CHARACTERIZATION OF SPATIAL VARIATION IN HURRICANE SURGE

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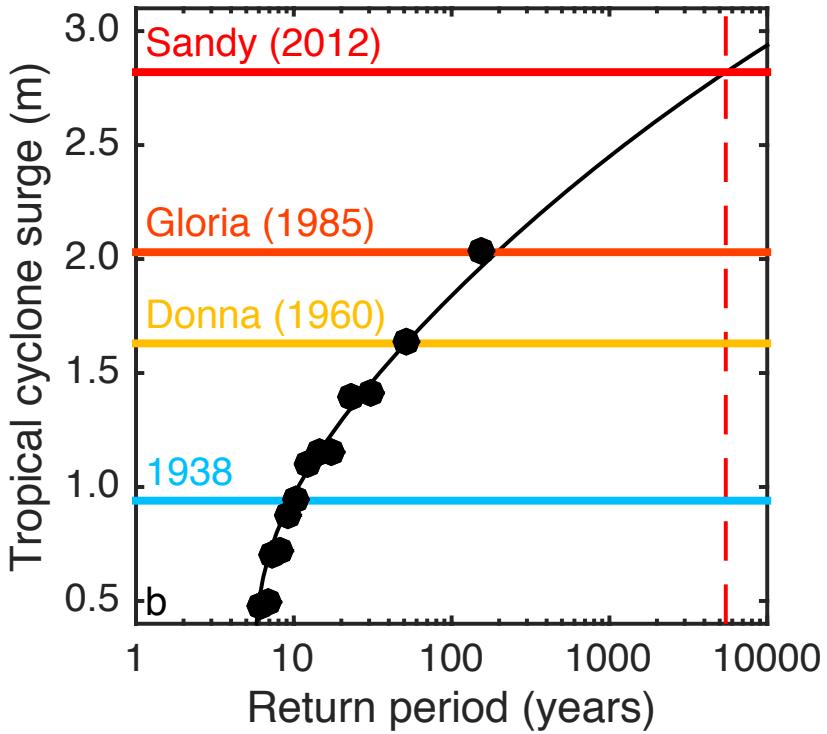
OUTLINE

- Motivation & background
- Study area & storm simulations
- Spatial decomposition
- Surge estimation with reduced storm sets
- Conclusions

HURRICANE IRMA (2017)
NAPLES, FL

MOTIVATION & BACKGROUND: PROBABILISTIC SURGE HAZARD ASSESSMENT

HISTORICAL STORM METHOD



For New York City, from Resio & Irish, 2015, *Curr. Clim. Change Rep.*

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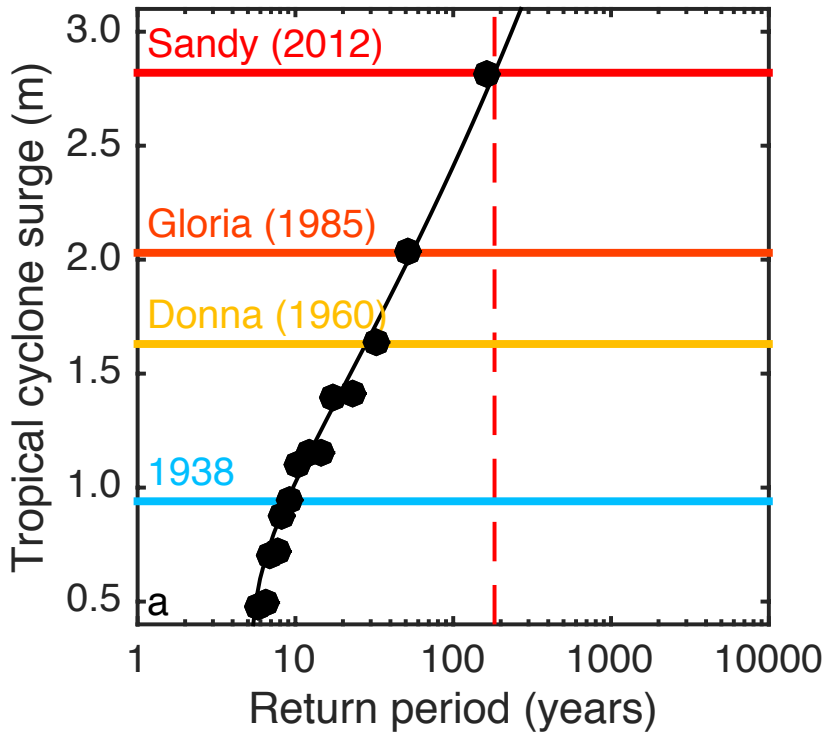
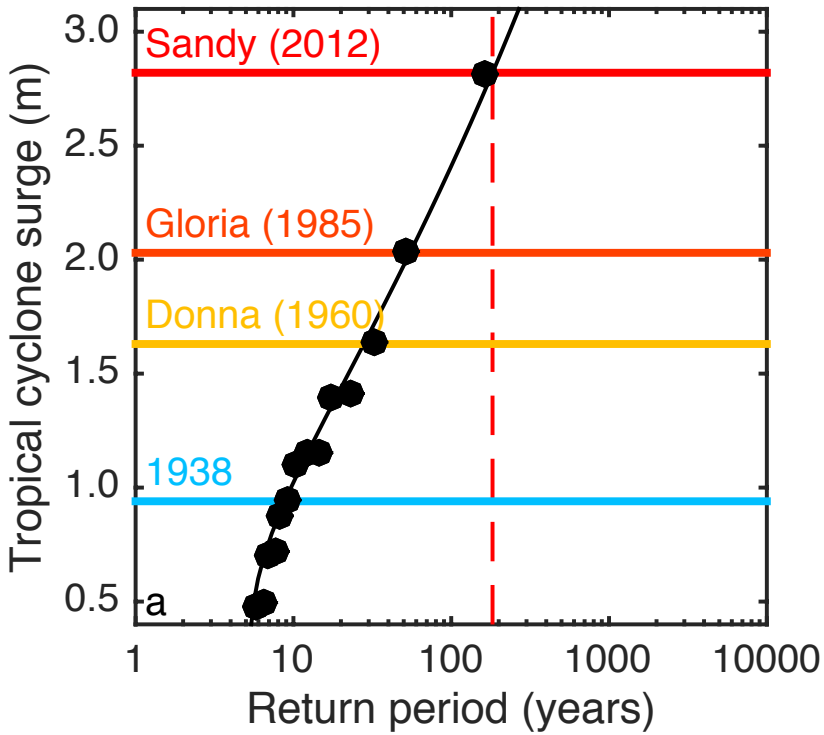


100-yr surge increases 33%

For New York City, from Resio & Irish, 2015, *Curr. Clim. Change Rep.*

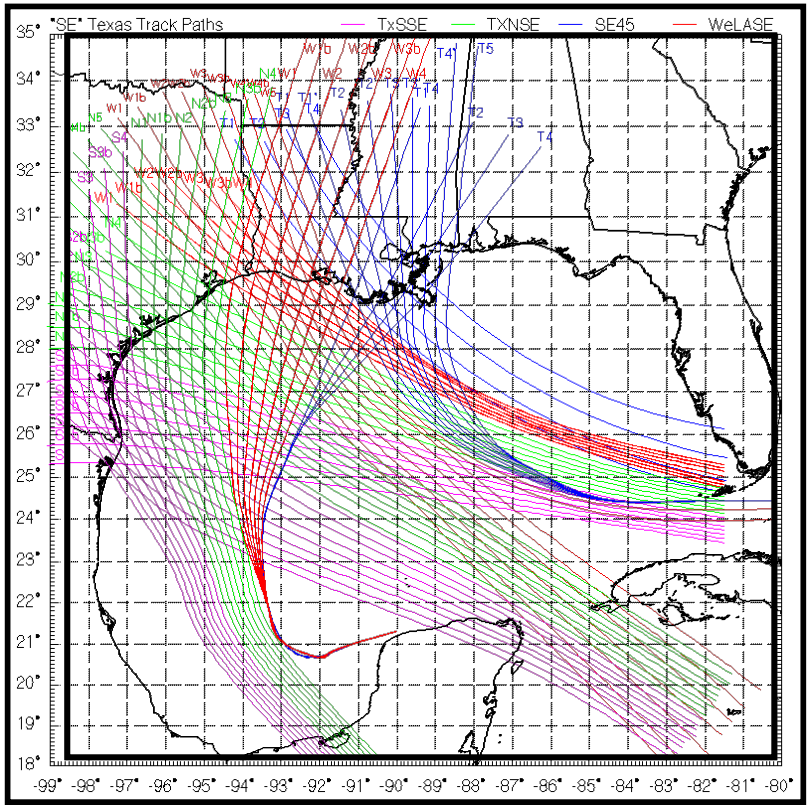
MOTIVATION & BACKGROUND: PROBABILISTIC SURGE HAZARD ASSESSMENT

HISTORICAL STORM METHOD



100-yr surge increases 33%

JOINT PROBABILITY METHOD (JPM)



For New York City, from Resio & Irish, 2015, *Curr. Clim. Change Rep.*

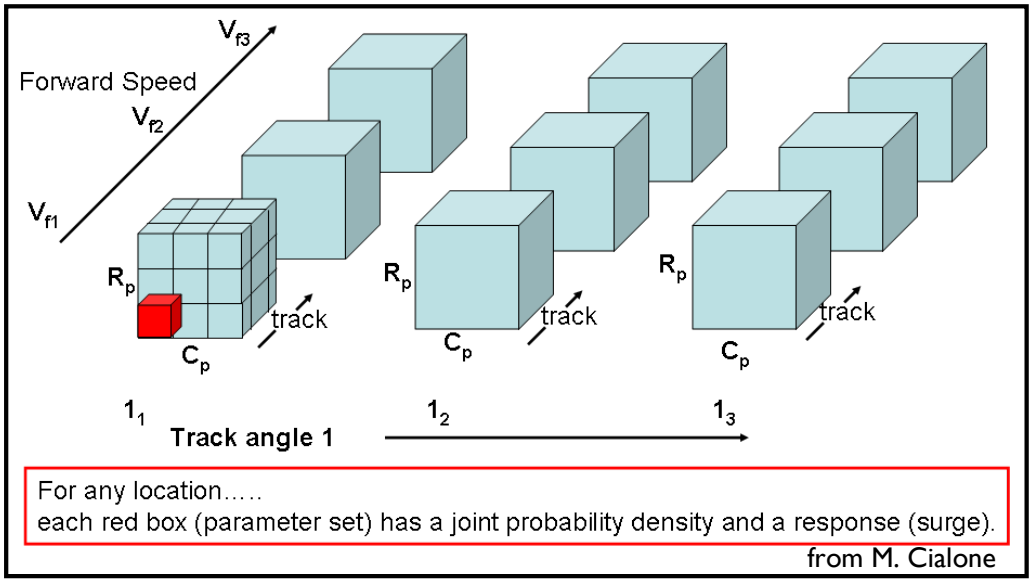
MOTIVATION & BACKGROUND: JPM WITH OPTIMAL SAMPLING (JPM-OS)

BAYESIAN QUADRATURE

- Assigns probability masses to discrete storm simulations

SURGE RESPONSE FUNCTIONS

- Physics-based functions developed from discrete storm simulations
- Probability density assigned over the continuum of storm possibilities



MOTIVATION & BACKGROUND: JPM-OS

CURRENT PRACTICE: SURGE RESPONSE FUNCTIONS

$$\eta' = \frac{\rho g \eta}{\Delta p}$$

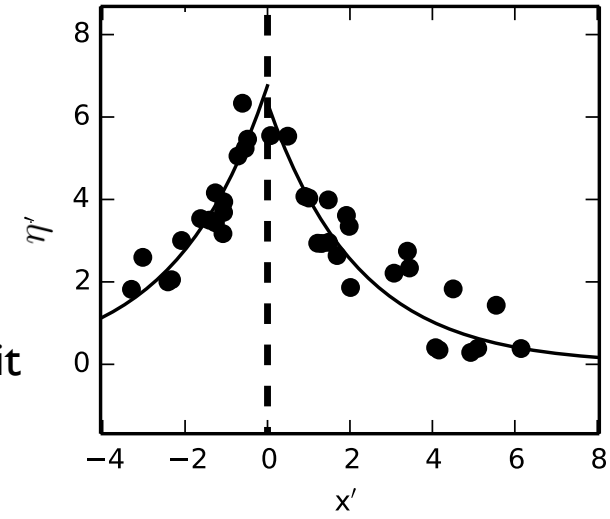
$$x' = \frac{x_{loc} - x}{R} - \lambda$$

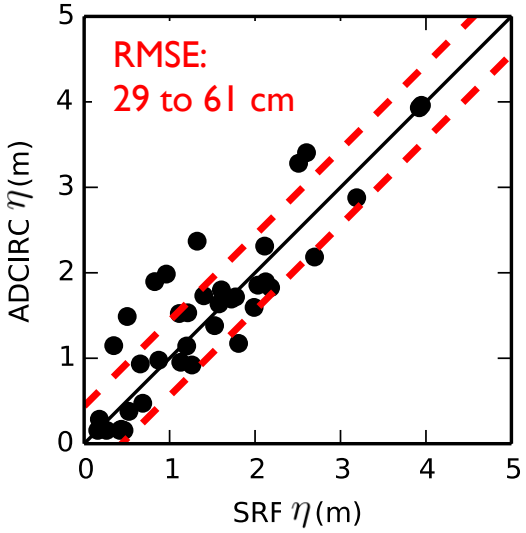
η is peak surge

Δp is central pressure deficit

x is landfall location

R is storm radius



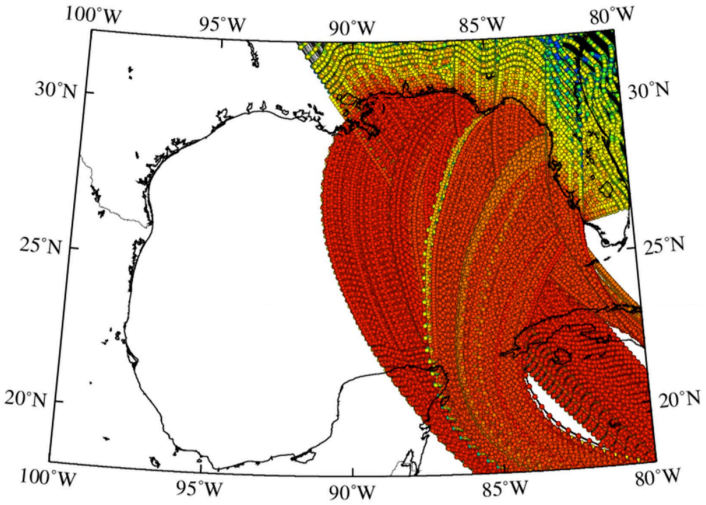


- SRFs at discrete geographic locations
- **Need approach for describing spatial variation**

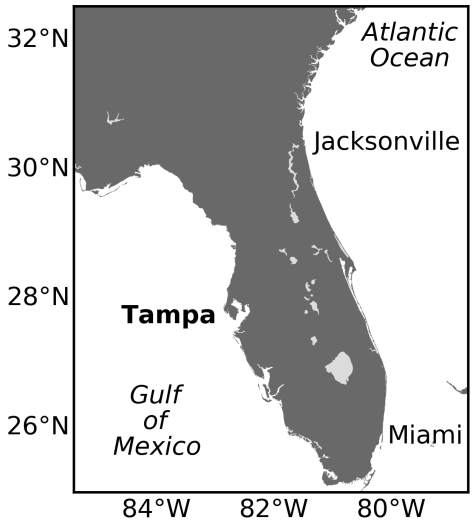
From Irish et al., 2009 *Nat. Hazards* and Taylor et al., 2015 *Nat. Hazards*

STUDY AREA & STORM SIMULATIONS

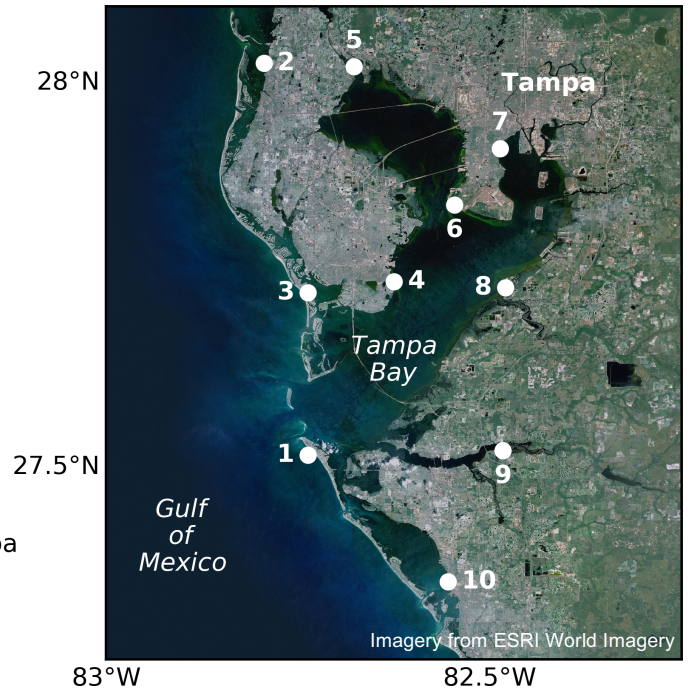
- FEMA's West Florida study
- ADCIRC coarse mesh
- 19406 storms
- 55 locations



From RAMPP 2016

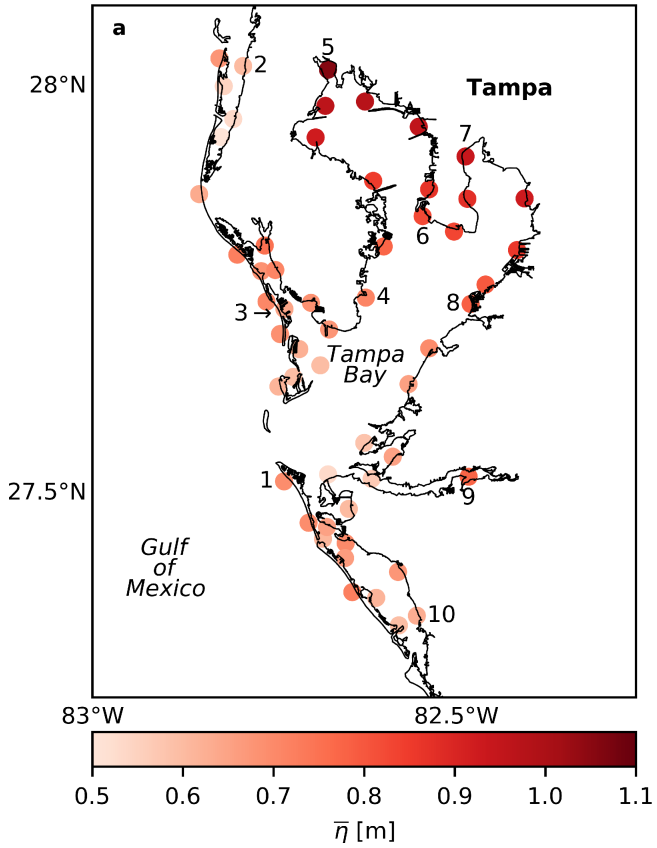


1: Anna Maria
2: Clearwater
3: St. Pete Beach
4: St. Petersburg
5: Oldsmar
6: South Tampa
7: Tampa
8: Ruskin
9: Fort Hamer
10: Sarasota

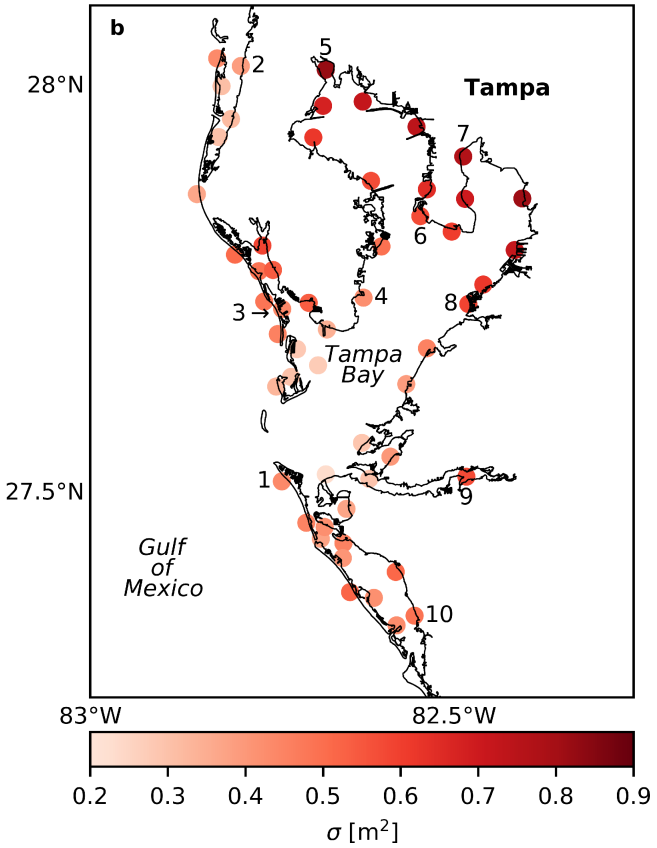


SPATIAL DECOMPOSITION: EMPIRICAL ORTHOGONAL FUNCTIONS (EOF)

MEAN



VARIANCE



$$\eta_{ij} = \sum_{k}^{K} e_{ik} w_{jk} + \bar{\eta}_i$$

$$\epsilon^2 = \epsilon^2_{sim} + \epsilon^2_{EOF}$$

η is peak surge

e is eigenfunction component

w is eigenfunction weight

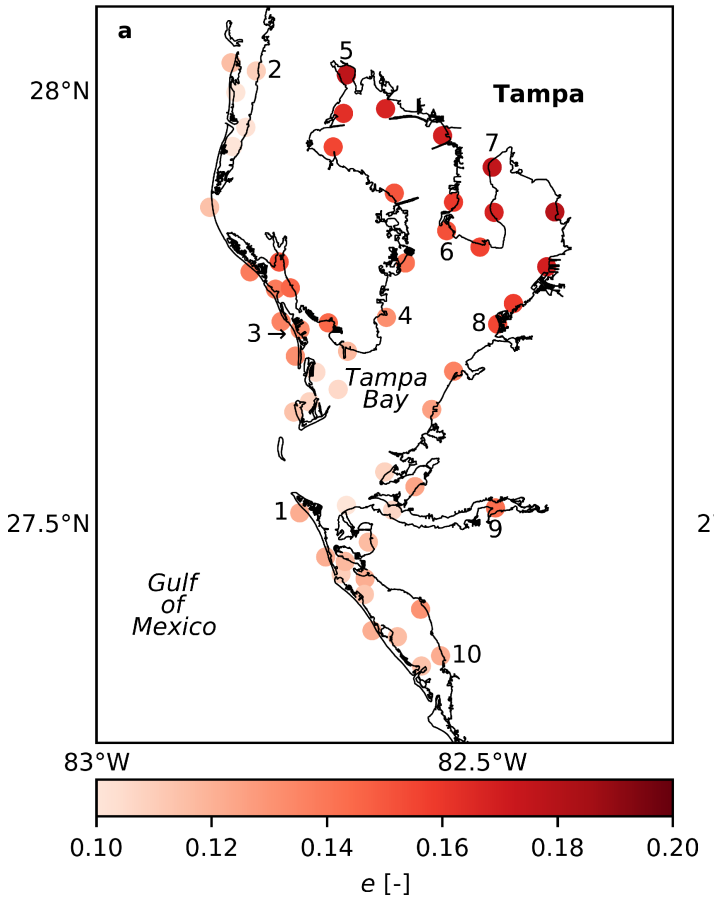
$\bar{\eta}$ is mean peak surge

ϵ is model uncertainty

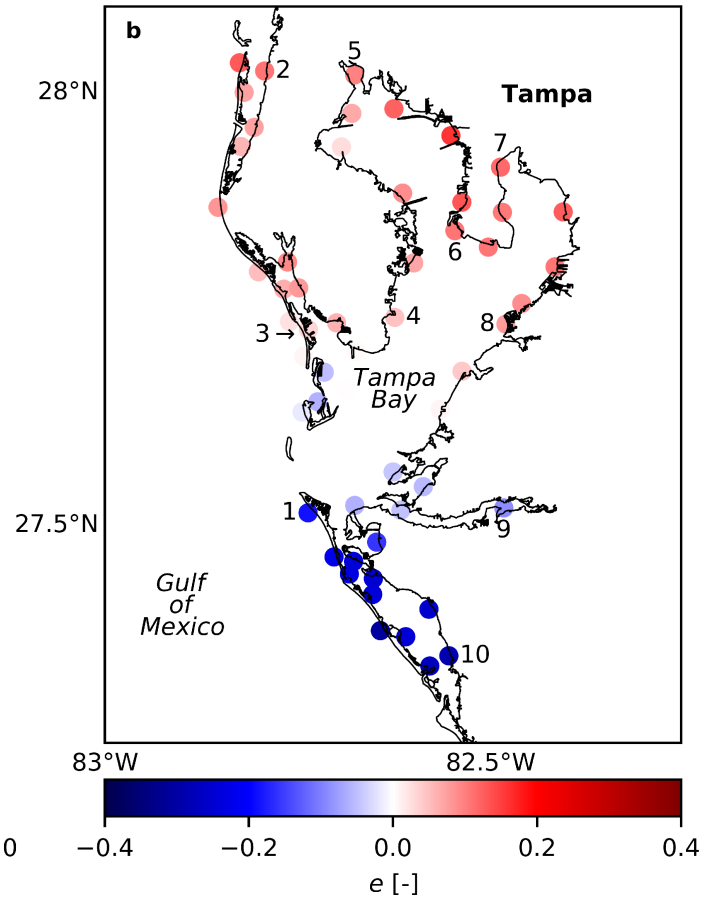
Preliminary work

SPATIAL DECOMPOSITION: EIGENFUNCTION COMPONENTS

MODE 1 (88.9%)



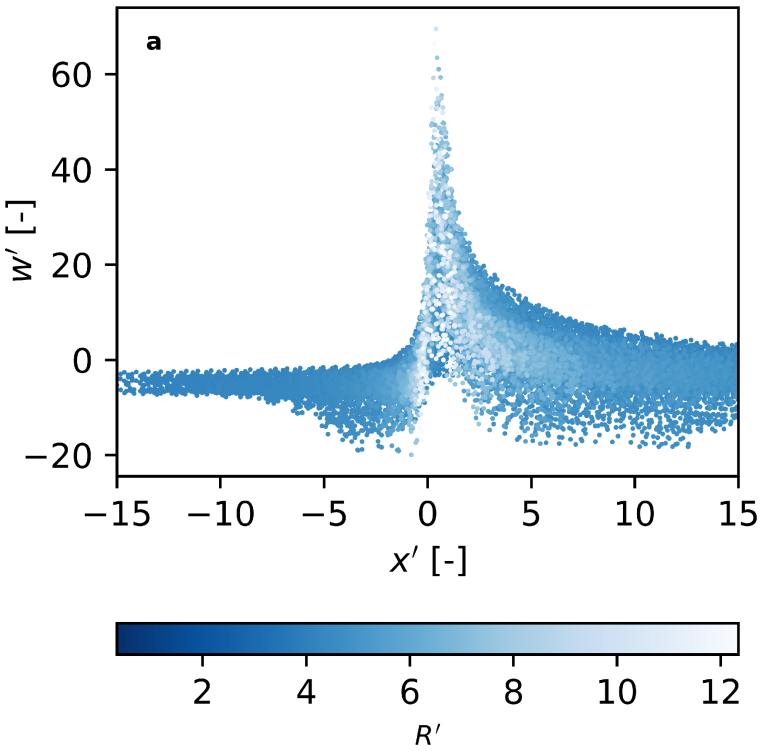
MODE 2 (5.4%)



Preliminary work

SPATIAL DECOMPOSITION: EIGENFUNCTION WEIGHTS

MODE 1 (88.9%)



$$w' = \frac{\rho g(w-\alpha)}{\Delta p}\left[\text{sign}(V_{f_{ref}} - V_f)\right]^{\beta} + \kappa\left(\frac{V_f}{V_{f_{ref}}}\right)$$

$$x' = \frac{x_{ref} - x}{R}\left(\frac{R}{R_{ref}}\right)^{\nu}$$

Δp is central pressure deficit

V_f is forward speed

x is landfall location

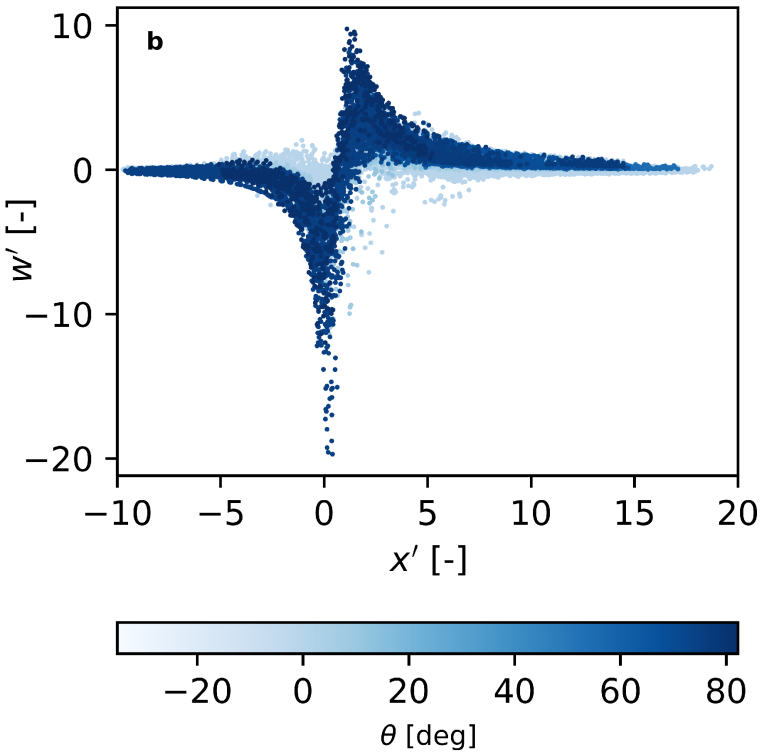
R is storm radius

θ is heading

Preliminary work

SPATIAL DECOMPOSITION: EIGENFUNCTION WEIGHTS

MODE 2 (5.4%)



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Δp is central pressure deficit

V_f is forward speed

x is landfall location

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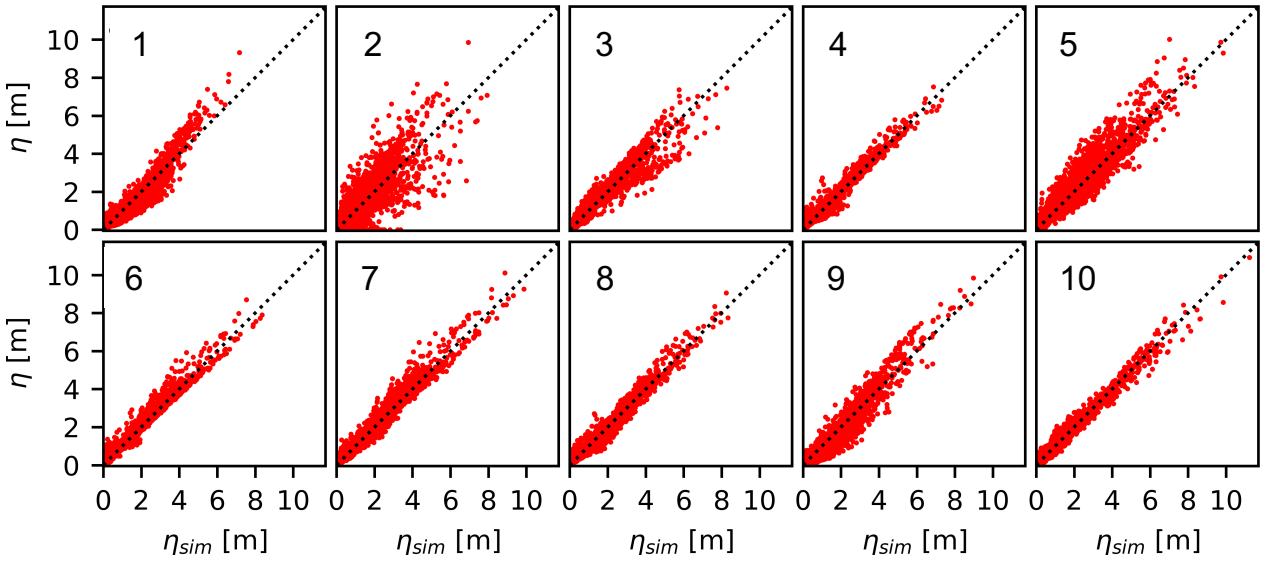
Preliminary work

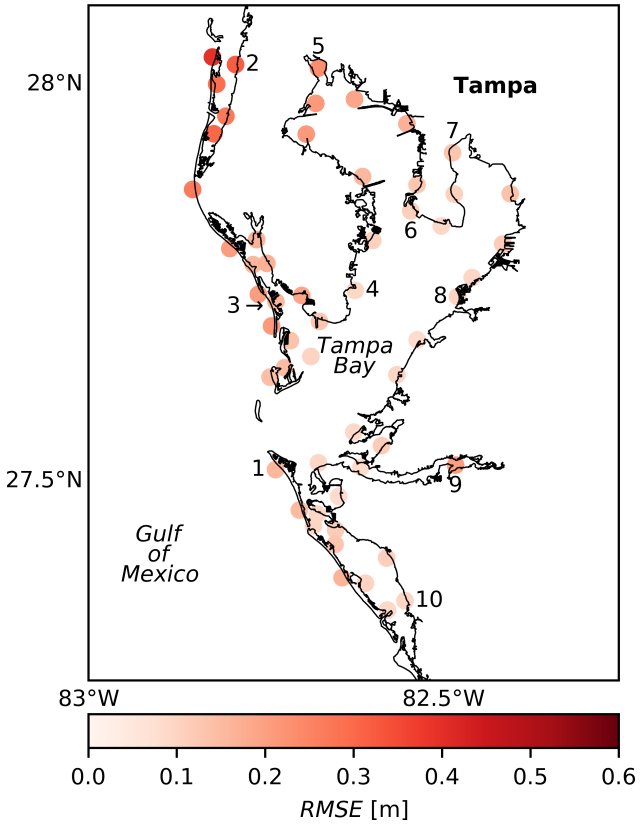
SPATIAL DECOMPOSITION: SURGE PREDICTION

ERROR STATISTICS

- Mean error: 0.00 m at all locations
- Root-mean square error (RMSE): 0.08 to 0.40 m



Using 4 modes (97.4% of variance)

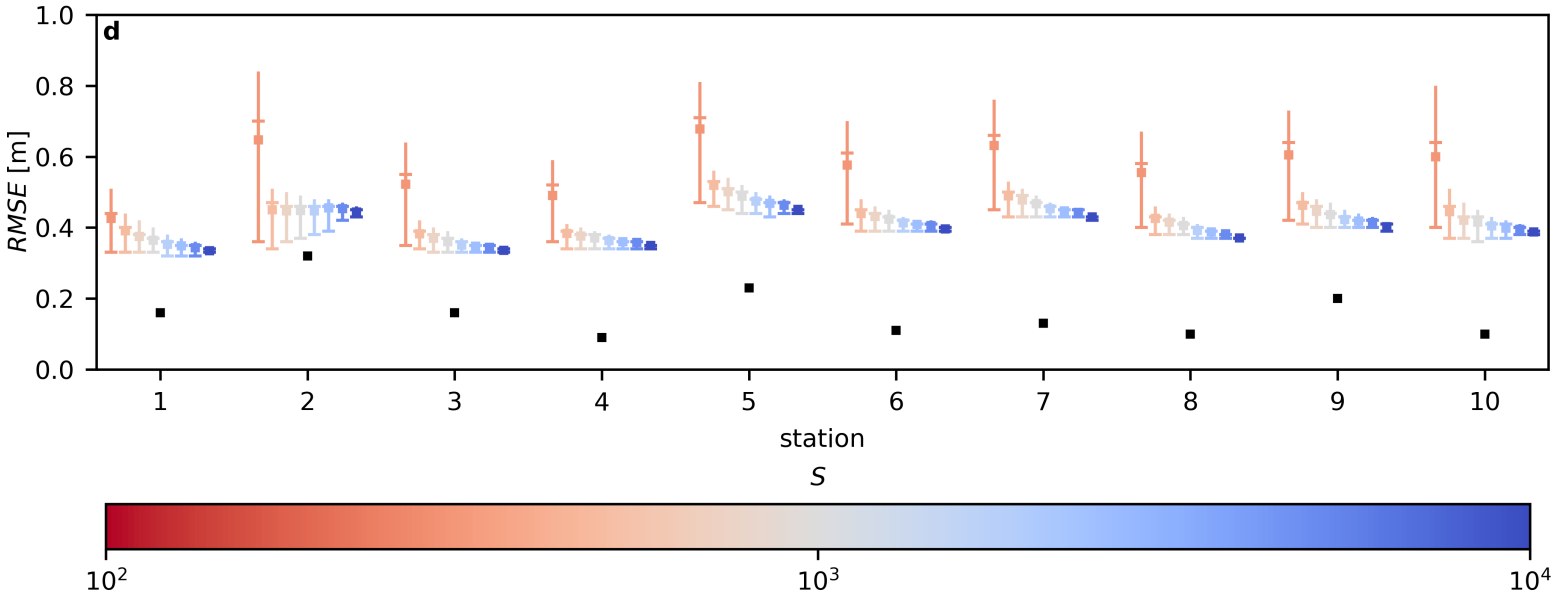


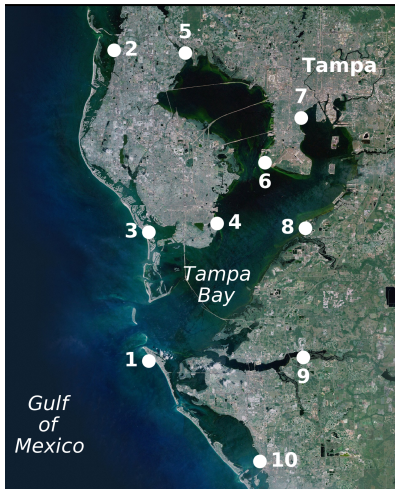
Preliminary work

SURGE ESTIMATION WITH REDUCED STORM SETS

ERROR STATISTICS

- Mean error: -0.07 to 0.07 m when S = 300 storms
- RMSE: 0.27 to 0.54 m when S = 750 storms





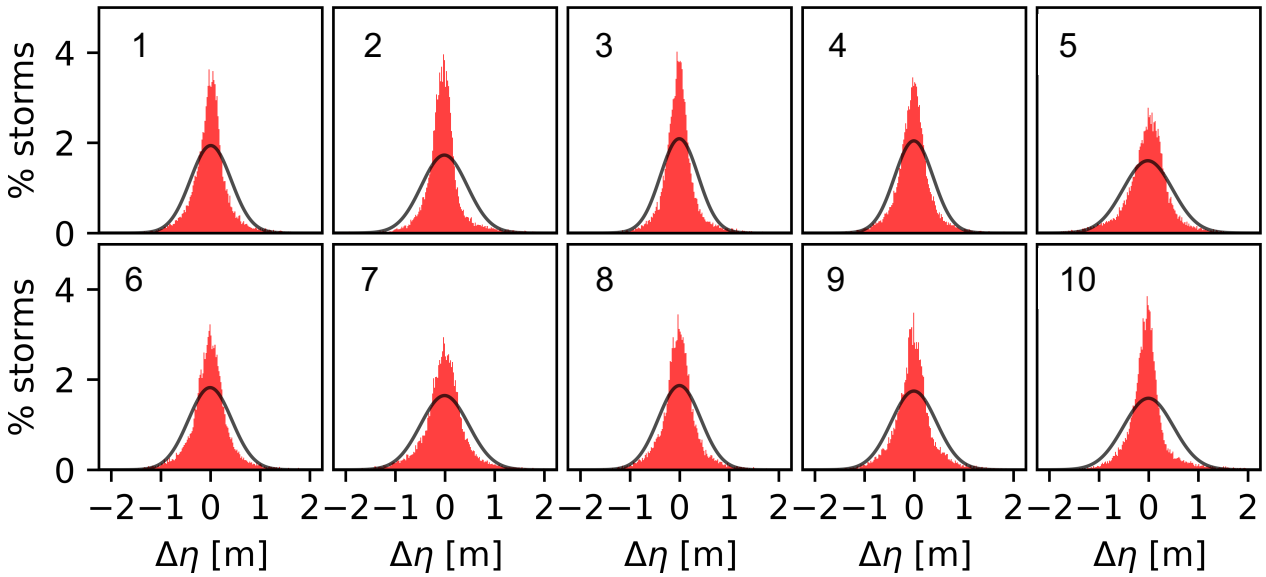
S = 300 to 10000 storms, using 4 modes (97.4% of variance)

Preliminary work

SURGE ESTIMATION WITH REDUCED STORM SETS

ERROR STATISTICS

- Mean error: -0.07 to 0.07 m when S = 300 storms
- RMSE: 0.27 to 0.54 m when S = 750 storms



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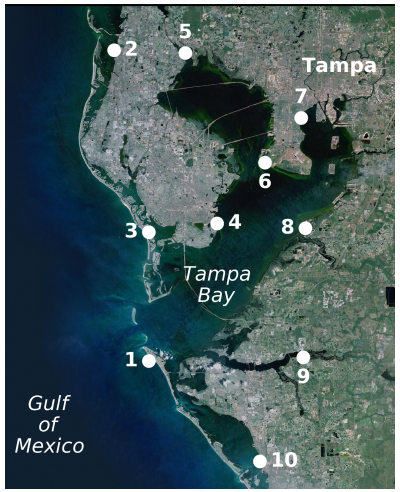

Preliminary work

CONCLUSIONS

- Eigenfunctions capture over 90% of variance in first two modes
- Eigenfunctions capture spatial variation:
  - Mode 1: Amplification of ocean surge wave as it propagates inland in response to topographic features
  - Higher-order modes: Local effects, e.g., local wind setup/setdown
- Eigenfunction weights depend on storm track parameters:
  - Mode 1: Leading order ocean surge scaling with landfall location, central pressure deficit, and storm radius
  - Higher-order modes: Local effects, e.g., influence of wind-field orientation (heading) on wind setup/setdown

Preliminary work

CONCLUSIONS

- Randomly selected, reduced storm sets sufficient to determine eigenfunctions
- Error introduced adds no more than 20% to model uncertainty
- Error may be assumed to be normally distributed

Preliminary work

QUESTIONS?

This material is based upon work supported by the National Science Foundation under Grant No. 1630099. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.