Assessment of Epistemic Uncertainty for Probabilistic Storm Surge Hazard Assessment using a Logic Tree Approach

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Protecting People and the Environment

4th Annual Probabilistic Flood Hazard Assessment Workshop

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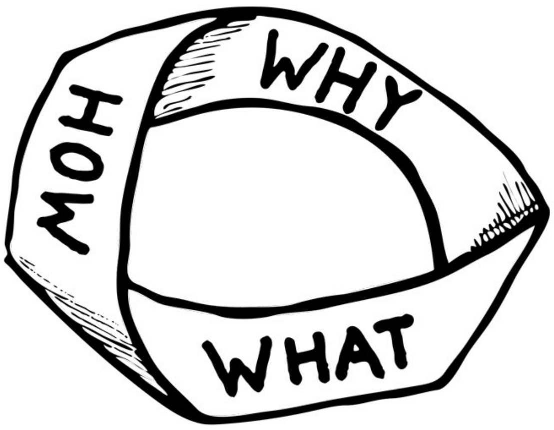
Outline

- Introduction/Background
- Logic Tree Method for Probabilistic Storm Surge Hazard Analysis
  - Framework;
  - Sensitivity results;
  - Takeaways;
- Discussion



Storm Surge Hazard

National Storm Surge Hazard Maps

NOAA/NWS/NHC Storm Surge Unit

This is not a real-time product. For active tropical cyclones, please see hurricanes.gov and consult local products issued by the National Weather Service

Texas to Maine | Puerto Rico and U.S. Virgin Islands | Hawaii | Hispaniola

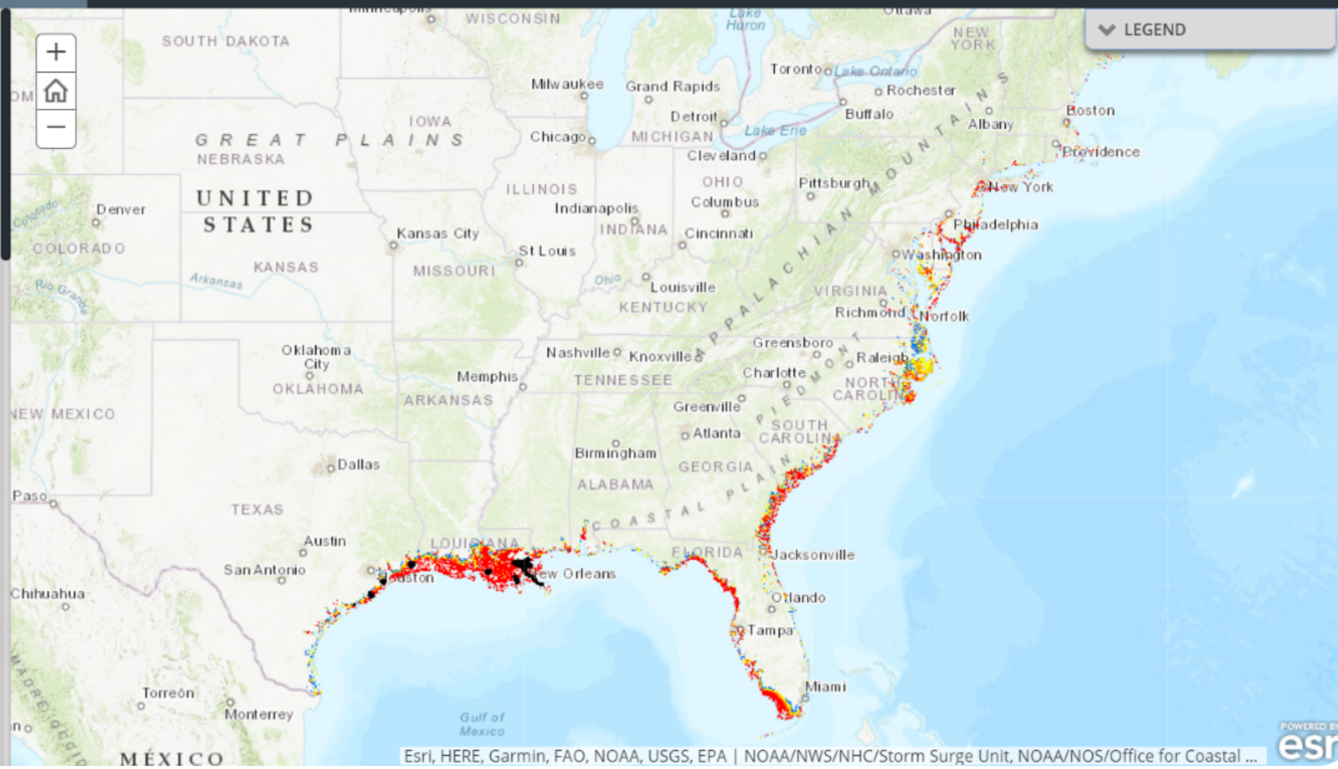
Category 1 | Category 2 | Category 3 | Category 4 | Category 5

This national depiction of storm surge flooding vulnerability helps people living in hurricane-prone coastal areas along the U.S. East and Gulf Coasts and Puerto Rico to evaluate their risk to the storm surge hazard. These maps make it clear that storm surge is not just a beachfront problem, with the risk of storm surge extending many miles inland from the immediate coastline in some areas. If you discover via these maps that you live in an area vulnerable to storm surge, find out today if you live in a hurricane storm surge evacuation zone as prescribed by your local emergency management agency. If you do live in such an evacuation zone, decide today where you will go and how you will get there, if and when you're instructed by your emergency manager to evacuate. If you don't live in one of those evacuation zones, then perhaps you can identify someone you care about who does live in an evacuation zone, and you could plan in advance to be their inland evacuation destination - if you live in a structure that is safe from the wind and outside of flood-prone areas.

- Less than 3 feet above ground
- Greater than 3 feet above ground
- Greater than 6 feet above ground
- Greater than 9 feet above ground
- Leveed area
  Consult local officials for flood risk

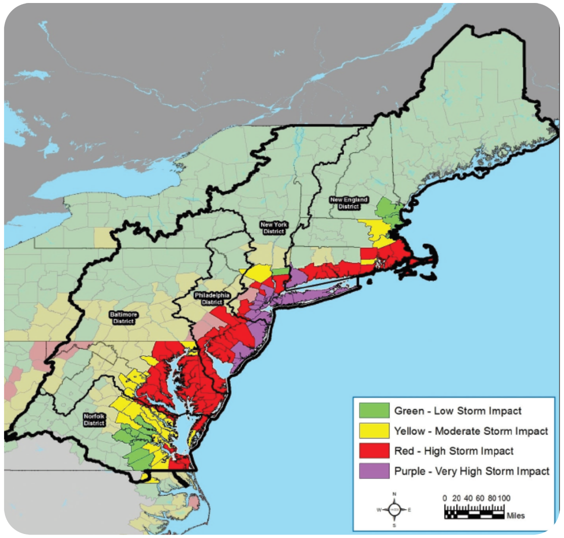
How this map was created:

The SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model is a

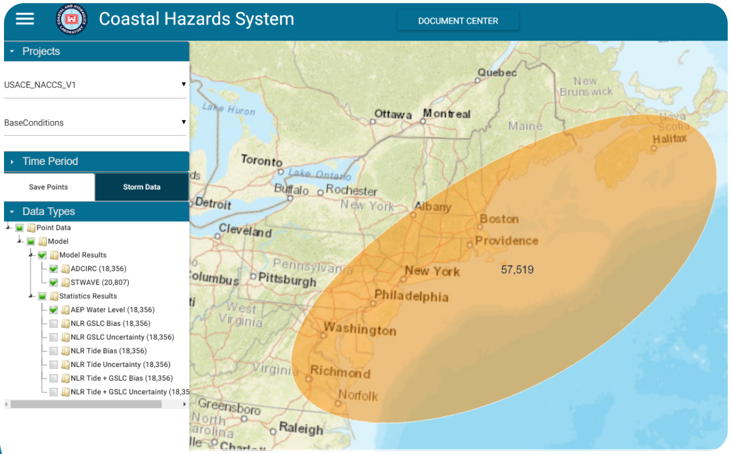


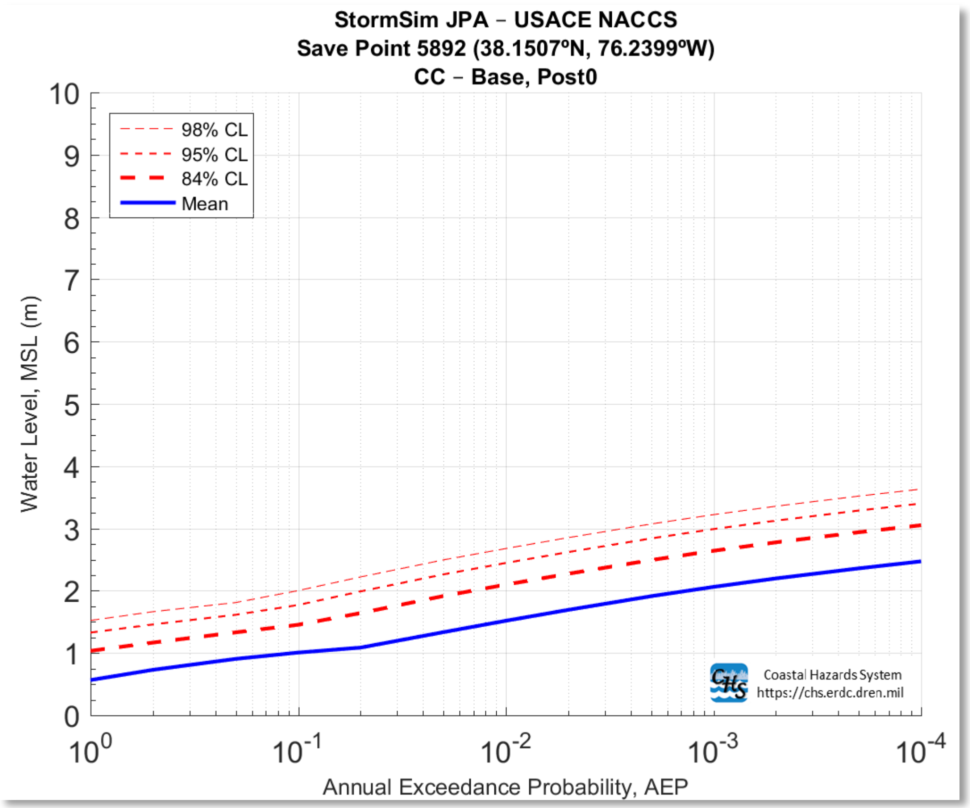
Storm Surge Hazard

FEMA – Hurricane Sandy Impact



USACE NACCS





Example Hazard Curves (Chesapeake Bay)

General Methodology / Example Analysis

- Deterministic analysis;
- Probabilistic analysis:
  - Empirical simulation technique (e.g., TR CHL-99-21, Scheffner, et al., 1999);
  - Empirical track method (e.g., Vickery et al., 2009);
  - Synthetic track method (e.g., Lin et al., 2010);
  - Joint probability method (e.g., FEMA, 2008 & 2014 and USACE TR-15-5, 2015);

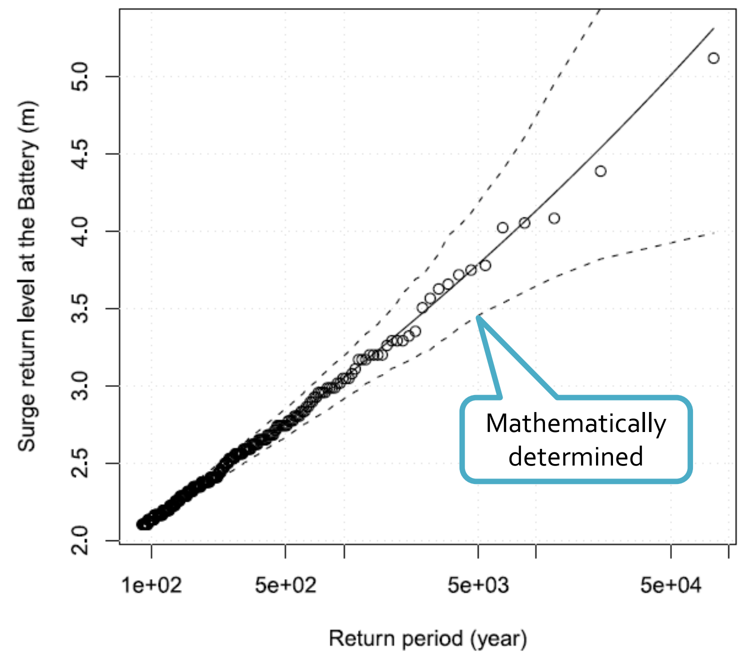


Figure 14. Return level plot for extreme storm surge heights for New York City. The solid curve is the mean return level. The dashed curves are the 95% confidence limits. The open circles are the empirically estimated return levels.

"Best Estimate"

Sources of Epistemic Uncertainty

- Uncertainty = **Knowledge Uncertainty** + **Natural Variability**

Knowledge Uncertainty: Facts that can be known with uncertainty, but are not currently known by the observer.

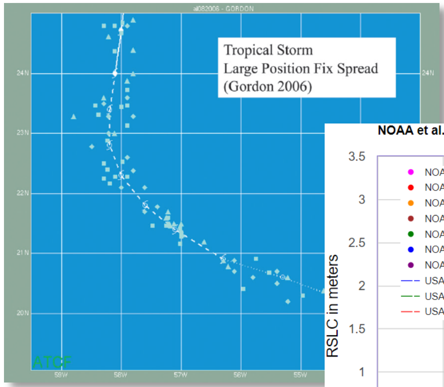
Obtaining more information can reduce this type of uncertainty.

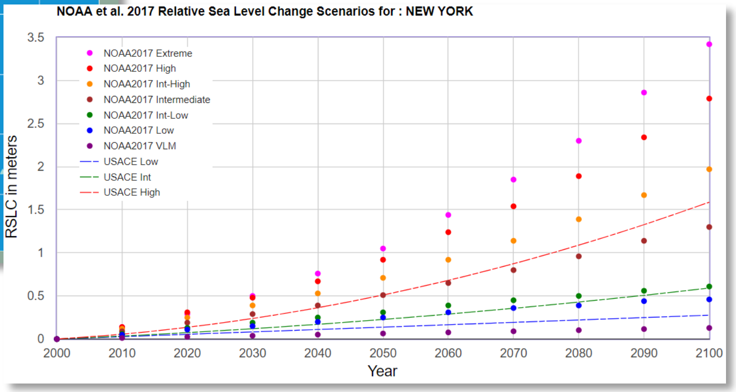
Natural Variability: Inherent variability in the physical world that cannot be known for certain.

Cannot be reduced, however, our estimation can be improved with more information.

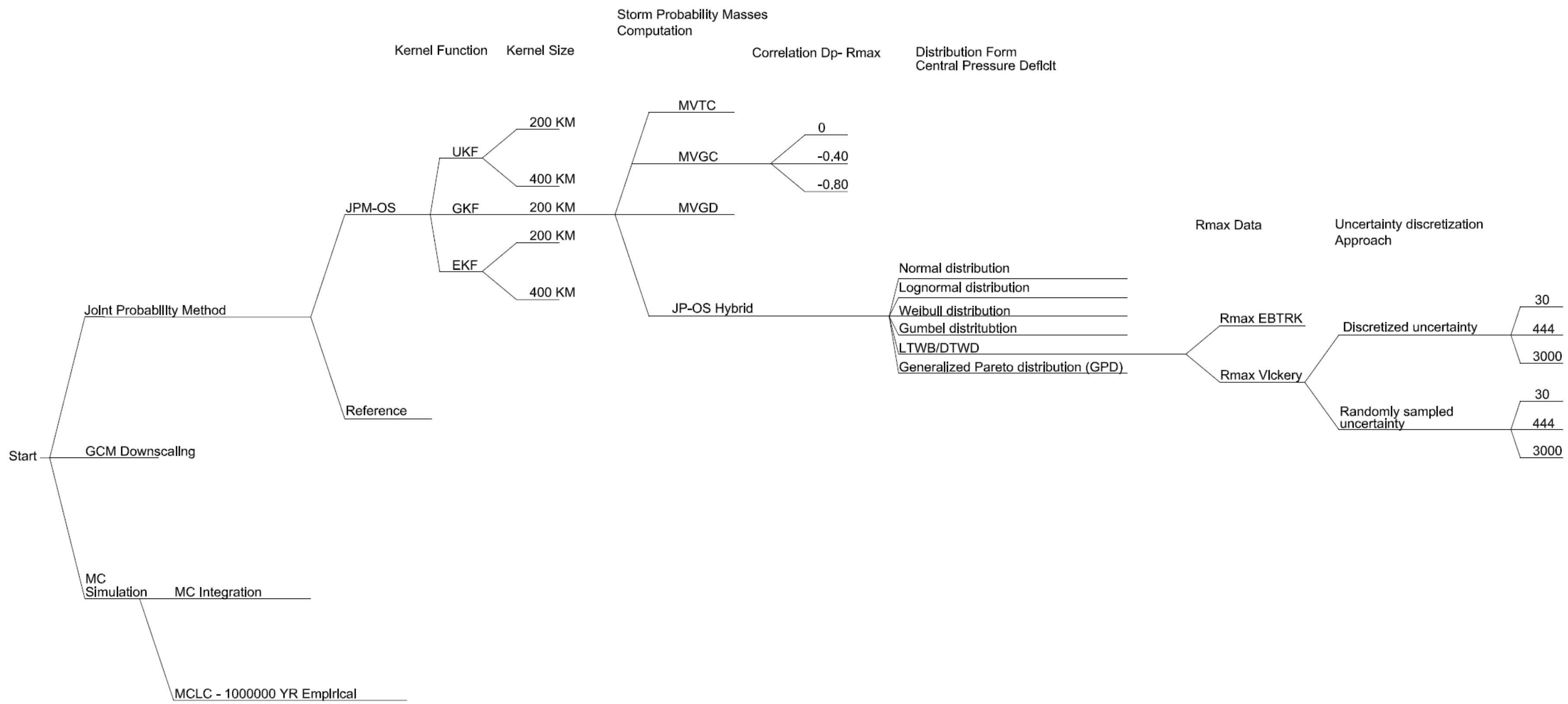
*** Storm surge hazard analysis – epistemic uncertainty, e.g.,**

- Limited historical record;
- Limitations in physical models;
- Storm recurrence rate;
- Coincident astronomical tides;
- Meteorological parameters;
- Hydrodynamic modeling;
- Projected sea level rise scenarios;
- …





Logic Tree Method



- Alternative models;
- Alternative parameter values;
- Weights;

Comprehensive & systematic treatment of uncertainty

Mean hazard + confidence interval

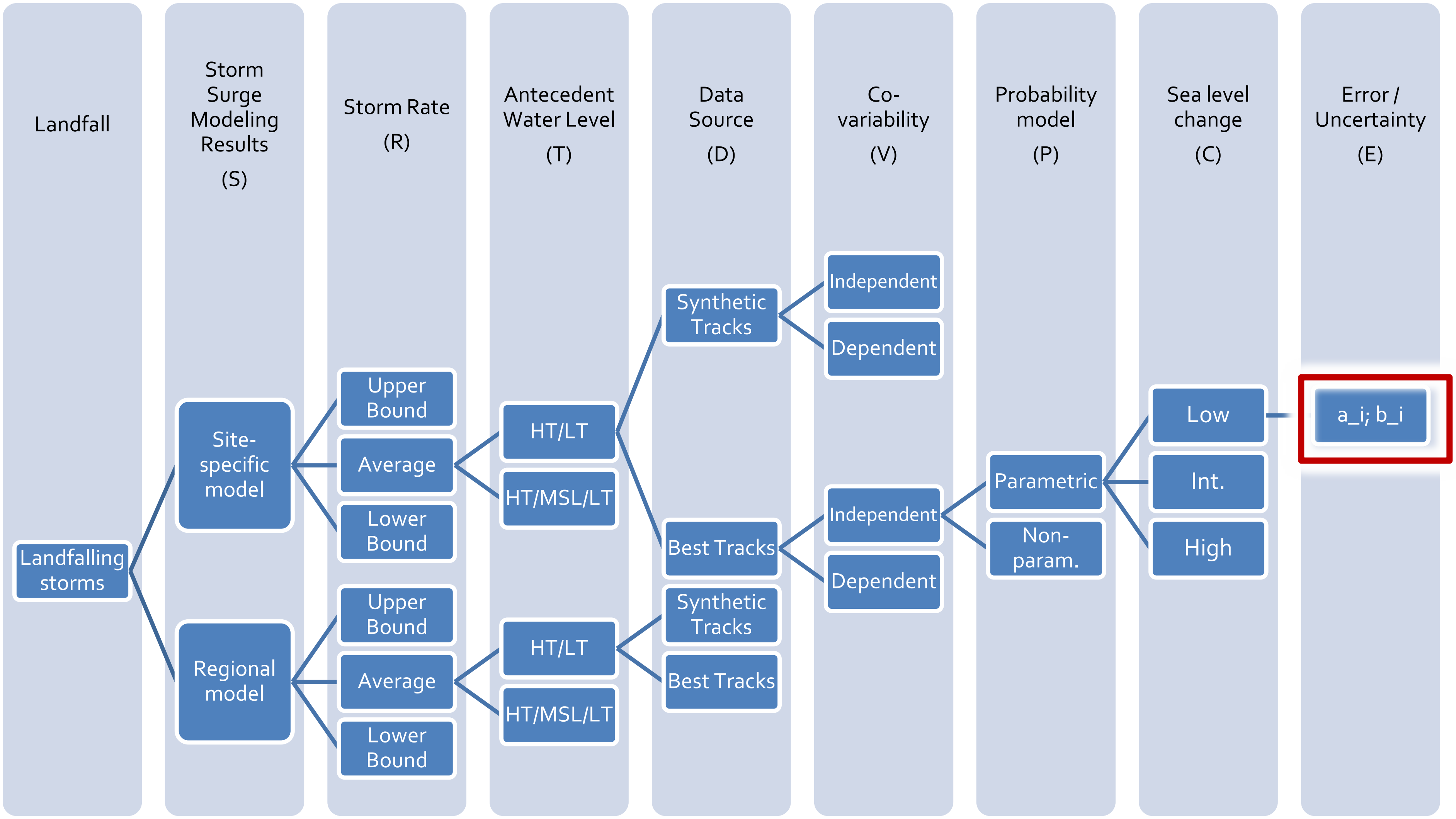
Logic Tree Example

for Probabilistic Storm Surge Analysis

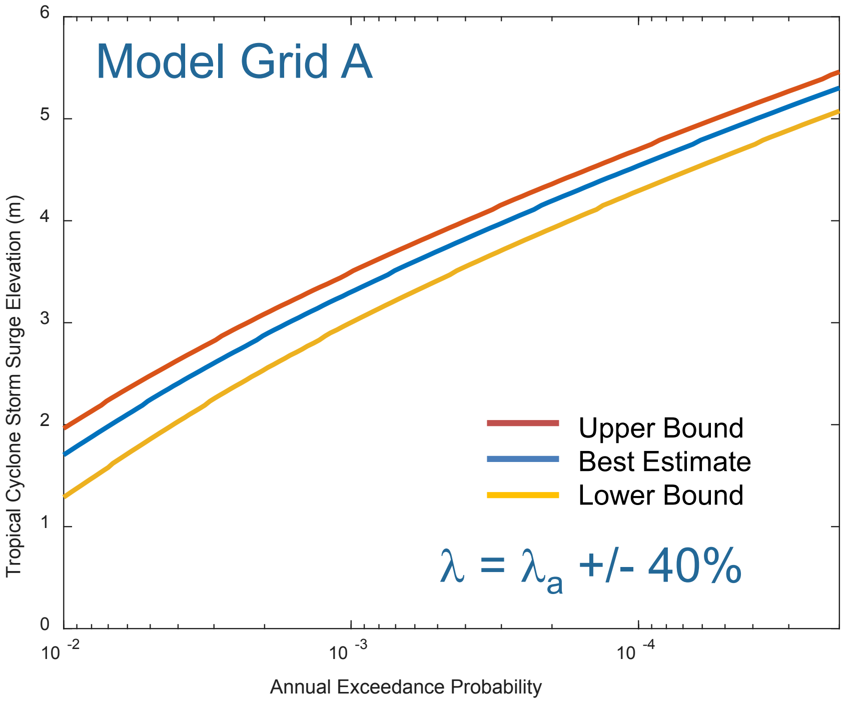
Example Alternatives

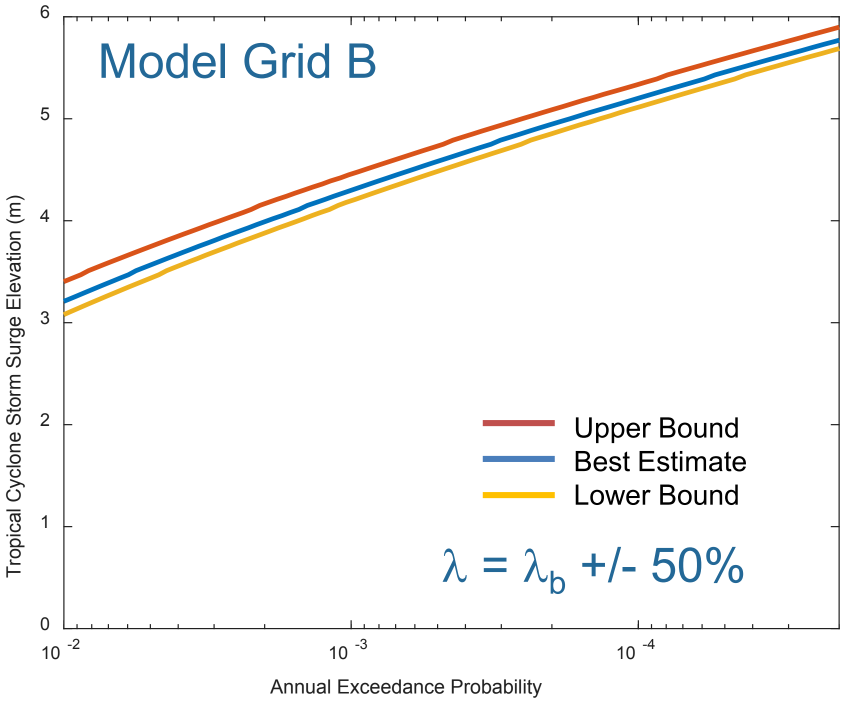
- PFHA Method
  - Empirical simulation technique
  - Synthetic tracks
  - Joint probability
- Annual storm recurrence rate
  - Historical record
  - Physical model-based
  - Stochastic model-based
- Meteorological parameters
  - Historical best tracks
  - Synthetic storms
  - Synthetic tracks under future climate
- Probability models
  - Parametric
  - Non-parametric
- Inter-parameter dependence
  - Univariate distributions
  - Conditional probability
  - Co-varying parameter vectors
- Treatment of errors
  - Constant
  - Proportional
  - Combined

Example Joint Probability Logic Tree

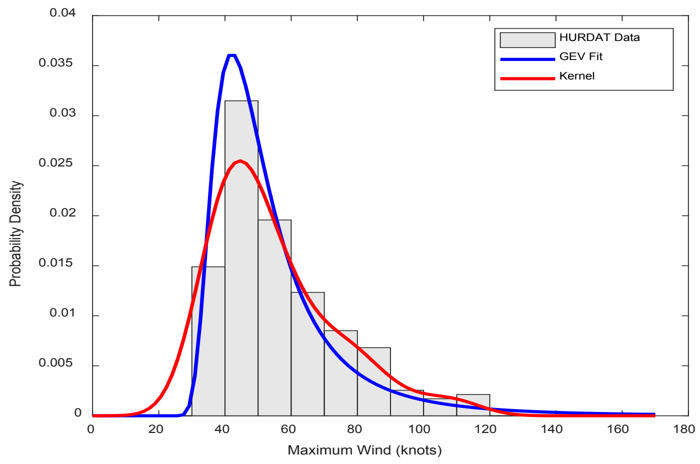


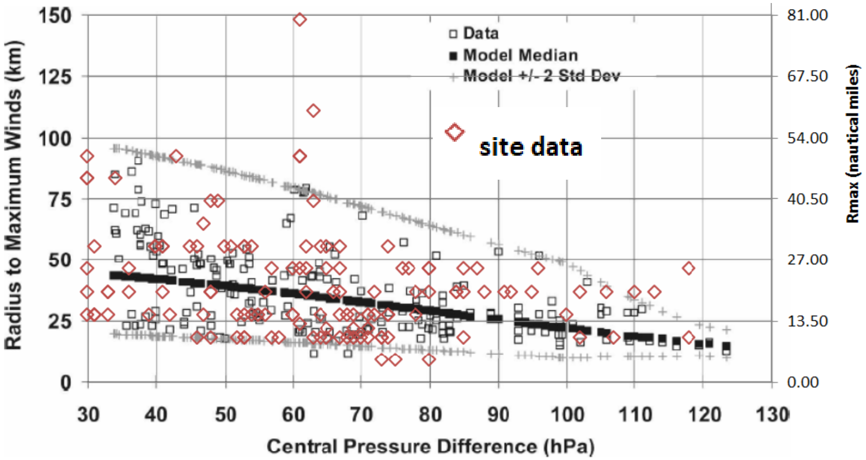
Sensitivity Analysis – Storm Recurrence Rate

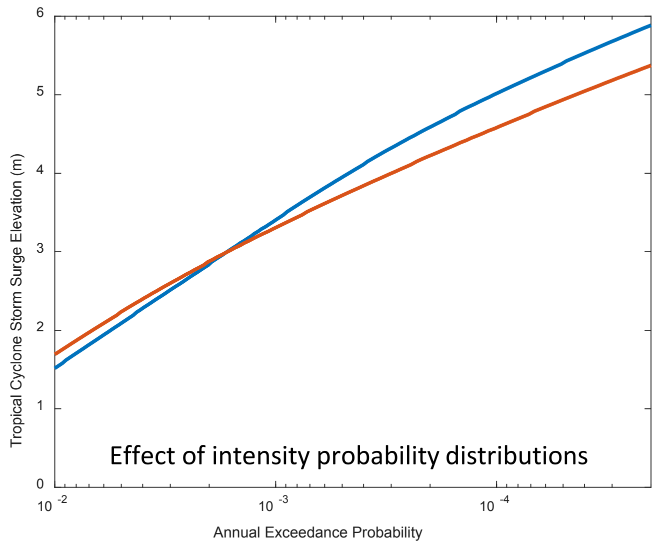


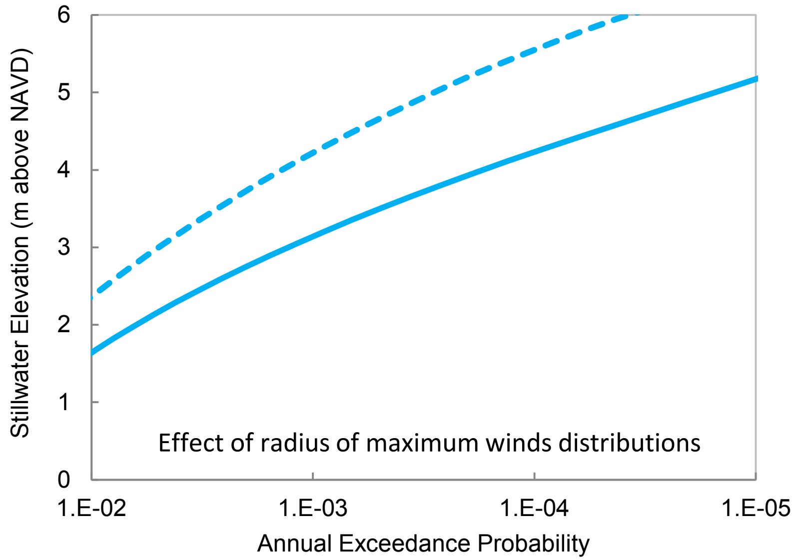


Sensitivity Analysis – Probability Distributions

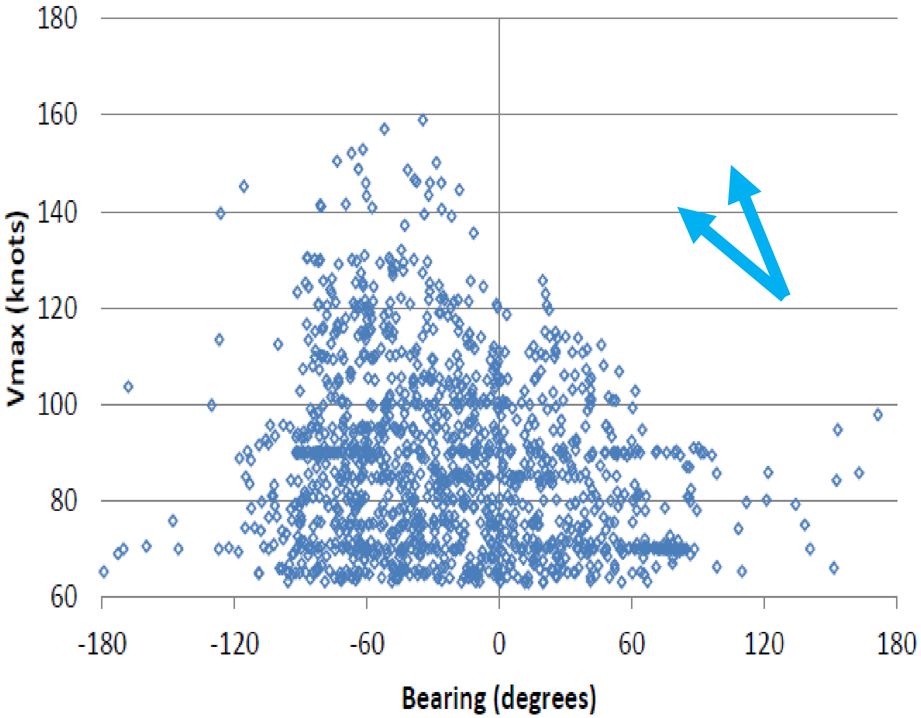


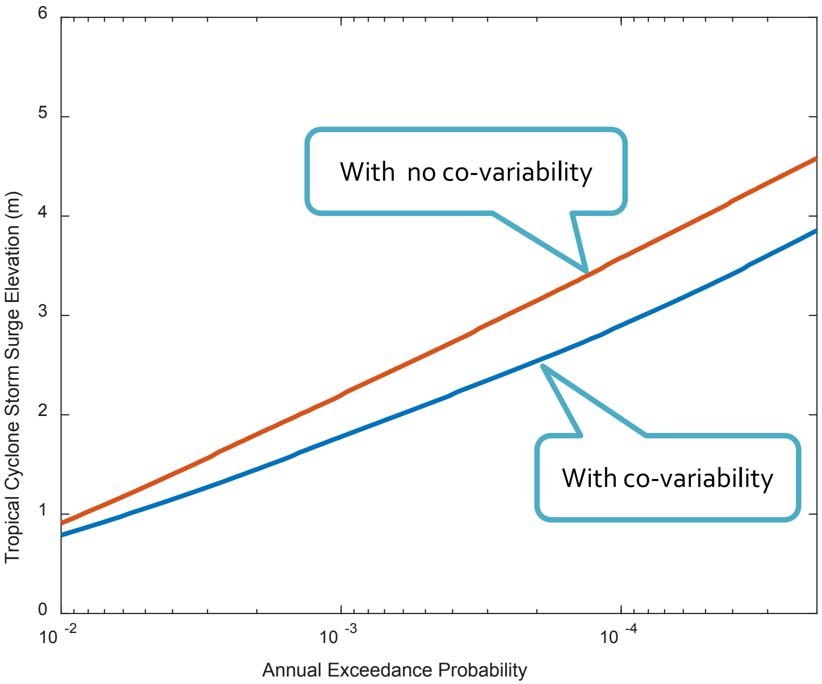






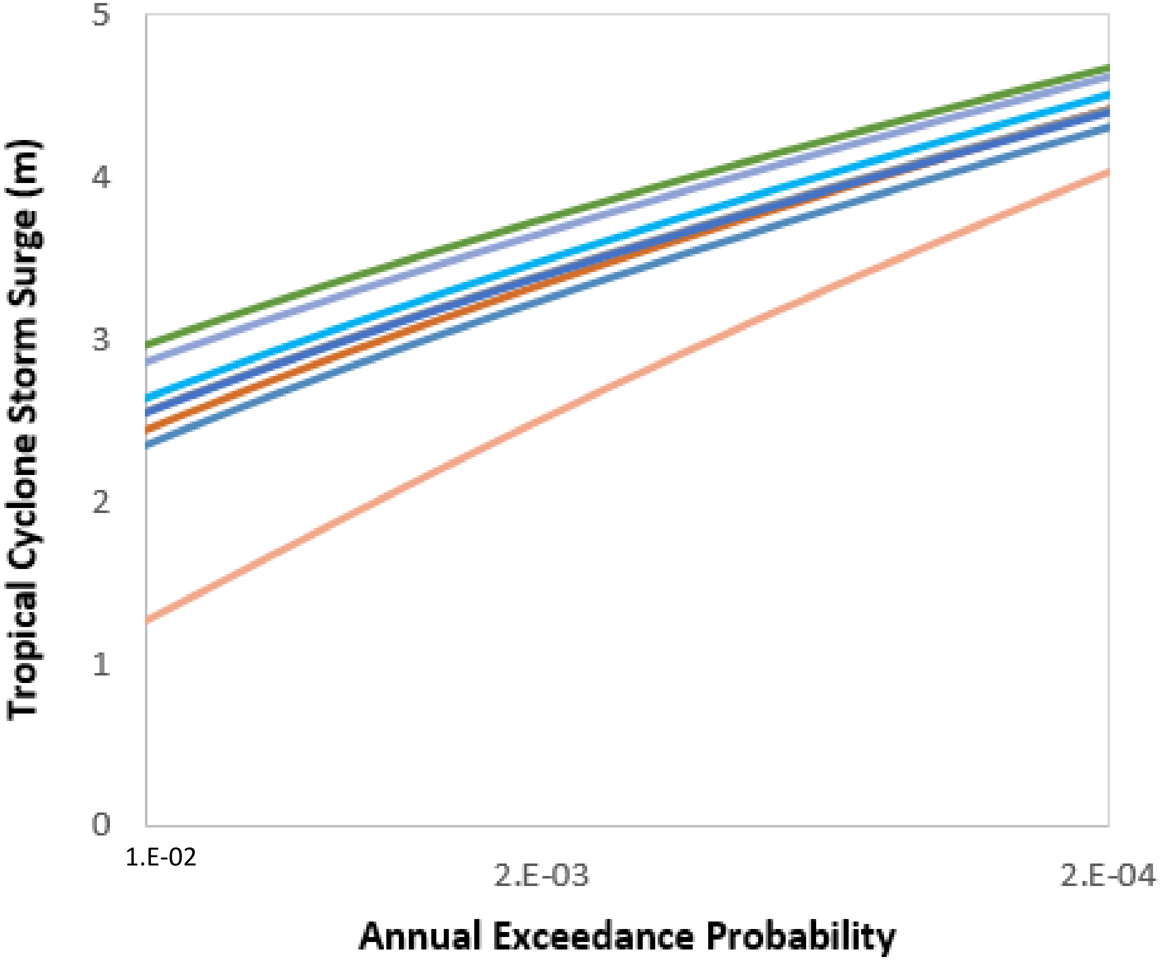
Sensitivity Analysis – Parameter Co-variability





Example: heading vs. wind intensity (Gulf of Mexico)

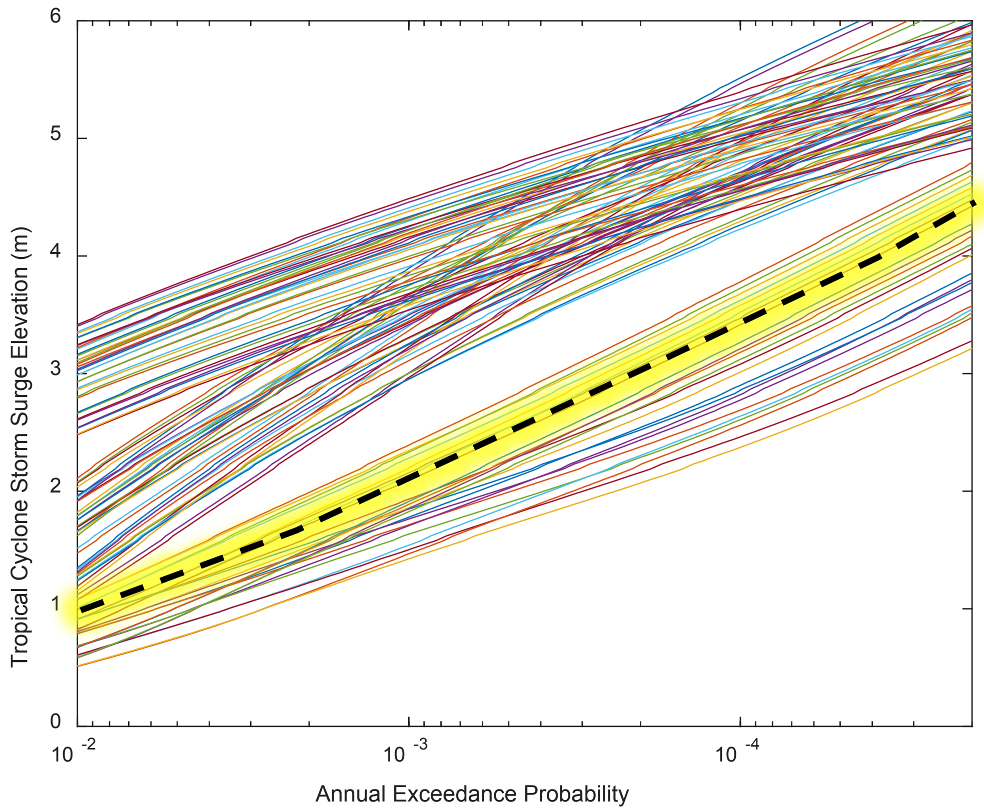
Effects of Different Input



Tested:

- Parameter co-variability;
- Parametric vs non-parametric;
- Storm surge modeling results;

Example Hazard Curves with Error/Uncertainty



$$P[\eta_{\max(1yr)} > \eta] \approx \sum_{i=1}^{n} \lambda_i P[\eta(\underline{x}_i) + \varepsilon > \eta]$$

$$\sigma = \sqrt{a_i^2 + (b_i \cdot \eta)^2}$$

where

$$a_i = \sqrt{{\varepsilon_1}^2 + {\varepsilon_2}^2} \qquad b_i = F(\varepsilon_3, \varepsilon_4)$$

i = branch number

ε_1 = uncertainty representing tide coincident with storm surge

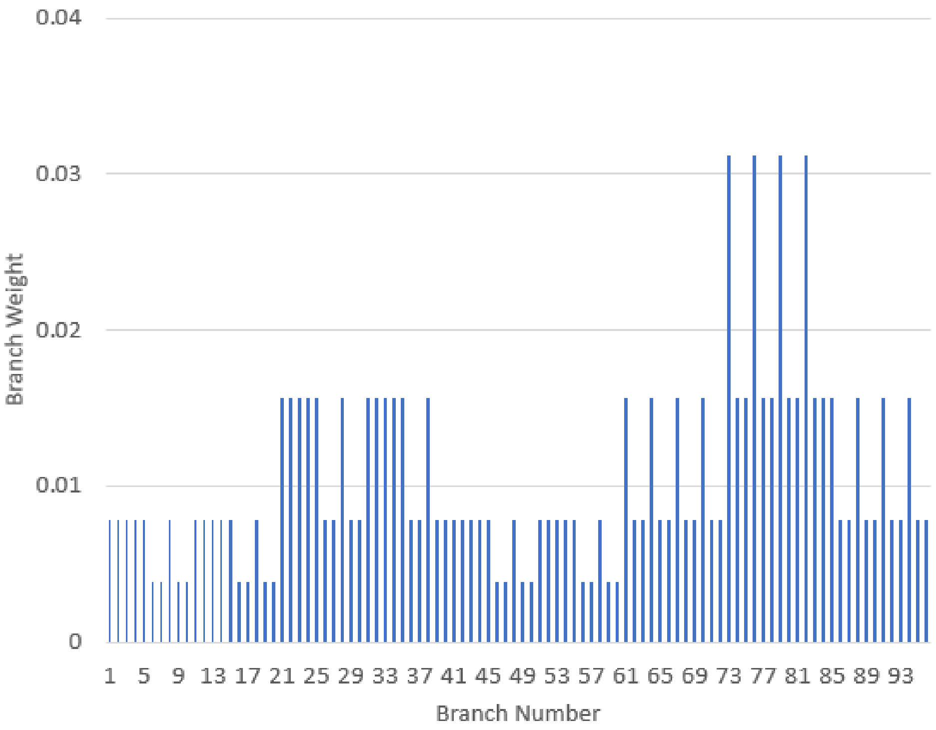
ε_2 = uncertainty in numerical surge modeling

ε_3 = uncertainty due to sampling (intensity variability)

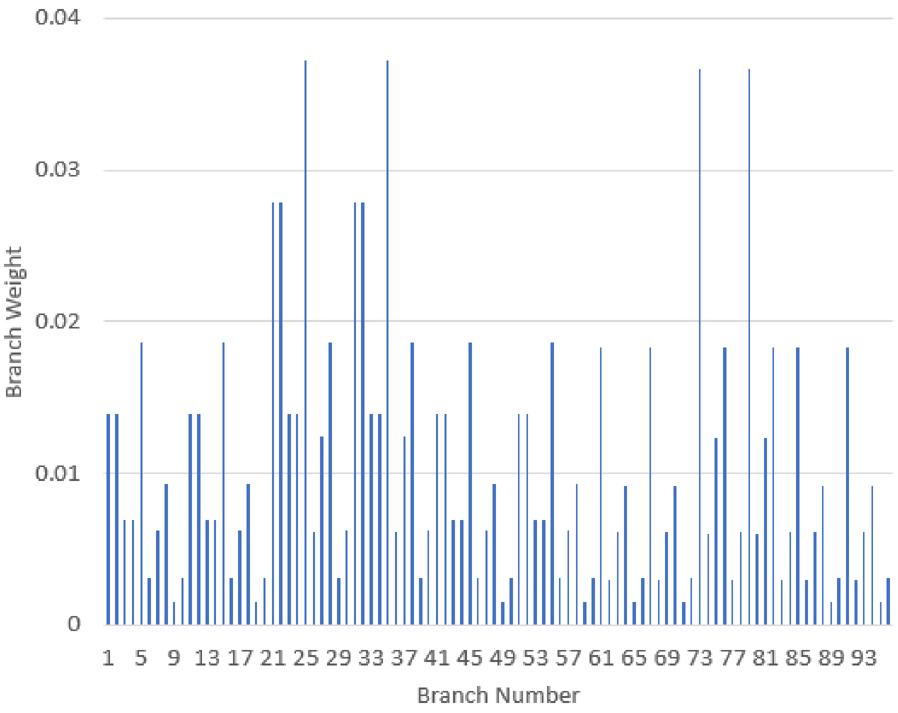
ε_4 = correction factor (project specific)

Example Branch Weights

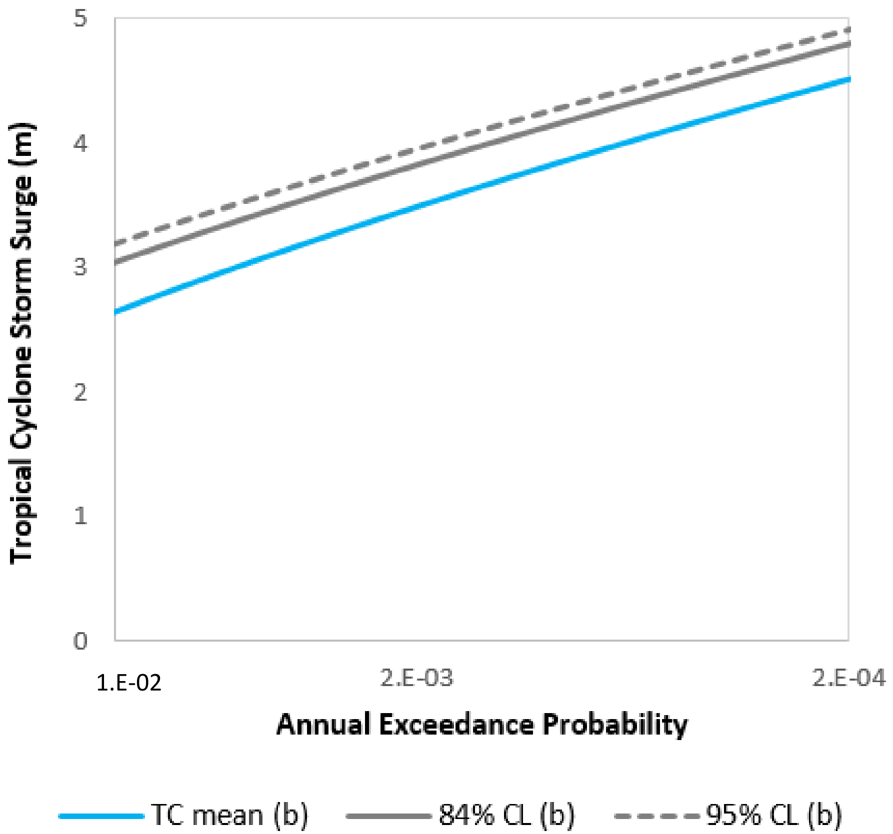
$\Sigma w_i = 1.0$

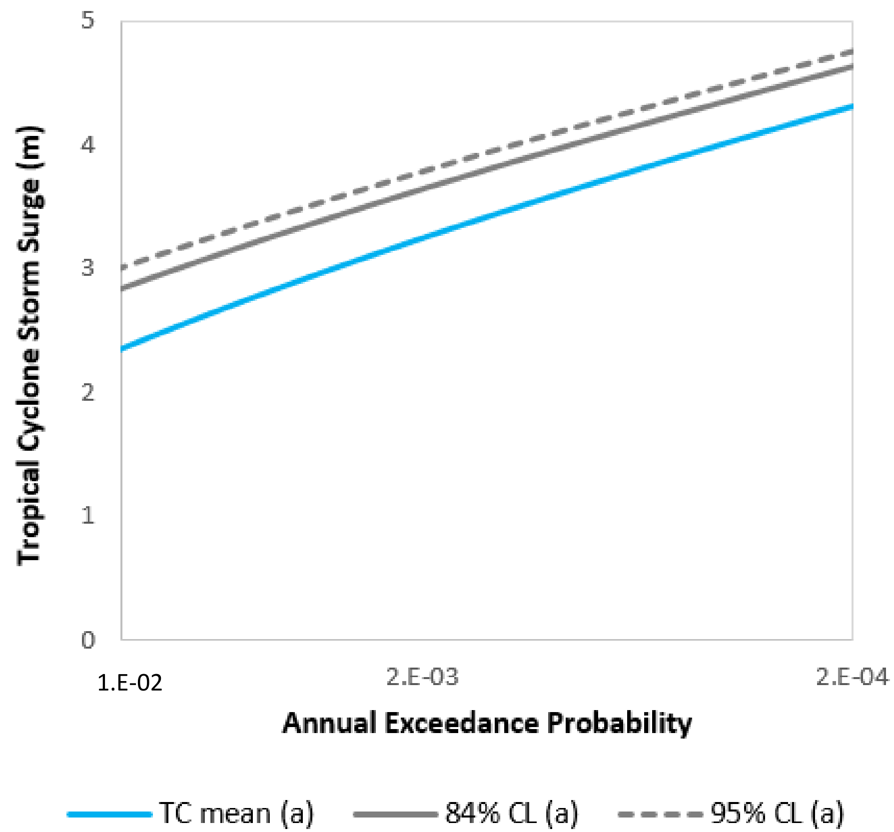


$\Sigma w_i = 1.0$

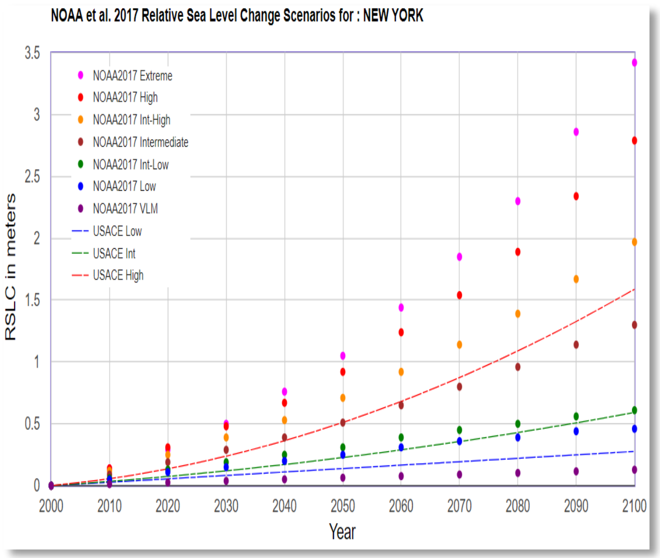


Effect of Weights on Mean Hazard Curves

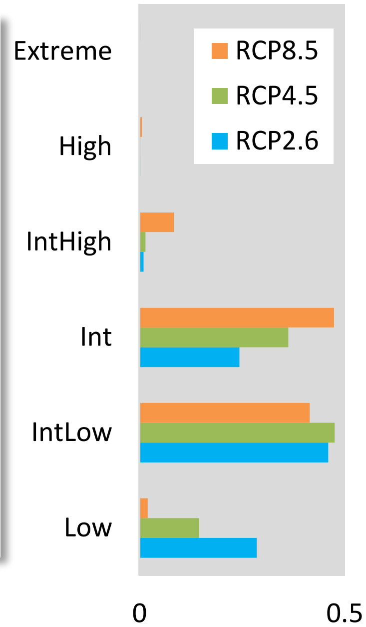




Effect of Sea Level Change Scenarios



Prob Mass of SLR Scenarios



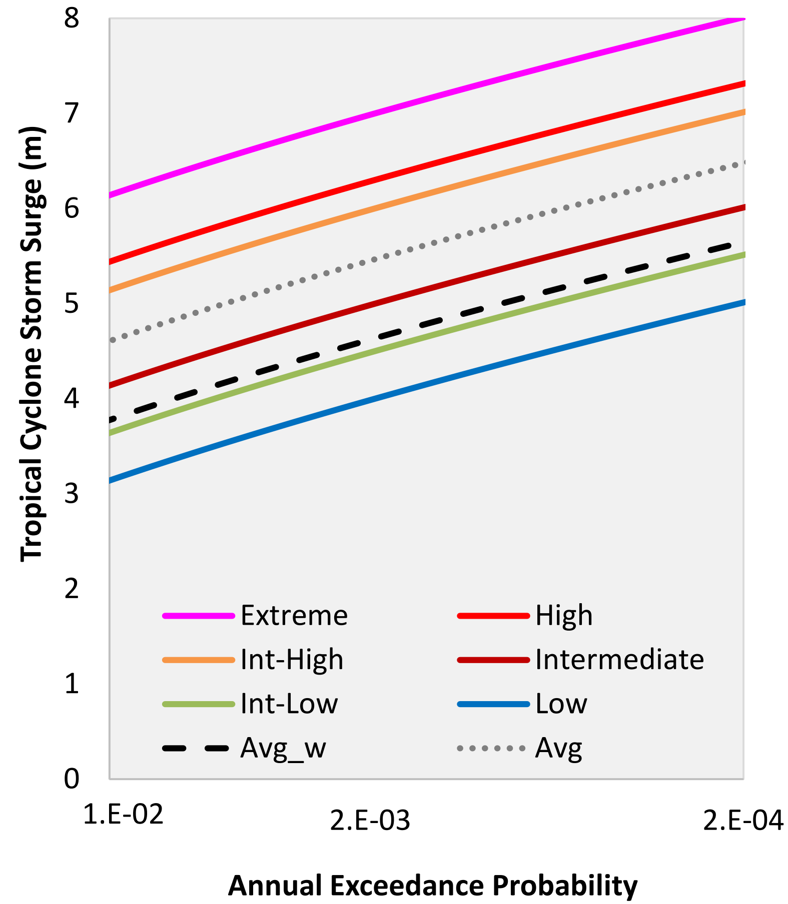


Table 4. Probability of exceeding GMSL (median value) scenarios in 2100 based upon Kopp et al. (2014).

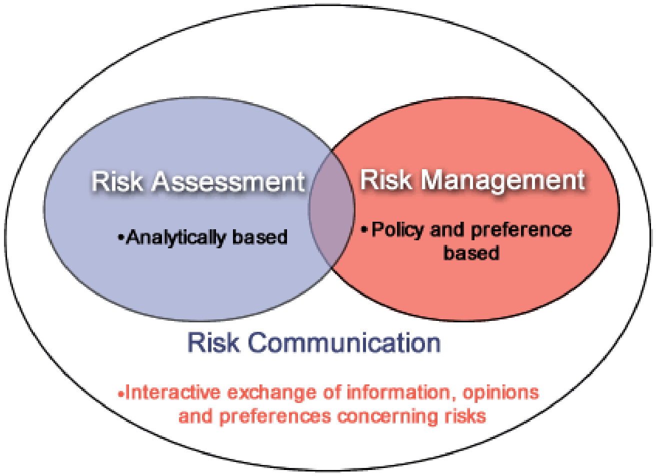
GMSL rise Scenario	RCP2.6	RCP4.5	RCP8.5
Low (0.3 m)	94%	98%	100%
Intermediate-Low (0.5 m)	49%	73%	96%
Intermediate (1.0 m)	2%	3%	17%
Intermediate-High (1.5 m)	0.4%	0.5%	1.3%
High (2.0 m)	0.1%	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.05%	0.1%

Note: SLC adjusted by linear superposition. Assumed RCP4.5

Sources: NOAA, 2017. USACE, 2017.

Takeaways

- Comprehensive and systematic approach for epistemic uncertainty assessment;
- Flexibility for sensitivity evaluation;
- Transparency for risk assessment and communication;
- Diverse applications for complex multi-component system;
- …



USACE Risk Analysis Gateway

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