Statistical Properties of Hurricane Surge

Jen Irish

Don Resio, David Divoky

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Statistical Properties of Hurricane Surge
Outline

- Motivation
- Methodology summary
- Conclusions summary
- Historical surge record approach (HSR)
- Joint probability method with response functions approach (JPM-RF)
- Methodology
- Results
  - Record length
  - Climate variability
  - Alongshore position
- Conclusions

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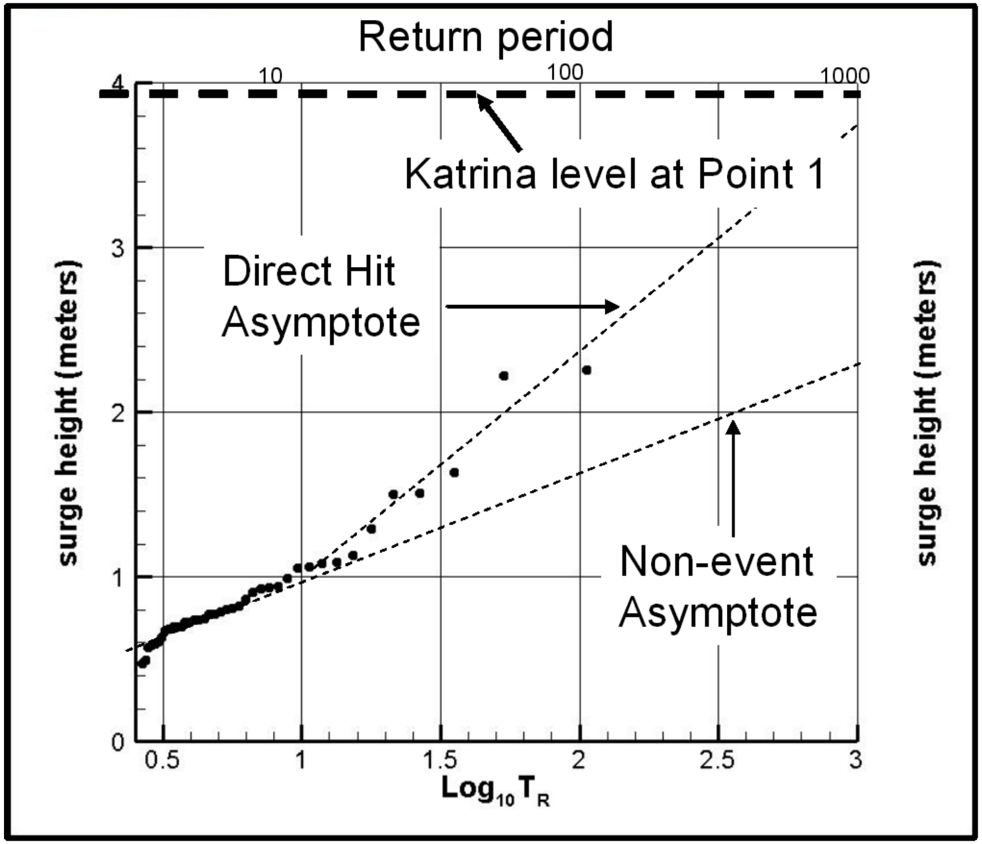
Statistical Properties of Hurricane Surge

Motivation

A robust and accurate method for determining hurricane surge extreme value statistics is required.

- Review popular statistical approaches
- Evaluate with respect to:
  - Water level record length
  - Climate variability
  - Alongshore position



Statistical Properties of Hurricane Surge
Methodology Summary

- Consider idealized, alongshore-uniform coasts
- Assume “actual” hurricane meteorological distribution
- Assume “actual” surge response
- Develop synthetic hurricane records of differing lengths
- Develop statistical estimates with:
    - “Historical” surge record (HSR)
    - Joint probability method with response functions (JPM-RF)
- Evaluate error with respect to assumed actual distribution

Statistical Properties of Hurricane Surge
Conclusions Summary

- HSR accuracy limited by record length
- JPM-RF accuracy minimally impacted by record length
- Short records yield insufficient data for HSR
- Decadal scale climate variability introduces negligible error (except for short records and HSR)
- HSR yields vastly different results, depending on along-coast position
- JPM-RF yields same result, regardless of along-coast position

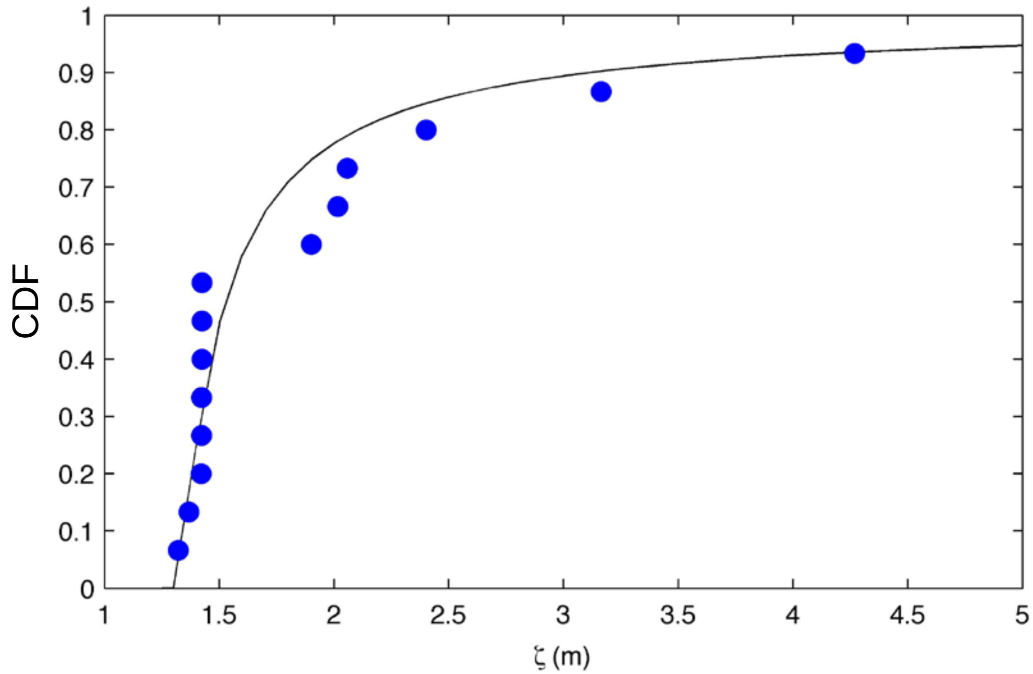
Statistical Properties of Hurricane Surge
Historical Surge Record Approach

- Form surge data set of “largest” storms (measurements or hindcasts)
- Typical applications:
  - Points over Threshold (POT)
  - Annual series
- PARAMETRIC (GEV, Weibull, Log Normal or other assumed form):
  - Considers sampling size effects on “fitted” curve
  - Uses various fitting methods (MLM, MOM, etc.)
  - Allows parametric estimation of return periods larger than given by the historical record
- NON-PARAMETRIC (e.g., EST):
  - No assumptions on data’s probability distribution in interior
  - Uses data to develop distribution in interior
  - Still extrapolates beyond data range using parametric “fit” to data
- Results known to be sensitive to record length
- Storms assumed to be from a homogeneous parent population
  - Climate variability typically excluded

Statistical Properties of Hurricane Surge
Historical Surge Record Approach

Cumulative distribution function: $$F(x) = \frac{m}{N+1}$$

Return period: $$T_R(x) = \frac{1}{\lambda[1 - F(x)]}$$



Statistical Properties of Hurricane Surge
Joint Probability Method with Response Functions Approach

General form for surge response at location x and time t:

$$\zeta(x,t) = \Phi(\underline{G}, \underline{W} \mid c_p, R_{\max}, v_f, \theta, S(t), t)$$

where

$\zeta(x,t)$ is the storm surge at location x and time t,

Φ is a numerical model used to generate surges over a grid,

$\underline{G}$ is a time invariant grid of bathymetry/topography,

$\underline{W}$ is a wind field over the grid at time t,

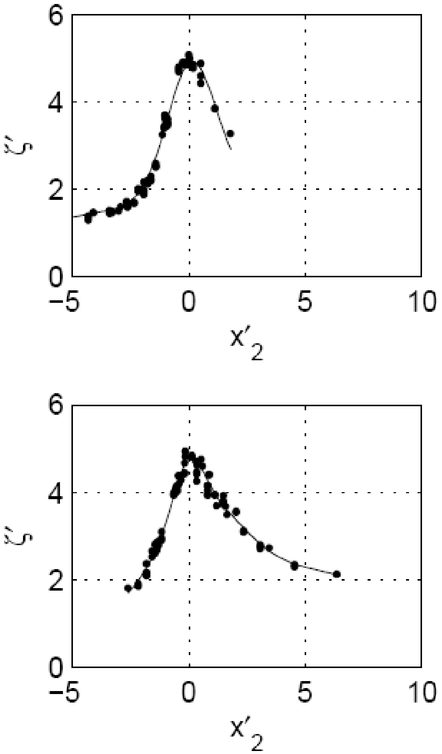
c_p is the central pressure,

$R_{\max}$ is the radius to maximum wind speed from the center of the storm,

v_f is the forward velocity of the storm,

θ is the geographic angle of the track, and

$S(t)$ is the position of the storm along the track at time t,



Statistical Properties of Hurricane Surge
Joint Probability Method with Response Function Approach

<u>Joint probability matrix:</u>

$$p(c_p, R_p, v_f, \theta_l, x) = \Lambda_1 \cdot \Lambda_2 \cdot \Lambda_3 \cdot \Lambda_4 \cdot \Lambda_5$$

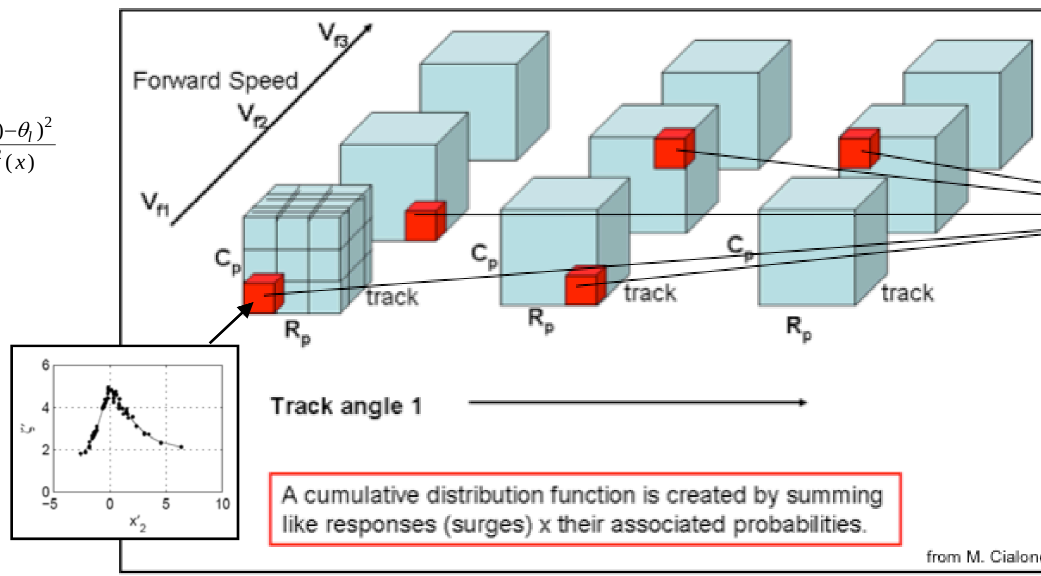
$$\Lambda_1 = p(c_p \mid x) = \frac{\partial F[a_0(x), a_1(x)]}{\partial(\Delta p \mid c_p)} = \frac{\partial}{\partial x}\left\{\exp\left\{-\exp-\left[\frac{\Delta p - a_0(x)}{a_1(x)}\right]\right\}\right\} \text{ (Gumbel Distribution)}$$

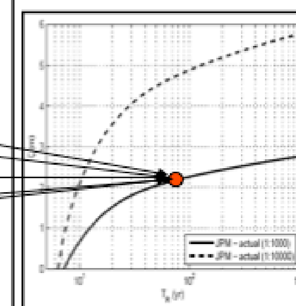
$$\Lambda_2 = p(R_p \mid c_p) = \frac{1}{\sigma(\Delta P)\sqrt{2\pi}} e^{-\frac{(\bar{R}_p(\Delta P) - R_p)^2}{2\sigma^2(\Delta P)}}$$

$$\Lambda_3 = p(v_f \mid \theta_l) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\bar{v}_f(\theta_l) - v_f)^2}{2\sigma^2}}$$

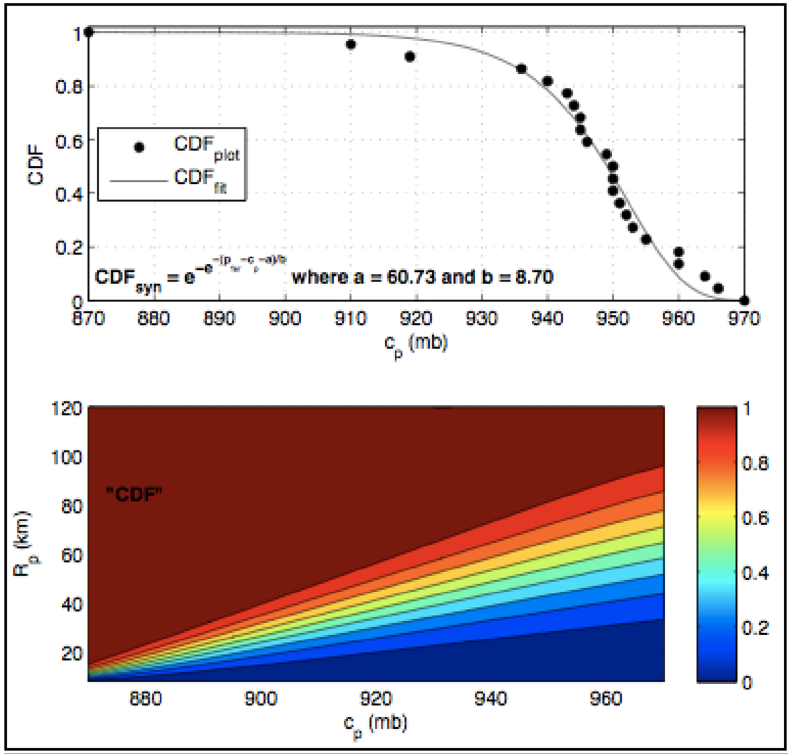
$$\Lambda_4 = p(\theta_l \mid x) = \frac{1}{\sigma(x)\sqrt{2\pi}} e^{-\frac{(\bar{\theta}_l(x) - \theta_l)^2}{2\sigma^2(x)}}$$

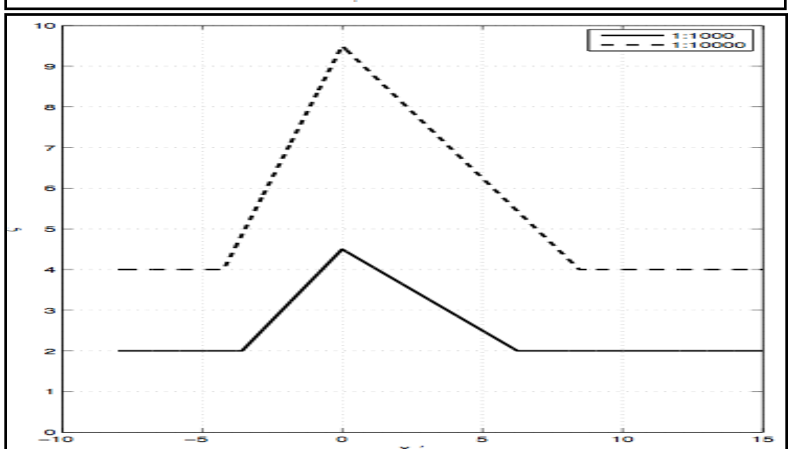
$$\Lambda_5 = \Phi(x)$$



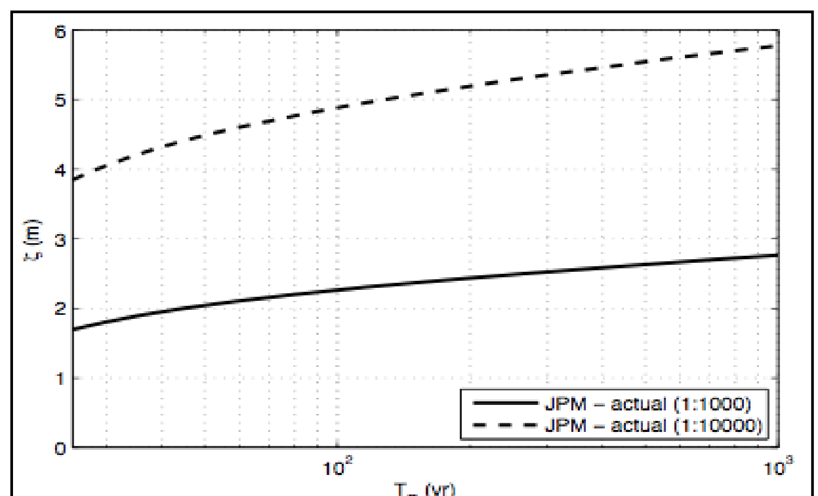


Statistical Properties of Hurricane Surge
Methodology – Assumed "Actual" Conditions





- Alongshore-uniform:
  - Slope = 1:1000 & 1:10000
  - 2000 km (~ US GOM length)
- Historical meteorological record:
  - $p(c_p, R_p, x) = \Lambda_1 \Lambda_2 \Lambda_5$
  - λ = 0.36* (Poisson assumed)
- Surge response functions from idealized ADCIRC simulations



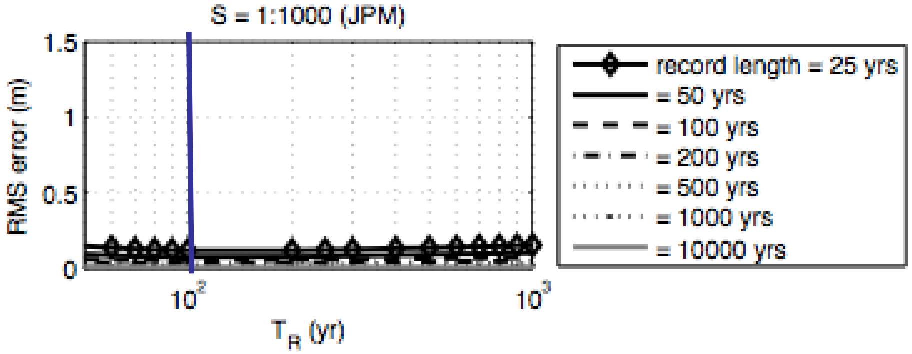
Statistical Properties of Hurricane Surge
Methodology – Surge Records and Statistical Estimates

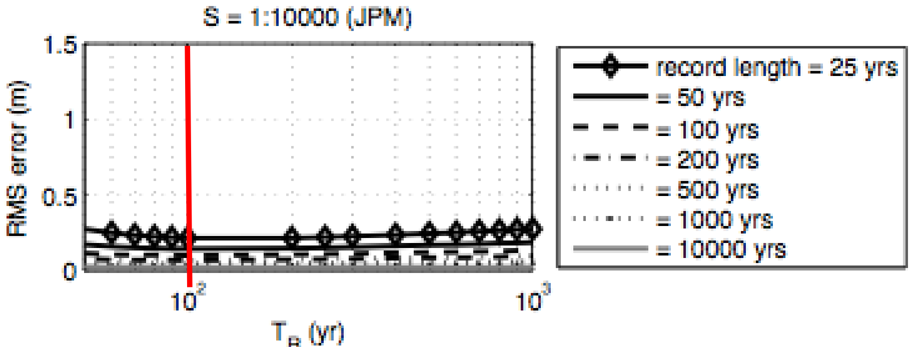
- Record lengths: 25 yrs to 10000 yrs
- Up to 850 records generated per length (to convergence)
- HSR application:
  - POT: > 1.5 m
  - Parameterized fit: GEV when N >= 5 & Gumbel otherwise
  - Evaluated at x = 500 to 1500 km, at 10-km increments
- JPM-RF application:
  - $p(c_p, R_p, x) = \Lambda_1 \Lambda_2 \Lambda_5$ recomputed

Statistical Properties of Hurricane Surge

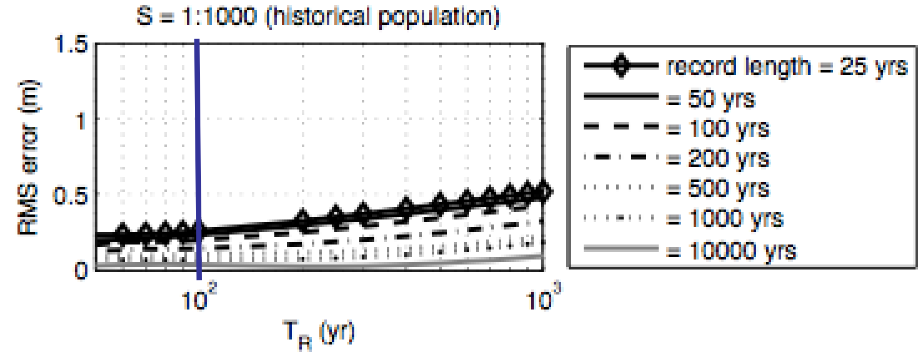
Results – Record Length

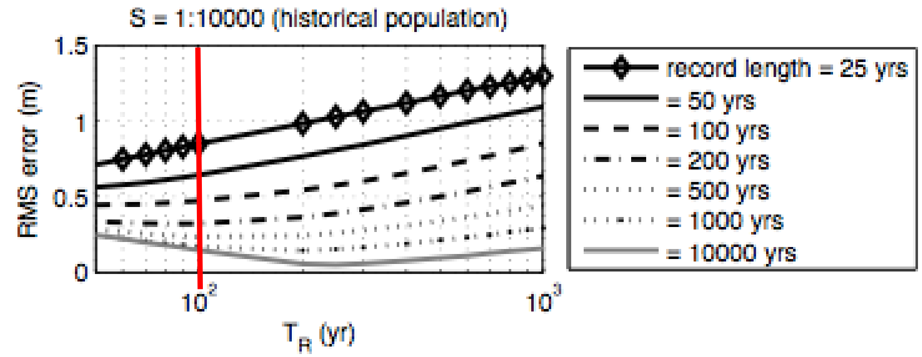
JPM-RF





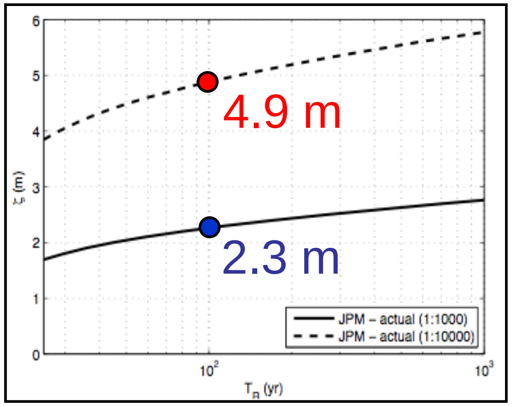
HSR





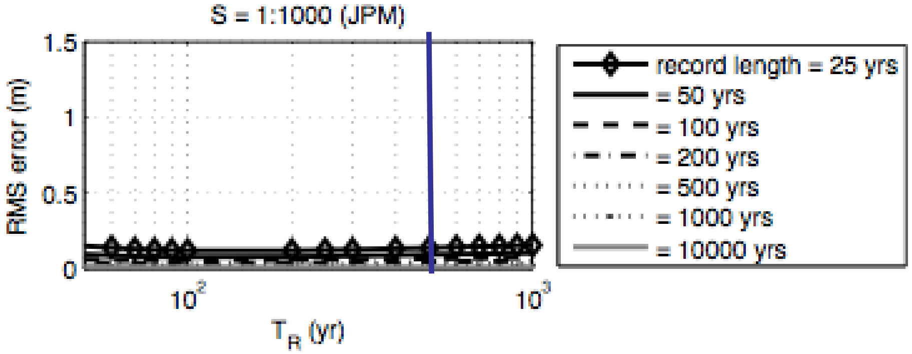
Return period = 100 yrs

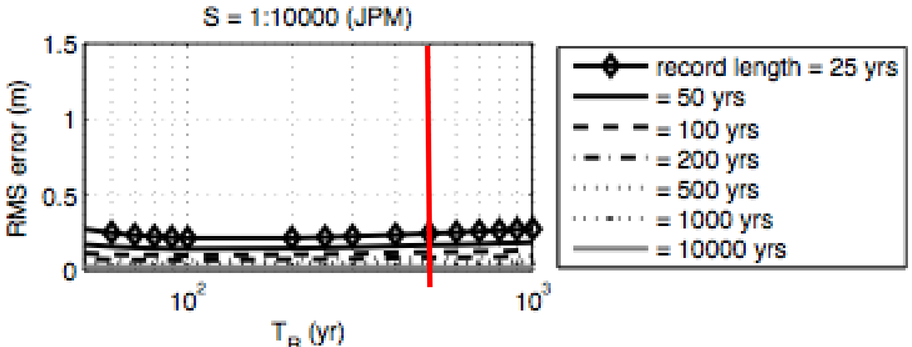
- JPM-RF RMS error <= 0.12 m/0.22 m
- HSR RMS error:
  - 0.26 m/0.85 m for 25-yr record
  - 0.23 m/0.64 m for 50-yr record
  - 0.20 m/0.47 m for 100-yr record
  - About 1000 years of data needed for similar accuracy



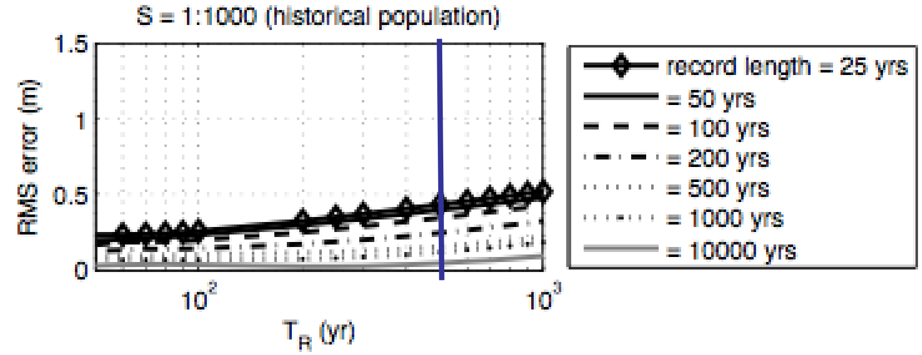
Statistical Properties of Hurricane Surge
Results – Record Length

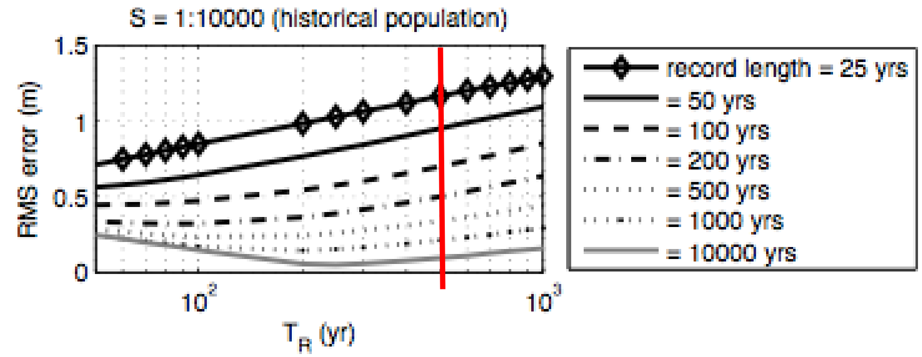
JPM-RF





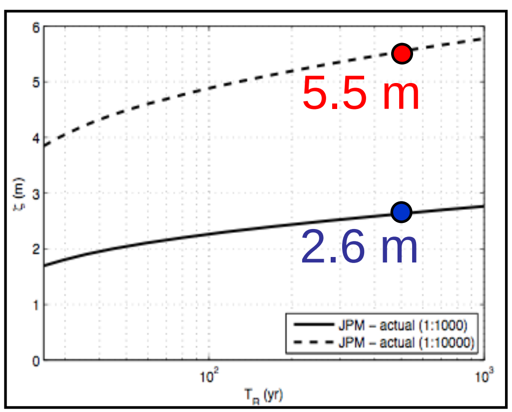
HSR





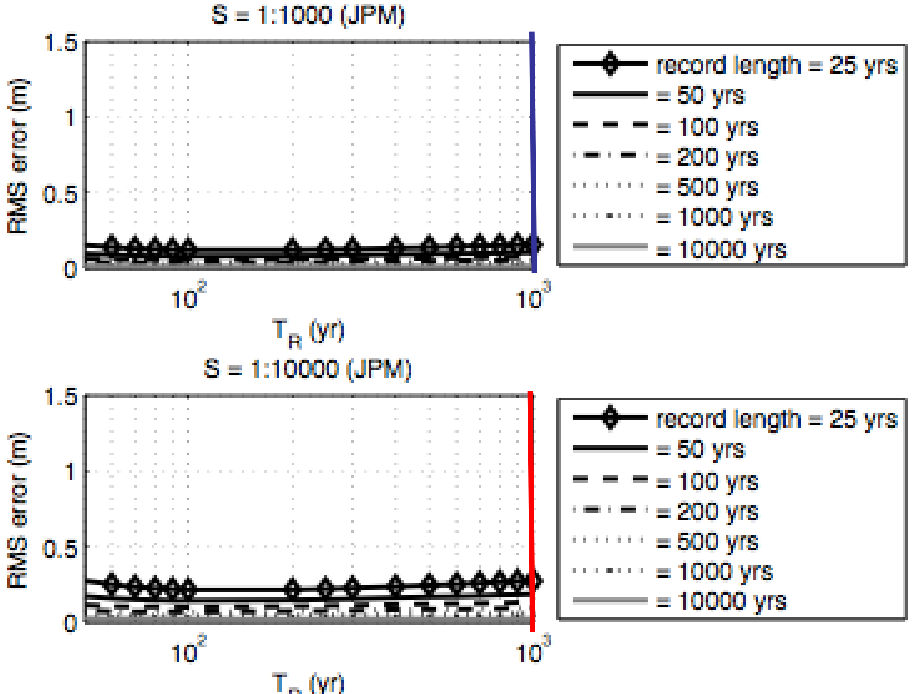
Return period = 500 yrs

- JPM-RF RMS error <= 0.14 m/0.25 m
- HSR RMS error:
  - 0.43 m/1.16 m for 25-yr record
  - 0.40 m/0.95 m for 50-yr record
  - 0.34 m/0.70 m for 100-yr record
  - More than 1000 years of data needed for similar accuracy

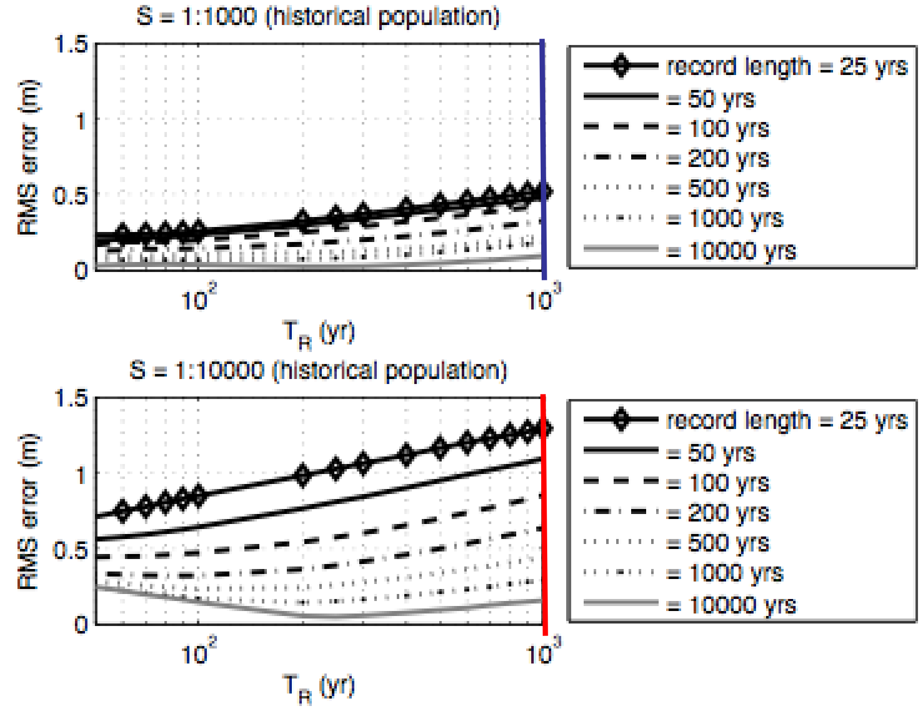


Statistical Properties of Hurricane Surge
Results – Record Length

JPM-RF

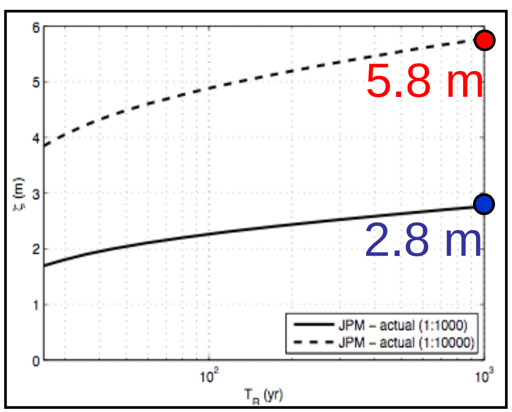


HSR



Return period = 1000 yrs

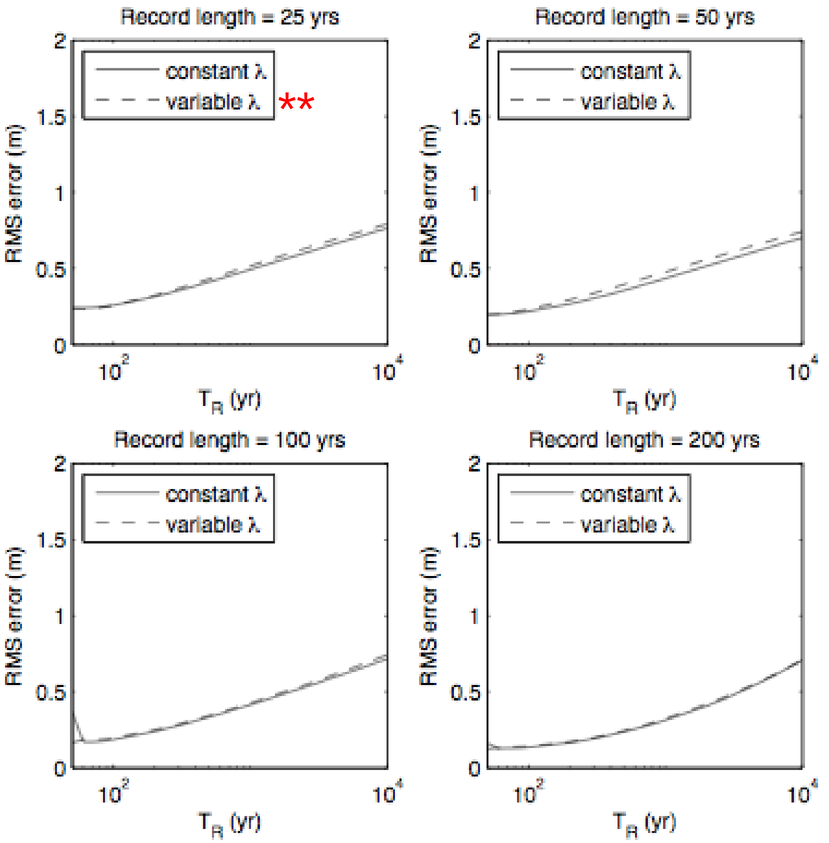
- JPM-RF RMS error <= 0.16 m/0.28 m
- HSR RMS error:
  - 0.52 m/1.29 m for 25-yr record
  - 0.48 m/1.09 m for 50-yr record
  - 0.43 m/0.85 m for 100-yr record
  - 1000s of years of data needed for similar accuracy



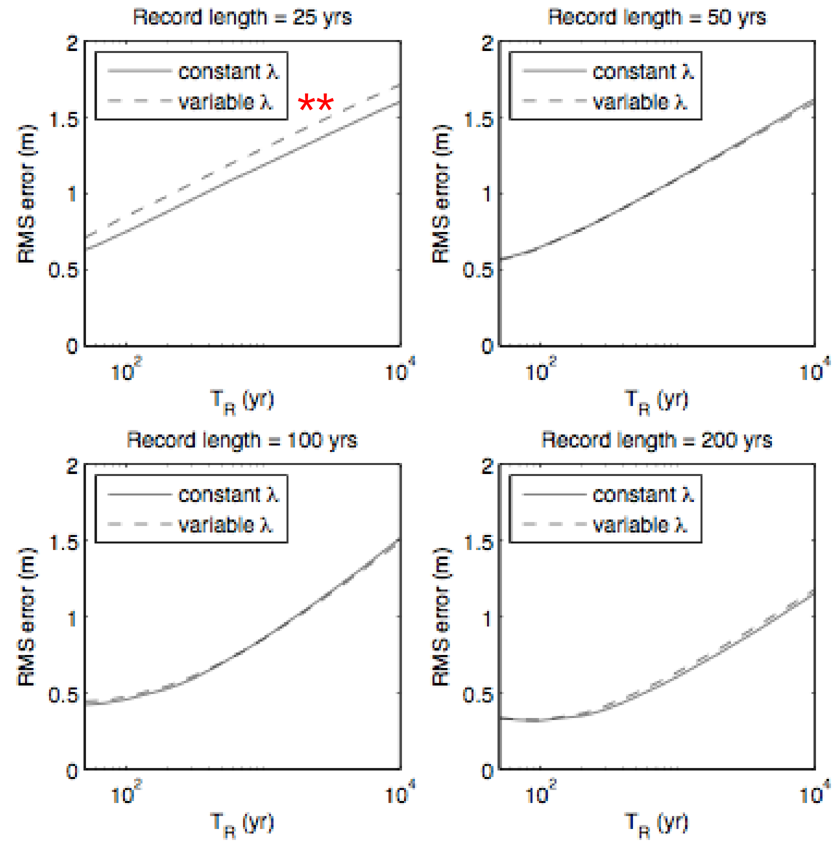
Statistical Properties of Hurricane Surge
Results – Climate Variability (Rate of Occurrence)

- Assumed λ(t):
  - 10 years of high activity: λ(t) = 1.14
  - 30 years of low activity: λ(t) = 0.10

HSR with 1:1000 slope



HSR with 1:10000 slope

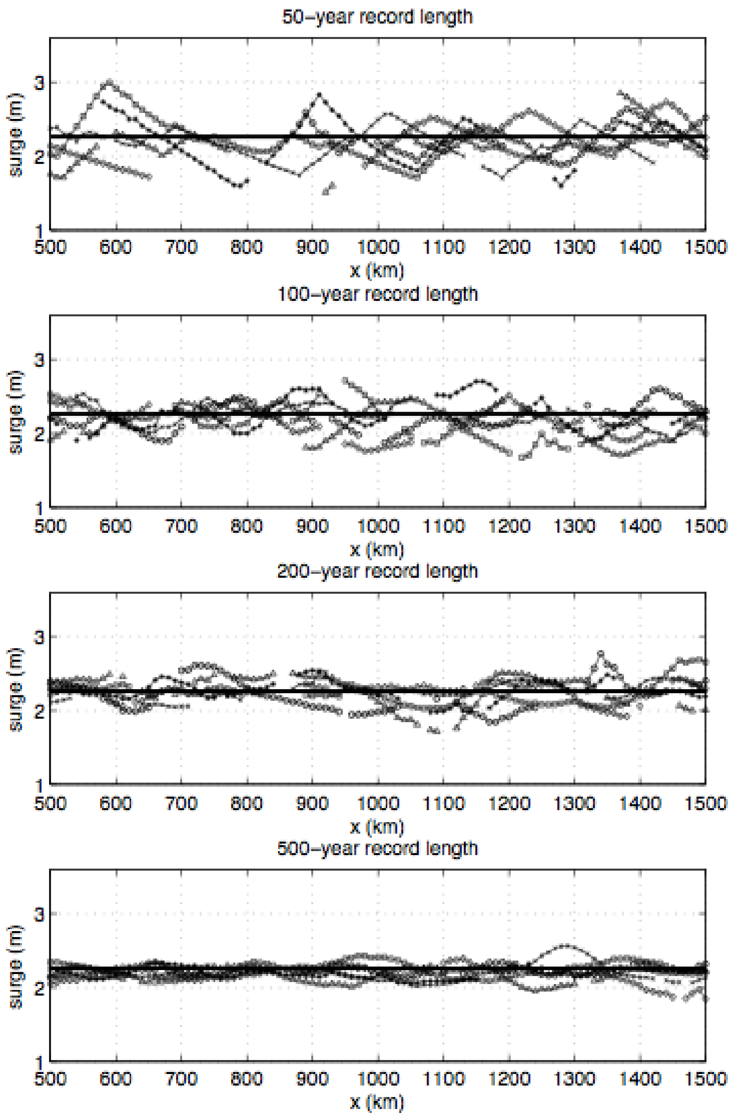


**6% yield insufficient data

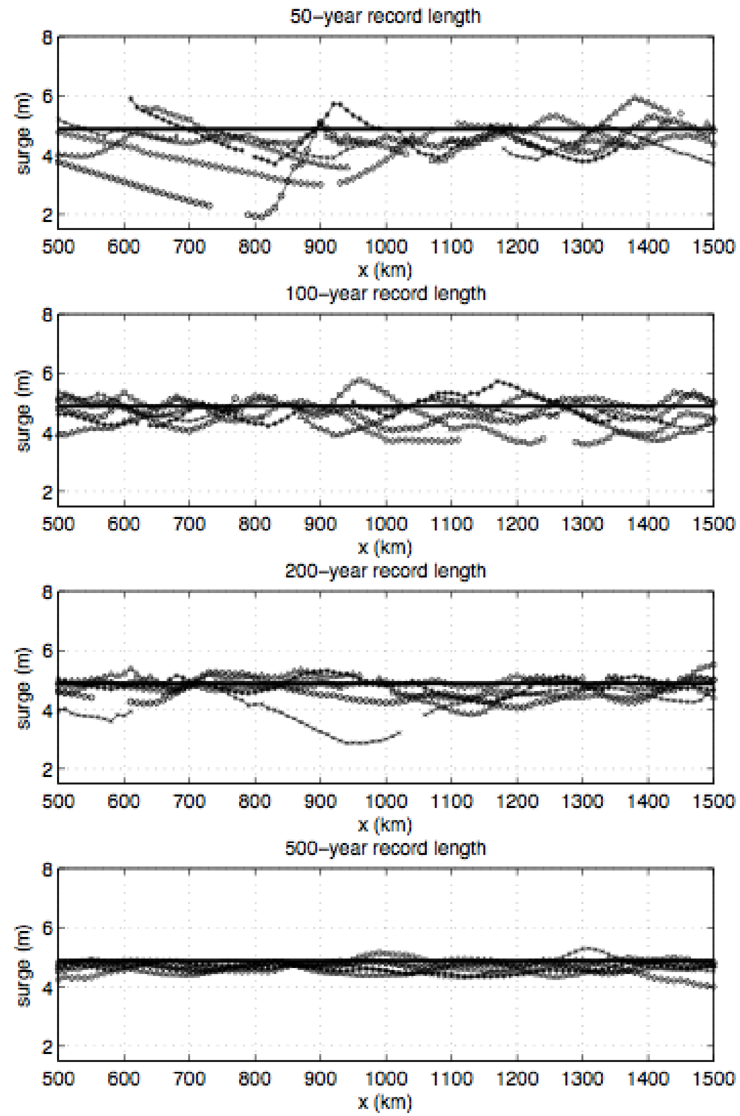
Statistical Properties of Hurricane Surge

Results – Alongshore Position (100-yr Return Period)

1:1000 slope



1:10000 slope



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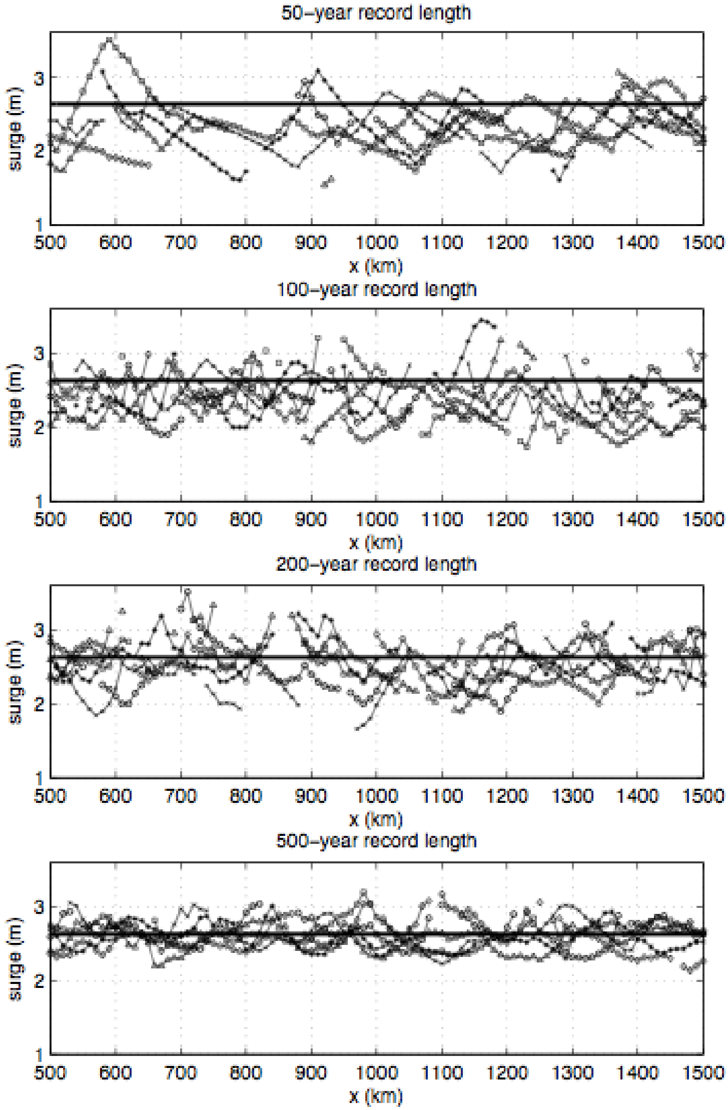
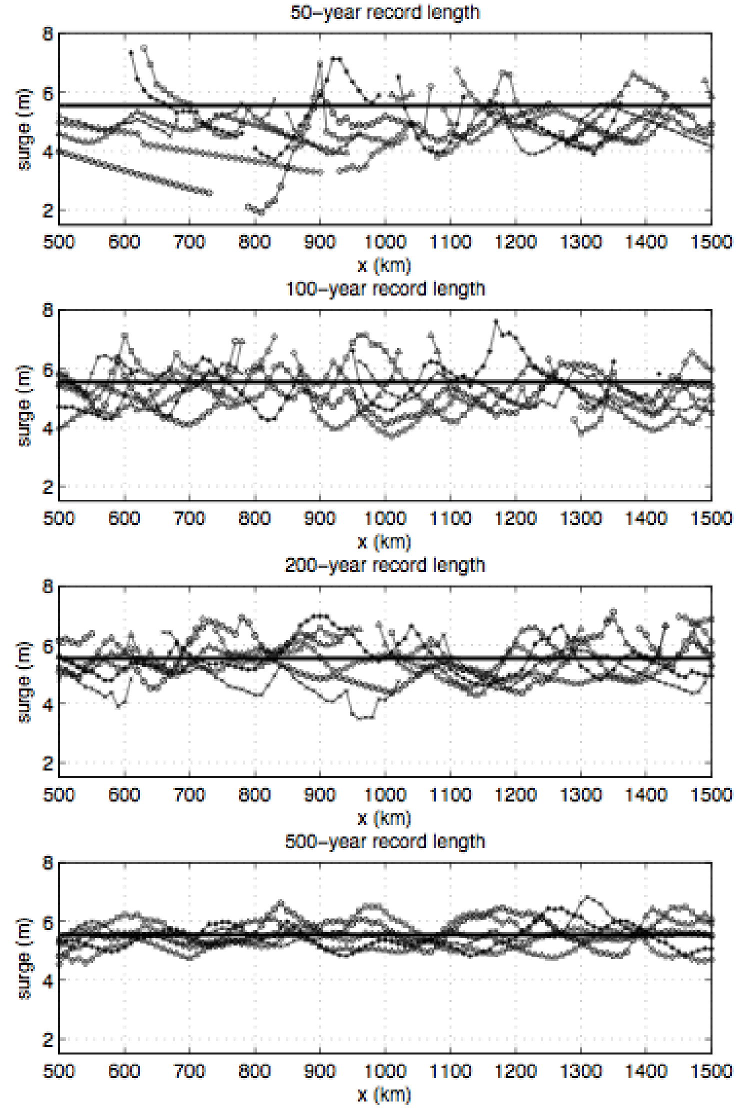
Statistical Properties of Hurricane Surge

Results – Alongshore Position (500-yr Return Period)

1:1000 slope



1:10000 slope



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Conclusions Summary – Revisited

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