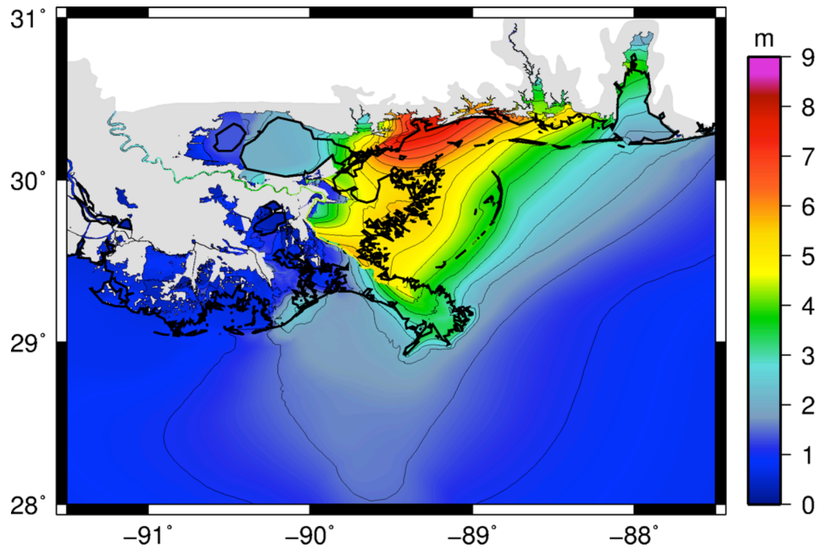
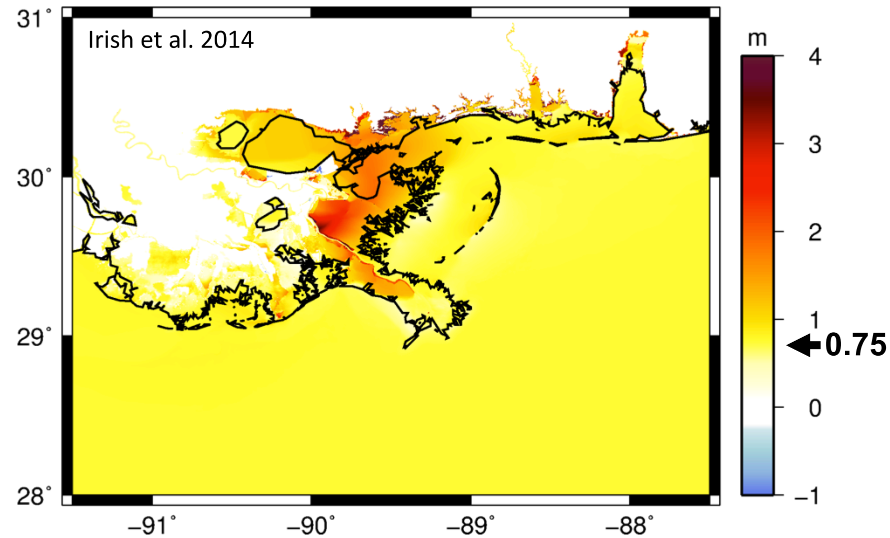
Future Tropical Cyclone Flood Hazard:
Impacts of Vegetation Change and Sea Level Rise



Estimated flooding during Hurricane Katrina (2005)



Estimated flood-elevation change due to 0.75 m of sea-level rise and vegetation loss since c. 1900

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November 13, 2015
Key West, FL

VirginiaTech

Sponsored by NOAA and NSF

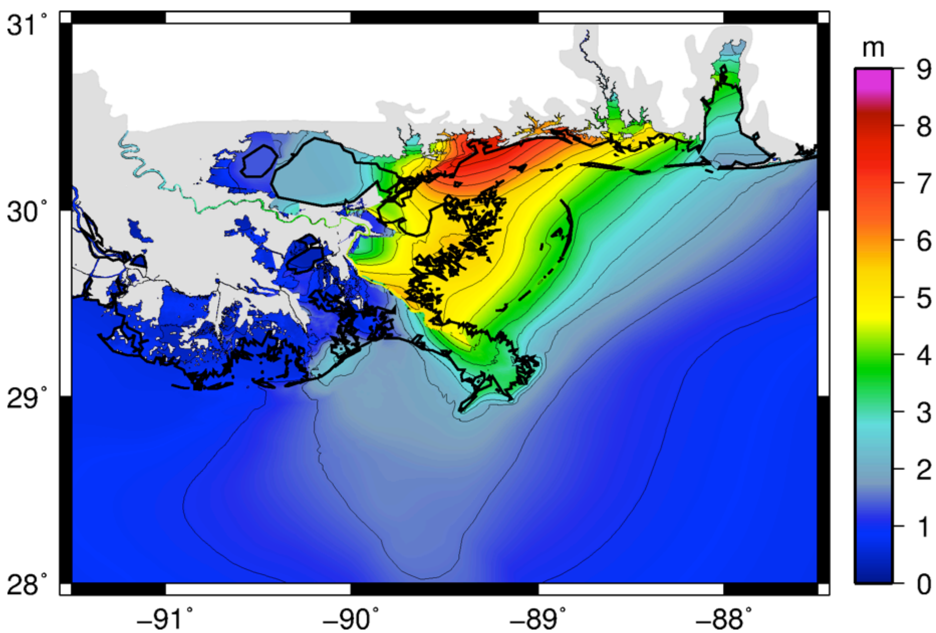
Future Tropical Cyclone Flood Hazard
Outline

- Motivation
- Joint probability method with optimal sampling (JPM-OS)
    - Surge response functions
- Impact of vegetation migration and loss
    - Screening approach using analytical solution
    - Preliminary results
- Conclusions & Future work

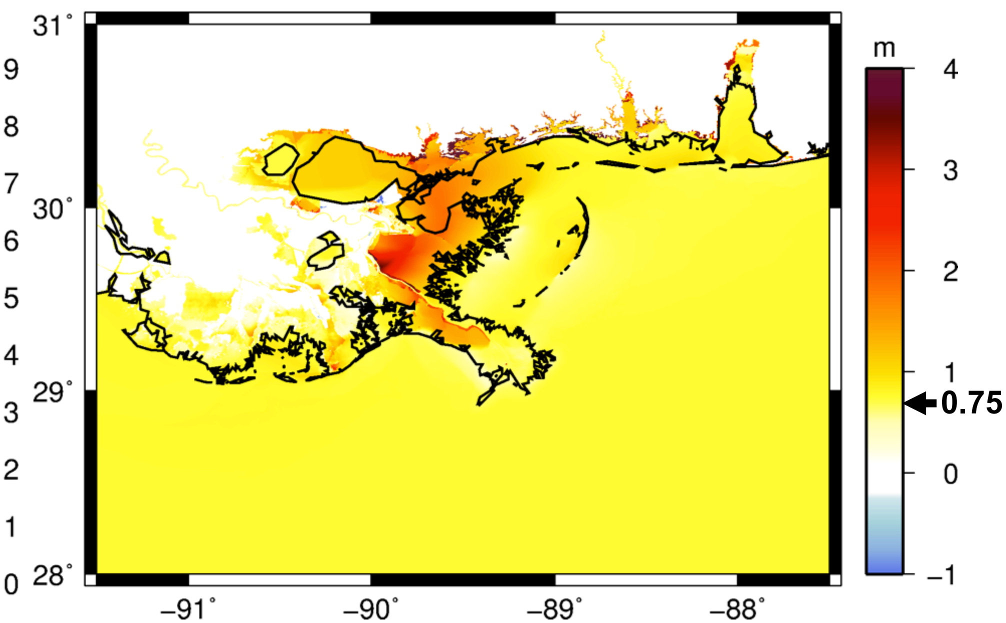
Future Tropical Cyclone Flood Hazard
Motivation

Sea level rise
Episodic hazards → Environmental Impacts → Altered hazard/risk
Population growth

Infrastructure Impacts
Social Impacts



Flooding during Hurricane Katrina (2005)



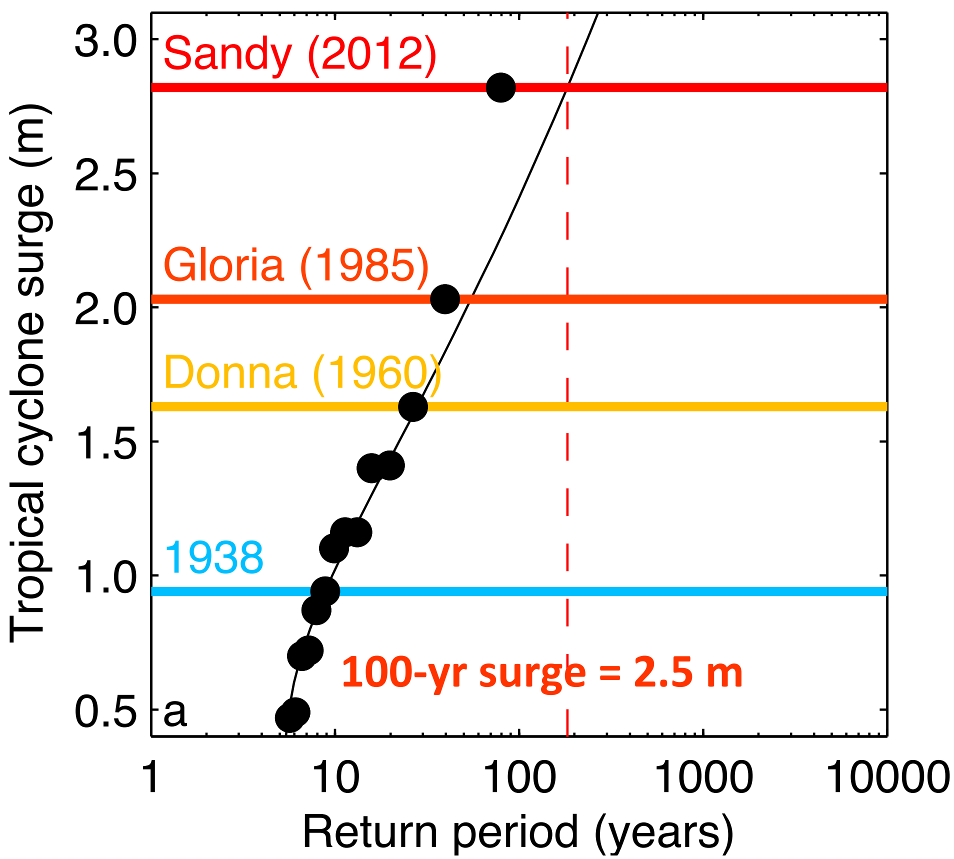
Estimated change due to the 0.75 m of sea-level rise since c. 1900

- A 0.75-m sea-level rise (SLR) leads to a 1.3-m increase in flood elevation
- Changes to wetlands dominant factor

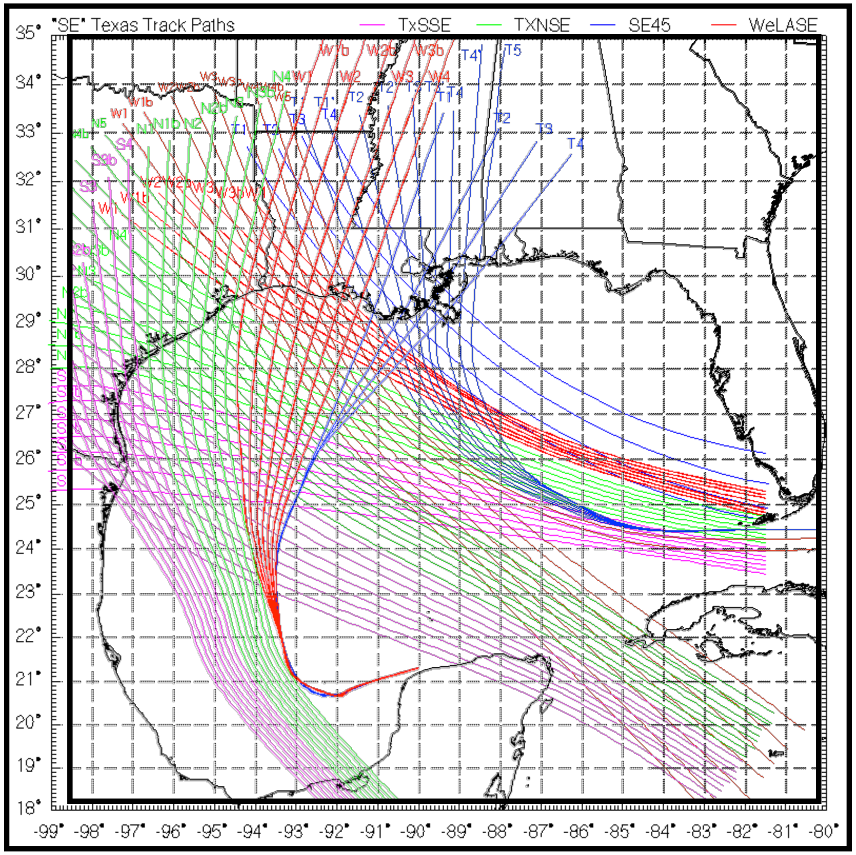
From Irish et al., 2014 *Clim. Change*

Future Tropical Cyclone Flood Hazard
Joint Probability Method with Optimal Sampling (JPM-OS)

Historical storm method



Joint probability method



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

Future Tropical Cyclone Flood Hazard
JPM-OS

Joint probability matrix

$$T_R\left(z_{\max}\right)=\left\{1-\int_{c_p}\int_{R_p}\int_{v_f}\int_{\theta}\int_{x_o} f(c_p,R_p,v_f,\theta,x_o)\left[H\left(z_{\max}-\left[\phi(x,c_p,R_p,v_f,\theta,x_o)+\varepsilon_z\right]\right)\right]dx_o\,d\theta\,dv_f\,dR_p\,dc_p\right\}^{-1}$$

$$f(c_p,R_p,v_f,\theta,x_o)=\Lambda_1\Lambda_2\Lambda_3\Lambda_4\Lambda_5$$

$$\Lambda_1=p(c_p\mid x_o)=\frac{1}{a_1(x_o)}\exp\left[-\frac{\Delta p-a_o(x_o)}{a_1(x_o)}\right]\exp\left\{-\exp\left[-\frac{\Delta p-a_o(x_o)}{a_1(x_o)}\right]\right\}(Gumbel\ Distribution)$$

$$\Lambda_2=p(R_p\mid c_p)=\frac{1}{\sigma\left(\Delta p\right)\sqrt{2\pi}}\exp\left\{-\frac{\left(\overline{R}_p(\Delta p)-R_p\right)^2}{2\sigma^2\left(\Delta p\right)}\right\}(Normal\ Distribution)$$

$$\Lambda_3=p(v_f\mid\theta)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left\{-\frac{\left(\overline{v}_f(\theta)-v_f\right)^2}{2\sigma^2}\right\}(Normal\ Distribution)$$

$$\Lambda_4=p(\theta\mid x_o)=\frac{1}{\sigma(x_o)\sqrt{2\pi}}\exp\left\{-\frac{\left(\overline{\theta}(x_o)-\theta\right)^2}{2\sigma^2(x_o)}\right\}(Normal\ Distribution)$$

$$\Lambda_5=f\left(\lambda,x_o\right)$$

Return Period =
(Annual Exceedance Probability)$^{-1}$

e.g., T_R = 100-yr is same as 1% AEP

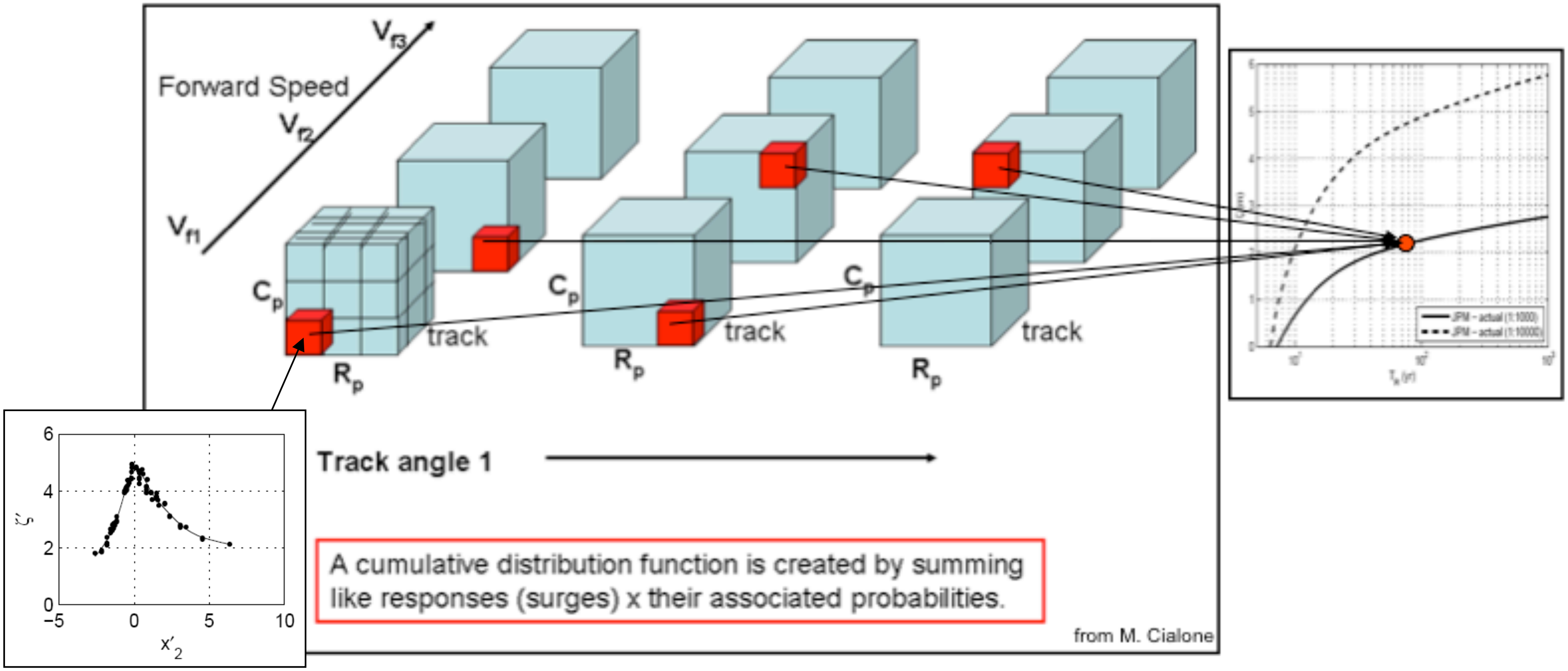
Assume sea-level rise (SLR) dominant (with respect to storm climate)

From Resio et al., 2009 *Nat. Hazards*

Future Tropical Cyclone Flood Hazard
JPM-OS

Joint probability matrix

$$f(p_o, R_p, v_f, \theta, x_o) = \Lambda_1 \Lambda_2 \Lambda_3 \Lambda_4 \Lambda_5$$



Accurate numerical integration requires 100,000s of storms ← Use optimal sampling

From Resio et al., 2009 *Nat. Hazards*

Future Tropical Cyclone Flood Hazard
JPM-OS: Surge Response Functions (SRF)

General form for maximum surge response

$$z_{max}\left(x\right)=\phi\left(x,x_o,c_p,R_p,\theta,v_f\right)+\varepsilon$$

$$\varepsilon^2=\varepsilon_{tide}^2+\varepsilon_{surge\ simulation}^2+\varepsilon_{waves}^2+\varepsilon_{winds}^2+\ldots$$

where:

- ϕ is a continuous surge response function
- x is location of interest
- x_o is landfall location
- c_p is hurricane central pressure near landfall
- R_p is hurricane pressure radius near landfall
- θ is hurricane track angle with respect to the shoreline
- v_f is hurricane forward speed near landfall
- ε is uncertainty in the surge response

From Resio et al., 2009 *Nat. Hazards*

Future Tropical Cyclone Flood Hazard
JPM-OS: SRFs

$$\lambda(x_o) = \begin{cases} 0.05L_{30}(x_o) - 0.70 \text{ when } L_{30}(x_o) < 40\text{ km} \\ \dfrac{2.03}{L_{30}(x_o) - 31.4} + 0.88 \text{ when } L_{30}(x_o) \geq 40\text{ km} \end{cases}$$

$$\zeta' = \frac{\gamma\zeta}{\Delta p} + m_2(x,x')\left(\frac{P_{far} - c_p}{P_{far} - c_{p-\max}}\right)^{\alpha(x,x')}\left(\frac{R_p / L_{30}(x_o)}{\left[R_p / L_{30}\right]_{ref}}\right)^{\beta(x,x')}$$

$$x' = \frac{(x - x_o)}{R_p} - \lambda(x_o) + cH\left(\frac{(x - x_o)}{R_p} - \lambda(x_o) - 1\right)\left(\frac{R_p}{L_{30}}\right) - F\left(1 - \frac{R_p}{R_{thres}}\right)H\left(1 - \frac{R_p}{R_{thres}}\right)$$

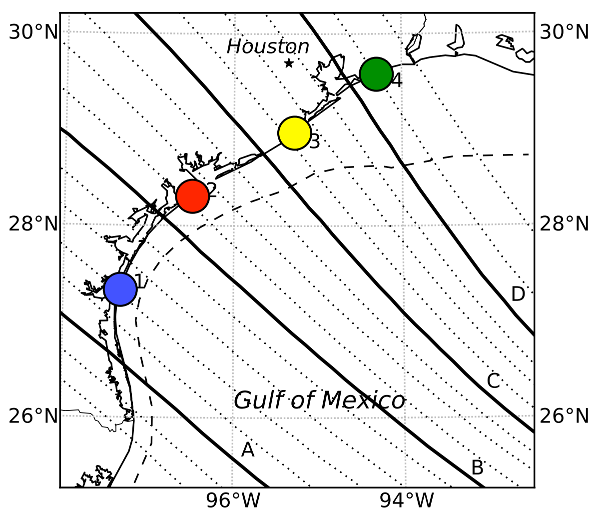
<ins>Using 145 simulations for Texas coast:</ins>

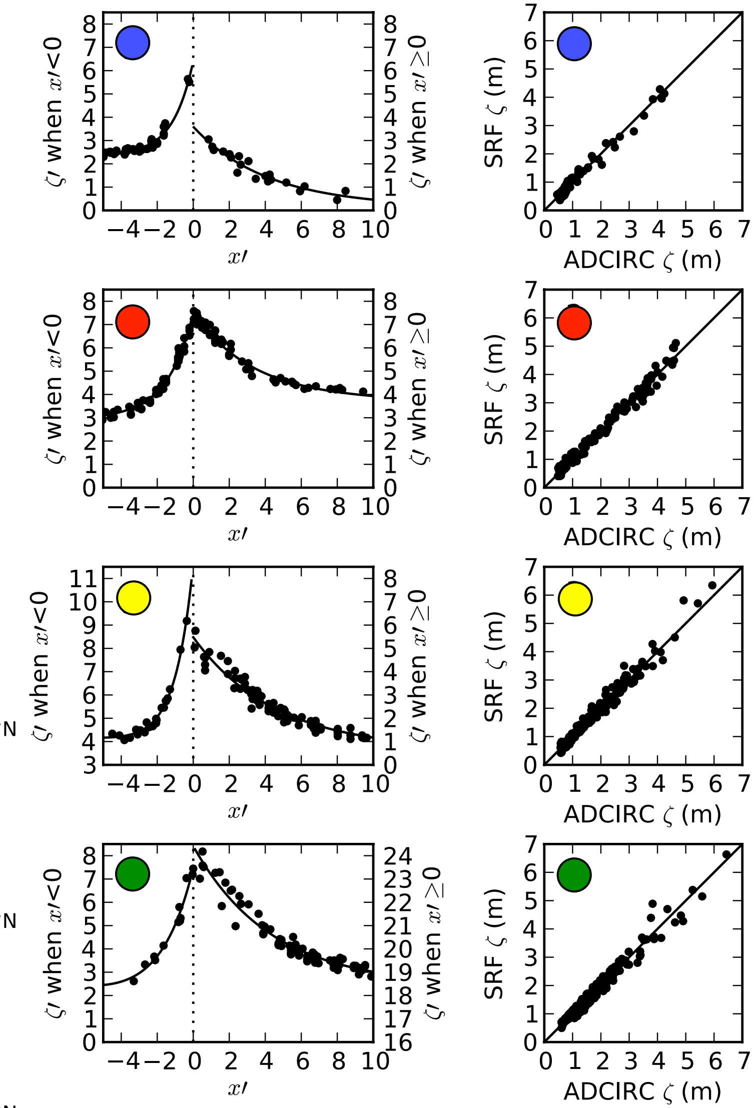
mean error = -3 to +1 cm

RMS error = 11 to 22 cm

Neglects:

- Wave setup
- Track angle
- Forward speed

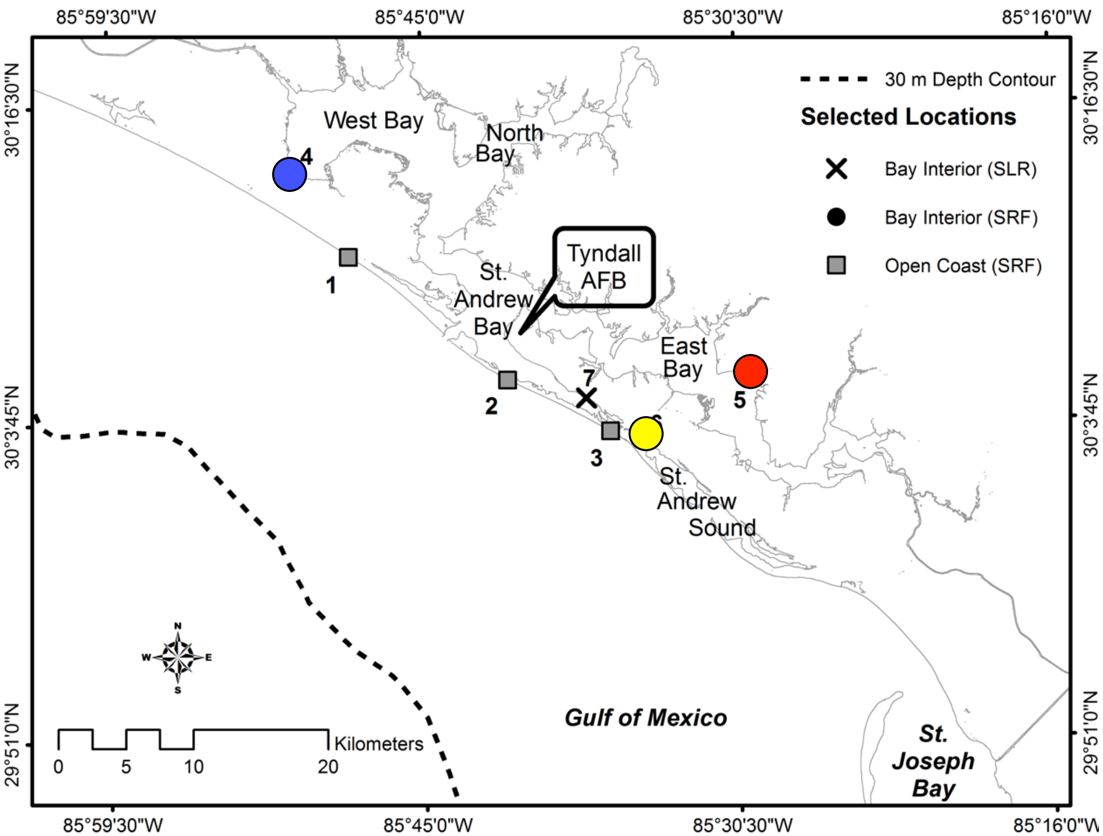


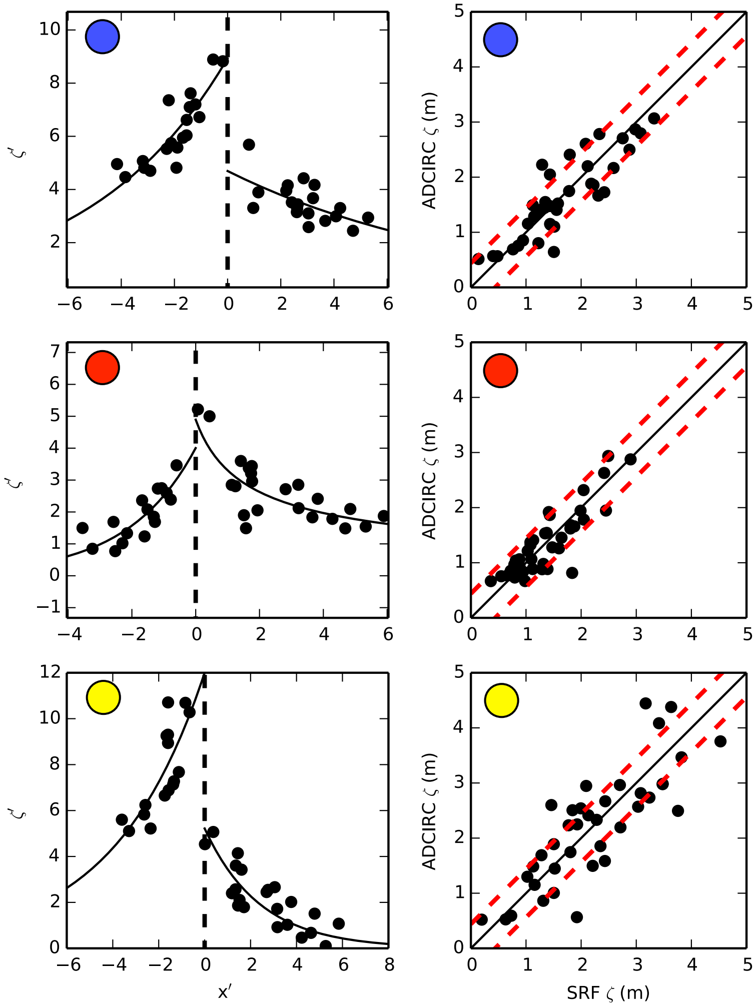


From Song et al., 2012 *Nat. Hazards*

Future Tropical Cyclone Flood Hazard
JPM-OS: SRFs - Wave Setup, Track Angle, Forward Speed

Panama City, FL: Coastal bays





<u>Applied at 259 locations using 38 simulations:</u>
mean error = -12 to +5 cm,
RMS error < 50 cm at 96% and < 40 cm at 76% of locations

From Taylor et al., 2015, *Nat. Hazards*

Future Tropical Cyclone Flood Hazard
Conclusions & Future Work

Conclusions (Preliminary)

- Response of future surge hazard to vegetation change is complex
- Shape of extreme-value distribution sensitive to vegetation change
- Magnitude of change in surge hazard 1 m or less

Future work

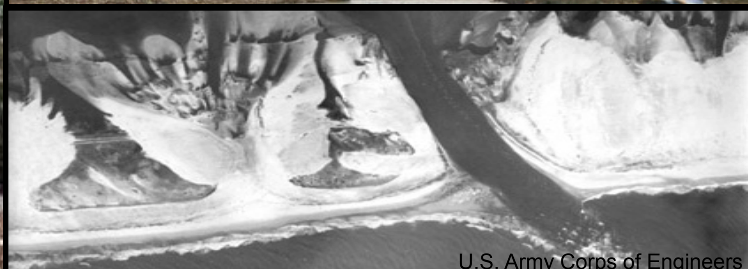
- Further evaluate sensitivity:
    1. Vegetation state
    2. Idealized bathymetry
- Evaluate changes in contributing joint-probability parameter space
- Significance of direct estimate versus added uncertainty
- Evaluate impact to flood plain (overland flow)

Questions?

www.coastal.cee.vt.edu


Associated Press

UPI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