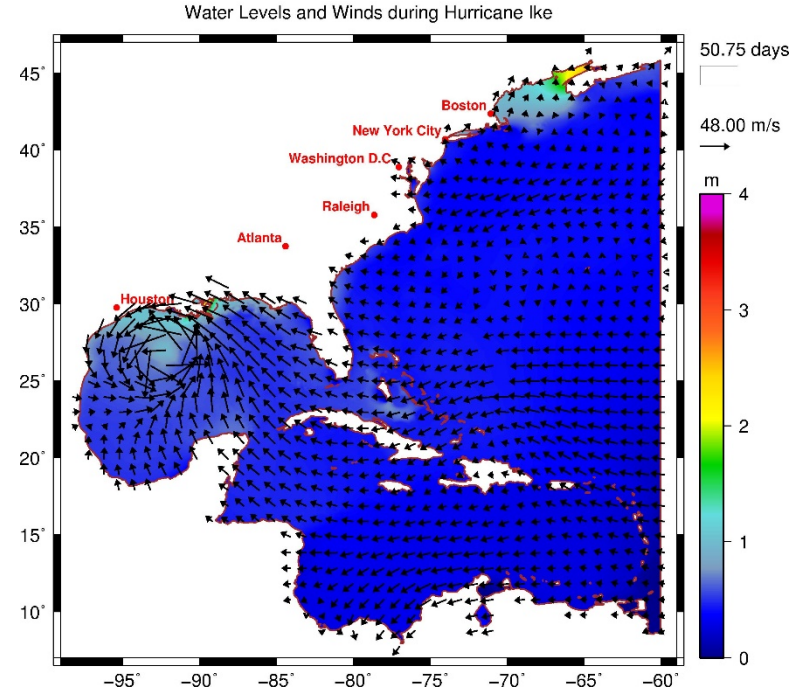
Model Parameterization and Calibration

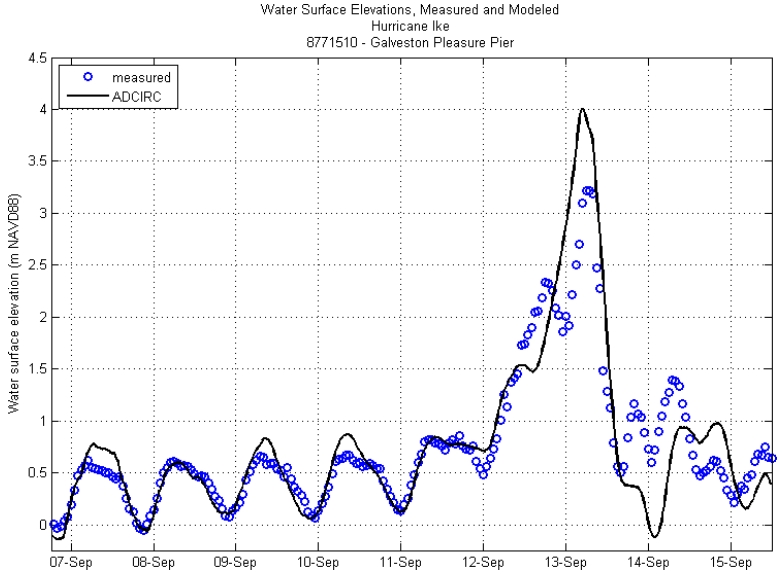
- Establishes important model parameters
- Examples:
  - Bottom friction
  - Wind Stress Formulation
  - Time step
  - Wave coupling parameters
- Sensitivities in results due to changes in parameter values need to be tested to verify model produces reasonable results within the standard of practice



Model Validation

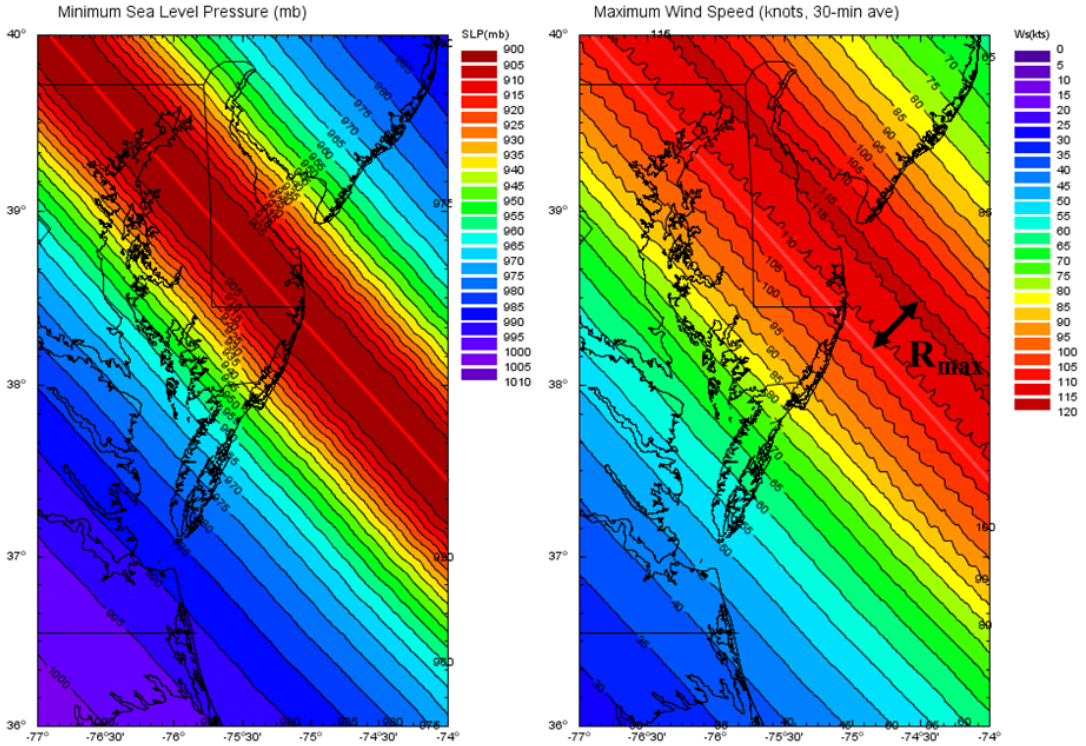
- Develop wind field data for each relevant historical storm event
  - Note that wind field data is often obtained from marine meteorological models, which have their own development and validation process
- Simulate each storm event using the storm surge model and wind field data
- Validate model results to measured data and compute error metrics





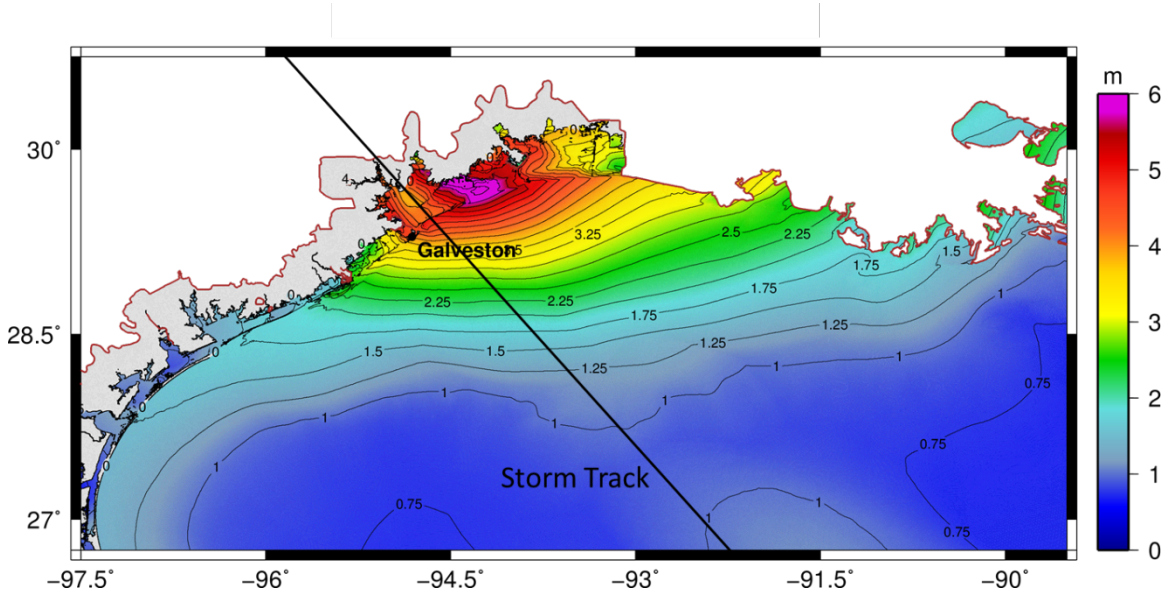
JPM - Storm Parameters

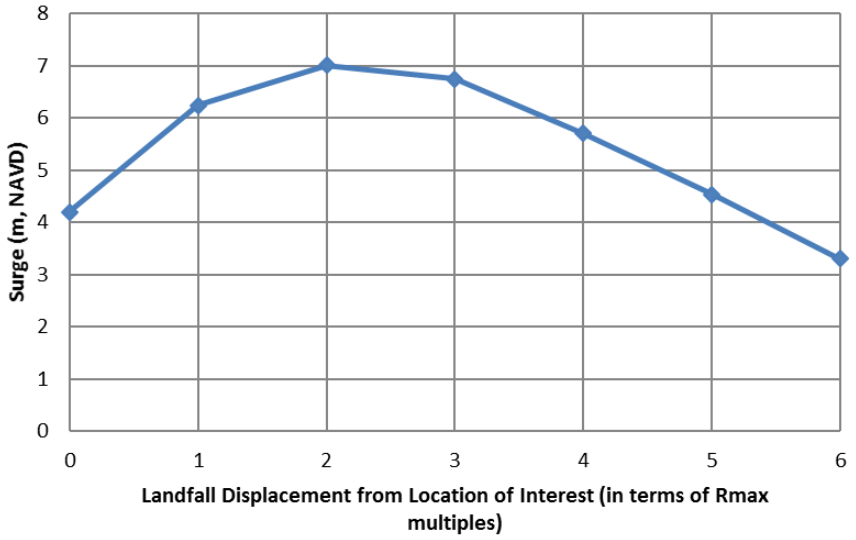
- Proximity of the landfall (x_0)
- Track angle of the storm (ϑ_f)
- Storm intensity (Δp)
- Storm size (R_{max})
- Storm forward speed (v_f)
- Other parameters (tides, etc.)



JPM – Range of Storm Parameter Values

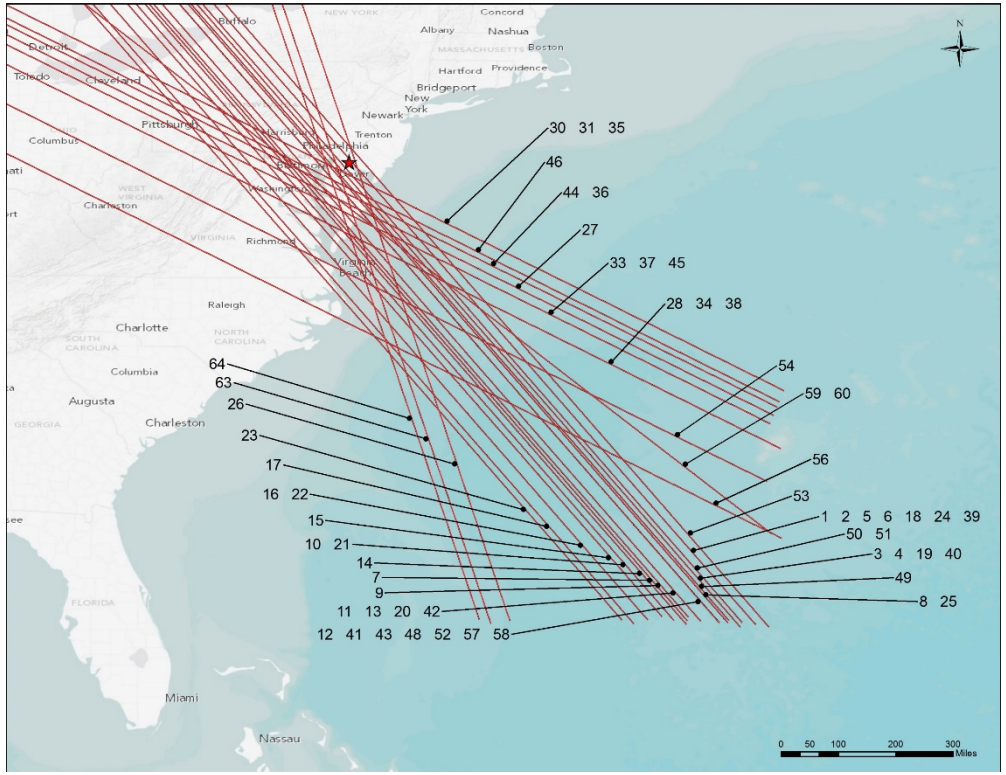
- Determine relevant range of parameter values
  - Sensitivity of each storm parameter varies by location
- Perform simulations and compare results for each parameter
- Some parameters (e.g., storm intensity) have physical limitations based on location

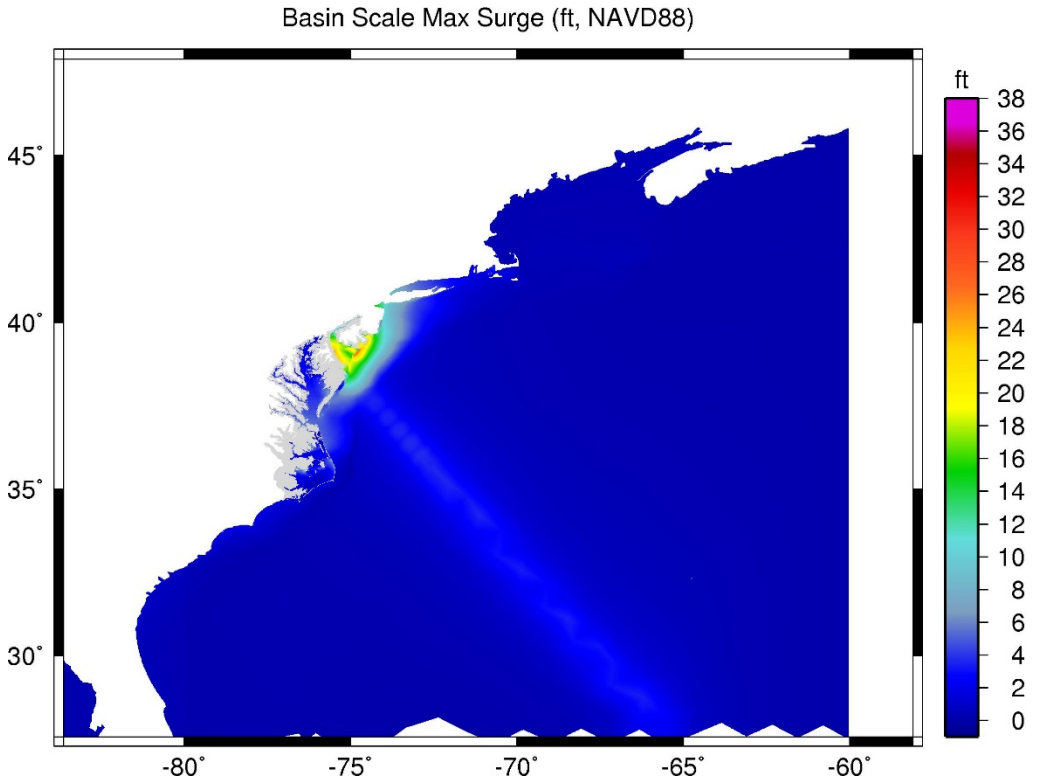




JPM – Simulate Synthetic Storm Events

- Create set of synthetic storm events with unique combinations of parameter values
- Simulate with the validated storm surge and wave model

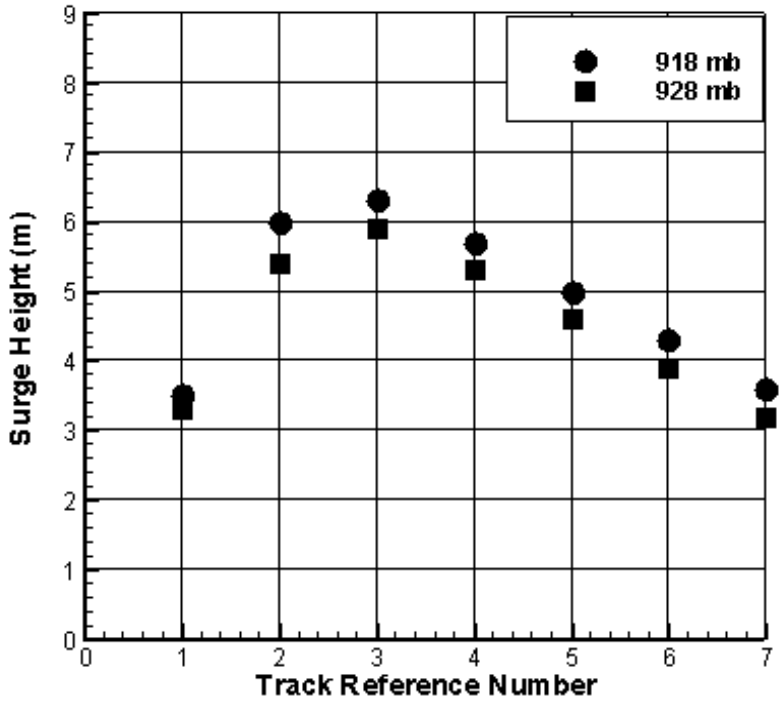




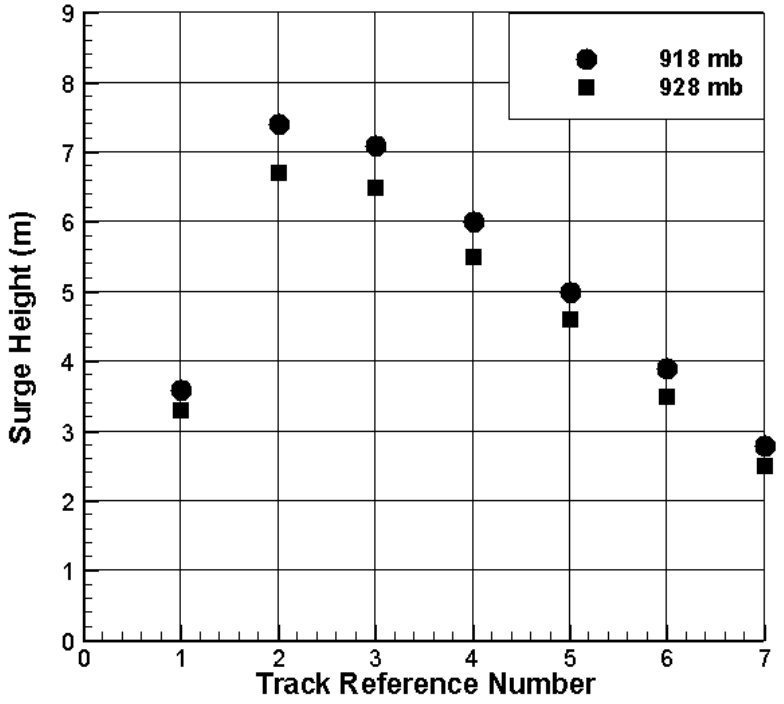
JPM – Develop Surge Response Functions

- Isolate influence of each individual storm parameter
- Results used to numerically evaluate JPM equation

R_{max} = 30 nm

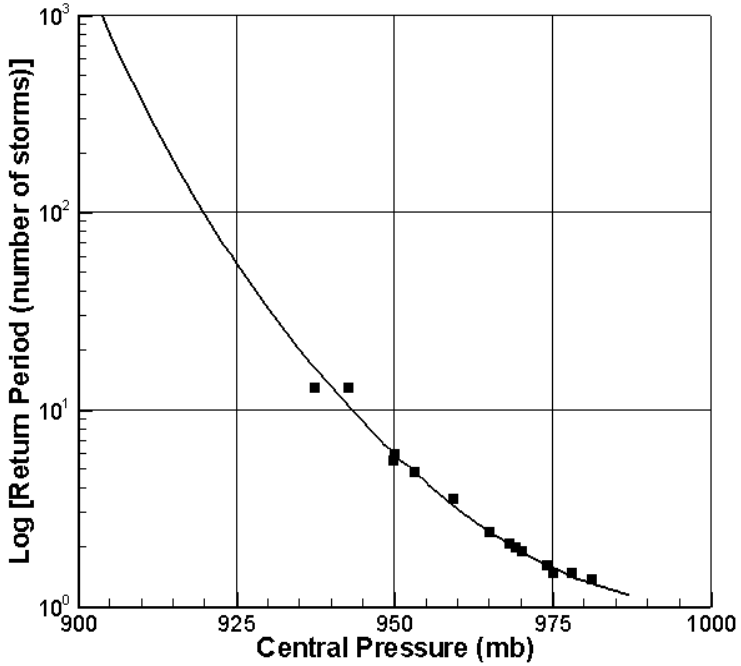


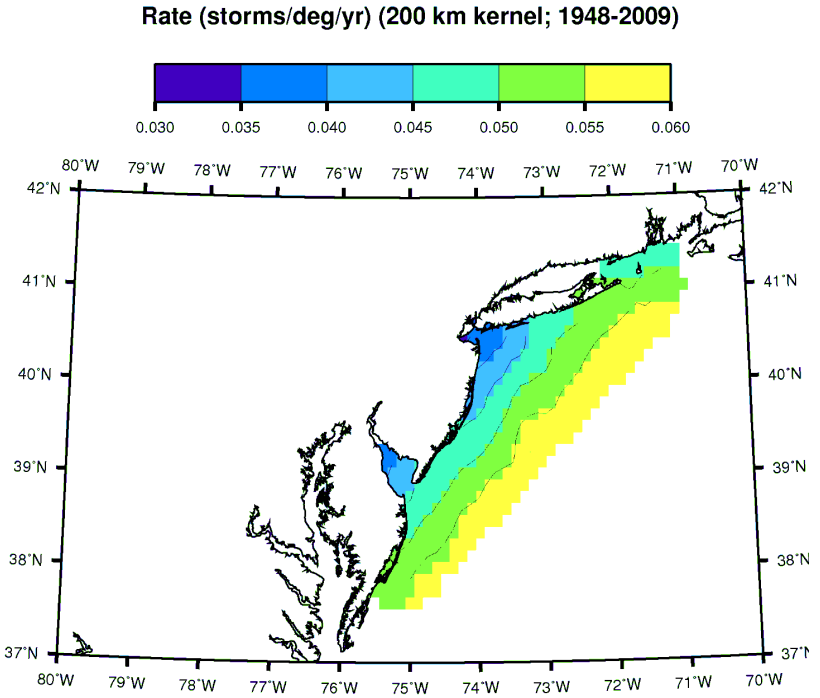
R_{max} = 45 nm



JPM – Estimate Storm Parameter Distributions

- Relies on best available data and previous statistical analyses to estimate probability distributions for each storm parameter
- Obtained from literature (journal articles, technical reports, etc.) and historical databases (HURDAT, IBTrACS, etc.)

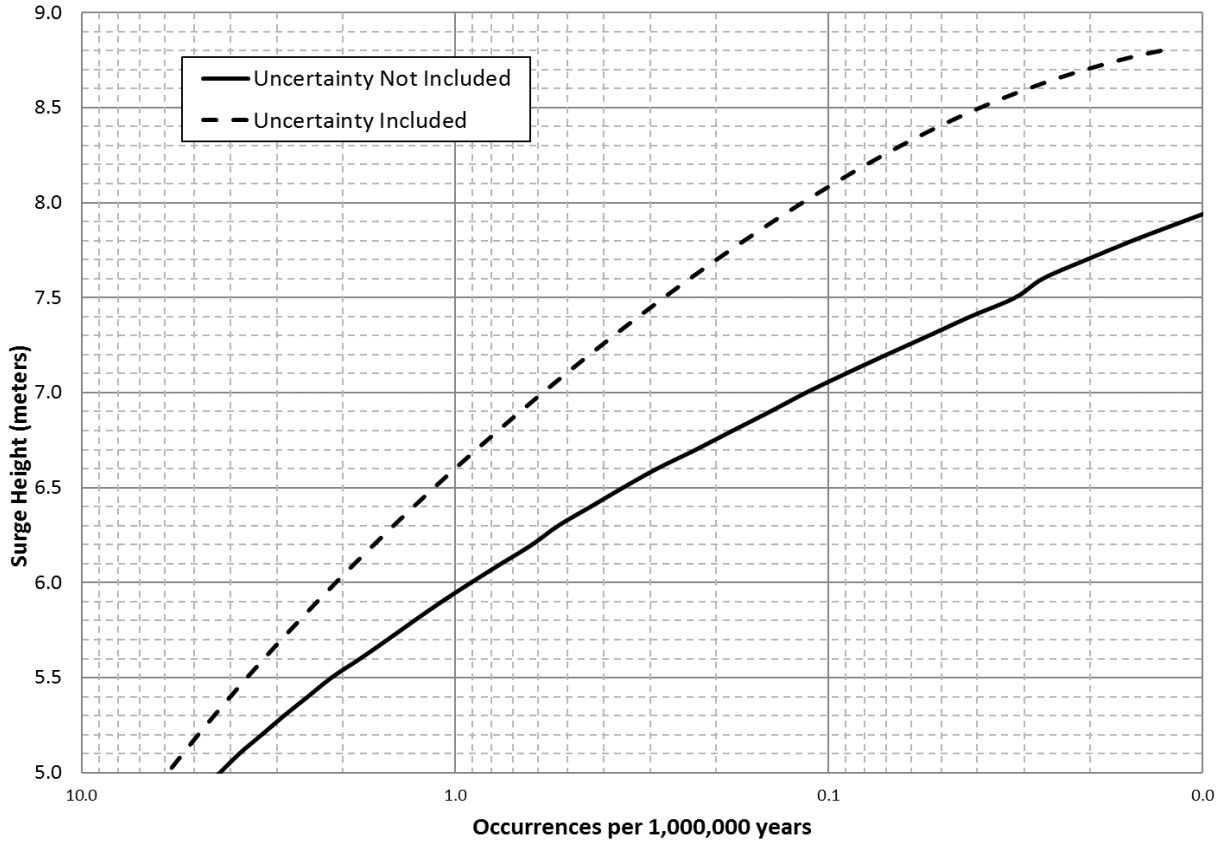




JPM – Estimate Flood Hazard Curve

$$F(\eta) = \sum_{i,j,k,l,m,n} p\left(\Delta p_i, R_{max_j}, v_{f_k}, \theta_{f_l}, x_{0_m}\right) p(\varepsilon|\eta) \text{ for } \left[\eta_* \left(\Delta p_i, R_{max_j}, v_{f_k}, \theta_{f_l}, x_{0_m}\right) + \varepsilon_n < \eta\right]$$

- Include uncertainty
  - Epistemic (modeling error)
  - Aleatory (sample size error)
- Storm surge vs. AEP relationship creates the storm surge flood hazard curve for use in a PRA



JPM Key Findings

- Robust framework that covers a range of scenarios.
- Can be used to support both design basis evaluations and PRA.
- Can be used to assess the frequency of a storm surge that would be expected to exceed a flood height.
- An iterative process with the storm surge model simulations informing the JPM analysis and vice versa. Therefore, it is important to have a close coordination between numerical modelers and statistical analysts to support JPM analysis.
- Full report available on EPRI website: Product ID 3002012996

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