QUANTIFYING SHIFTS IN JOINT RAINFALL-SURGE HAZARD UNDER FUTURE CLIMATE WARMING

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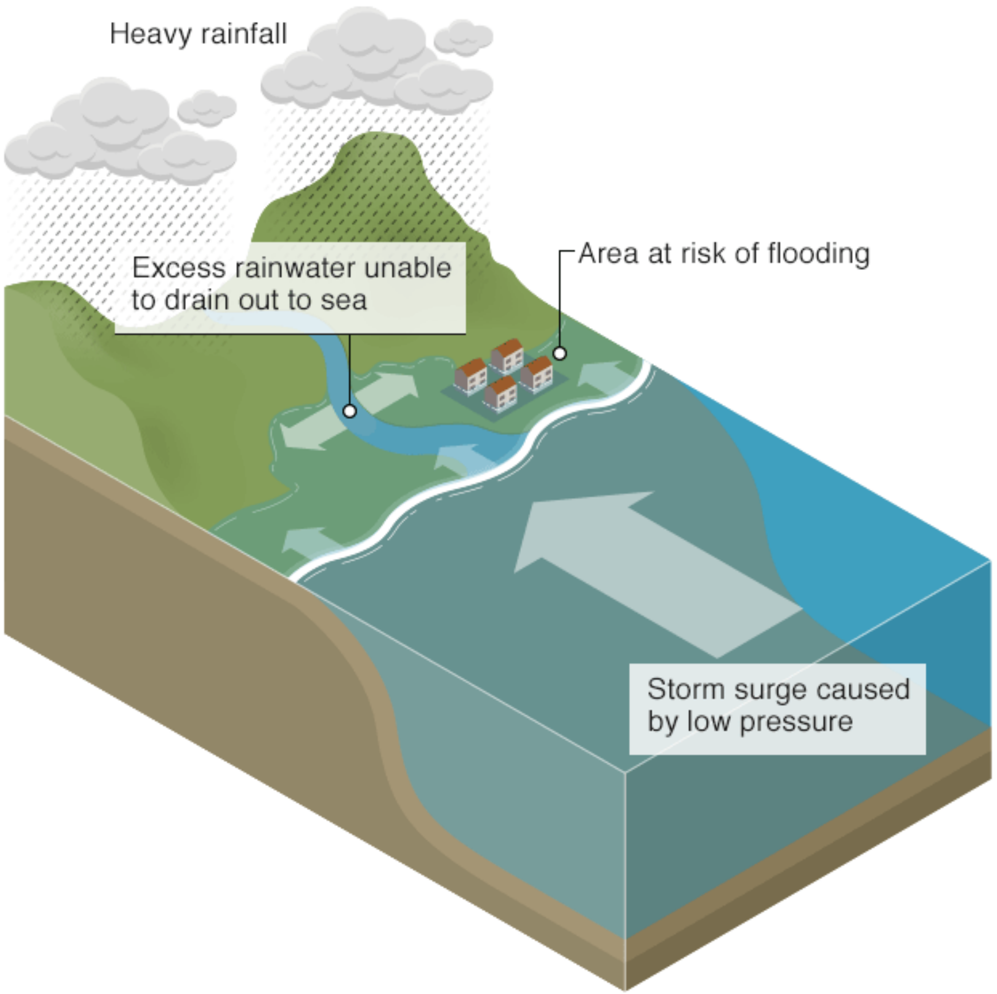
What is Compound Flooding?

- Compound flooding results from the the occurrence of multiple types of flooding (rainfall, riverine, storm surge) simultaneously or sequentially such that overall hazard is increased.

(Zscheischler et al., 2018, Nature)

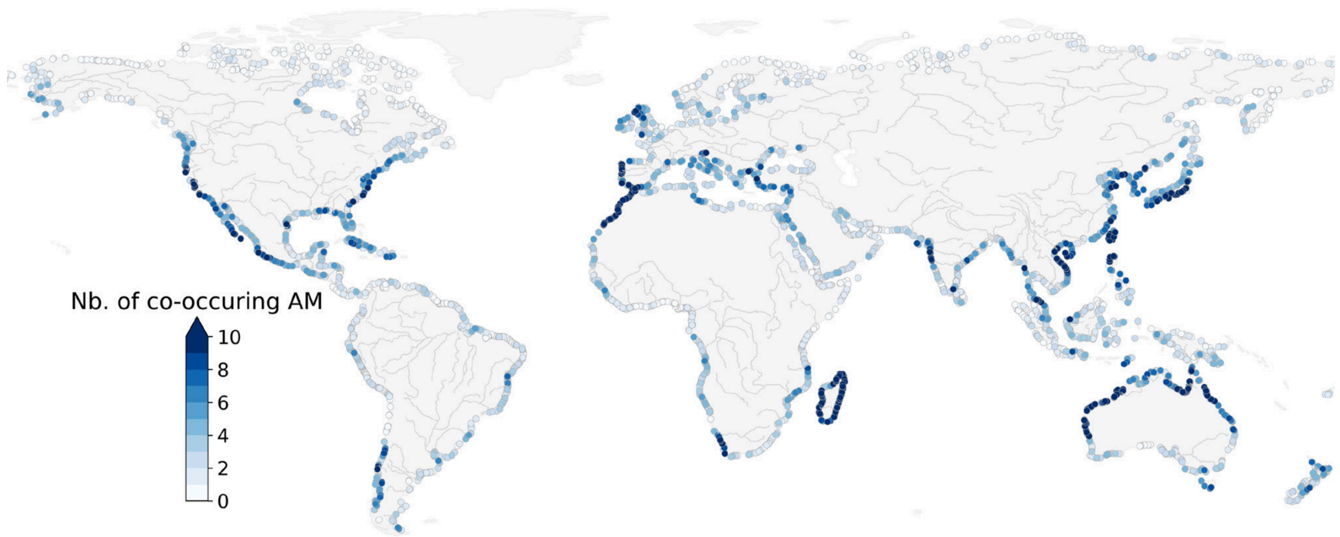


Source: Douglas Maraun/Science Advances

BBC

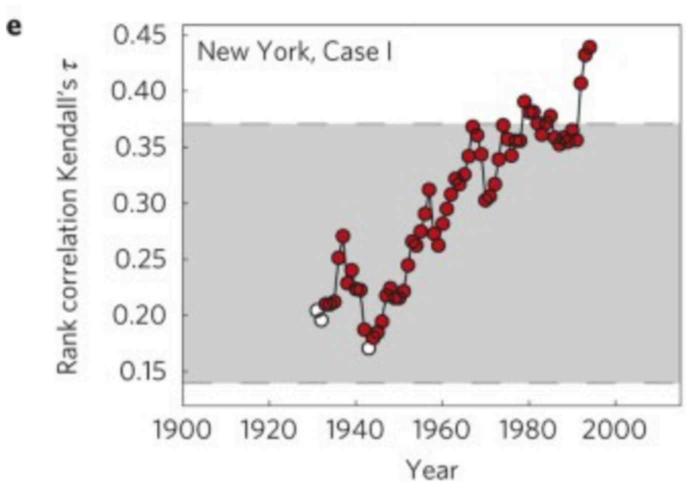
Coastlines across the world are vulnerable to compound flooding

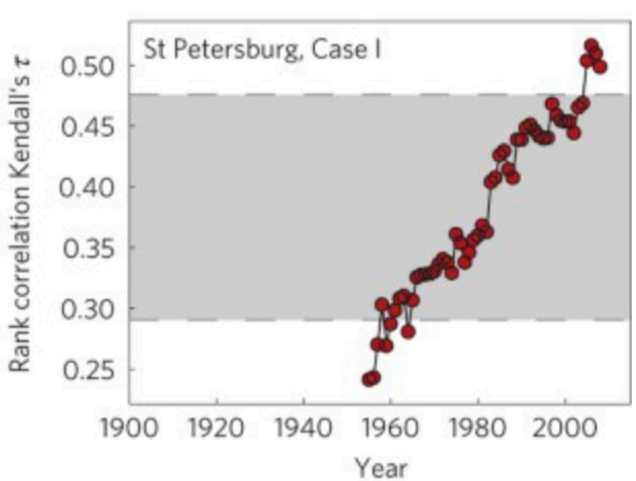
Couasnon et al. (2019), NHESS



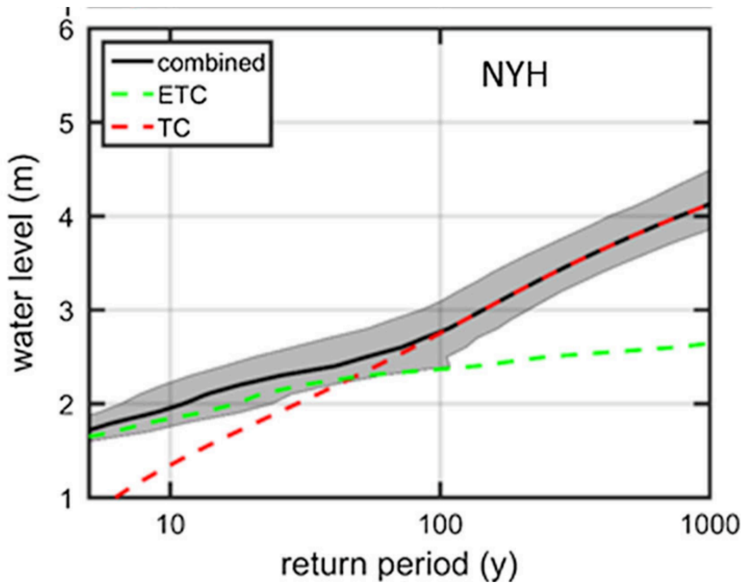
Dependence between storm surge and precipitation may have been rising

Wahl et al. (2015) *Nature*

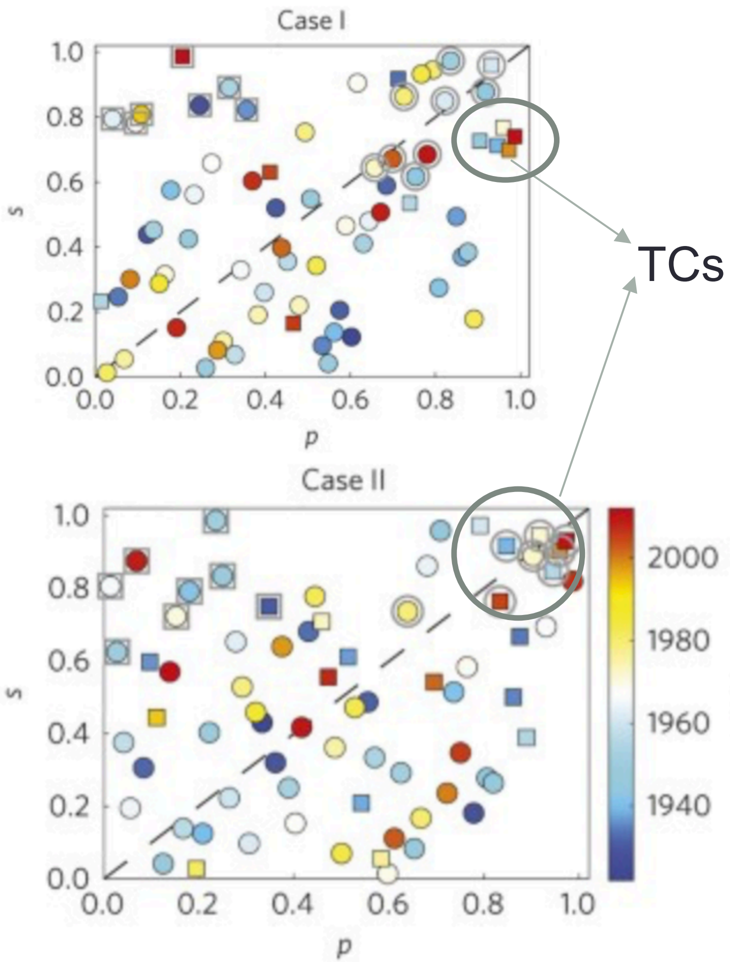




Tropical cyclones (TCs) are one of the main causes of compound flooding along the US East and Gulf Coast



Orton et al. (2018) *Nat Hazards*

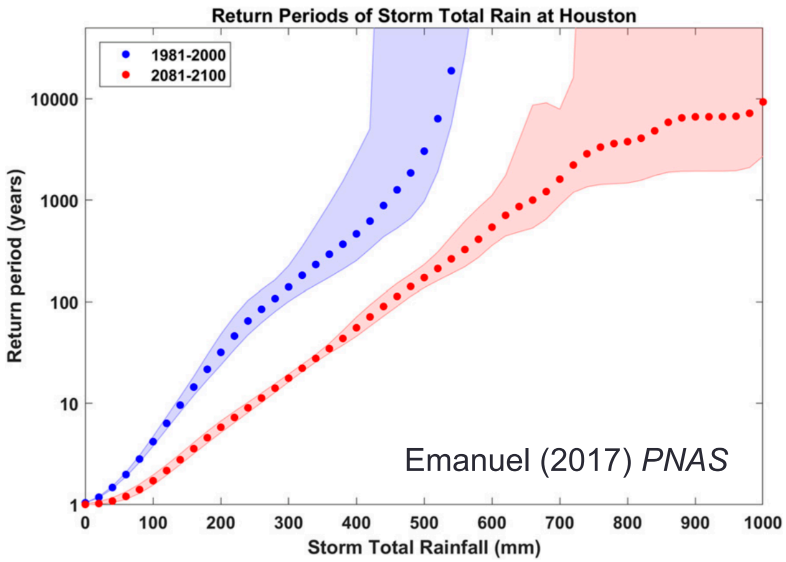


Rescaled pairs of ranks of storm surge (*s*) and precipitation (*p*) for NYC; Wahl et al. (2015) *Nature*

The threat of TC compound flooding may be rising…

Projections of future storm surge and rainfall hazard due to climate change

Marsooli et al. (2019) *Nature*

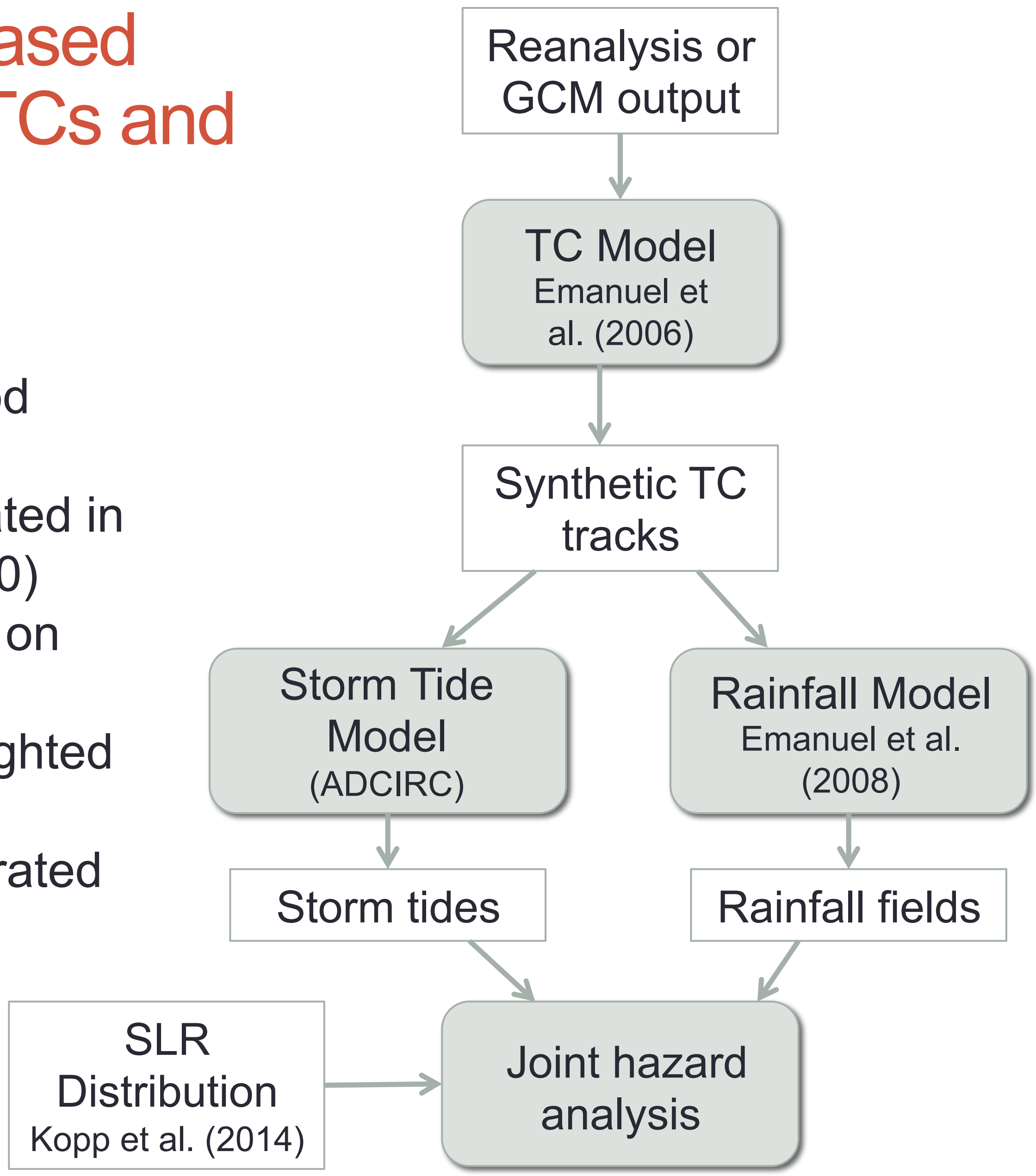


Emanuel (2017) *PNAS*

Will the interaction of these hazards also increase due to climate change?

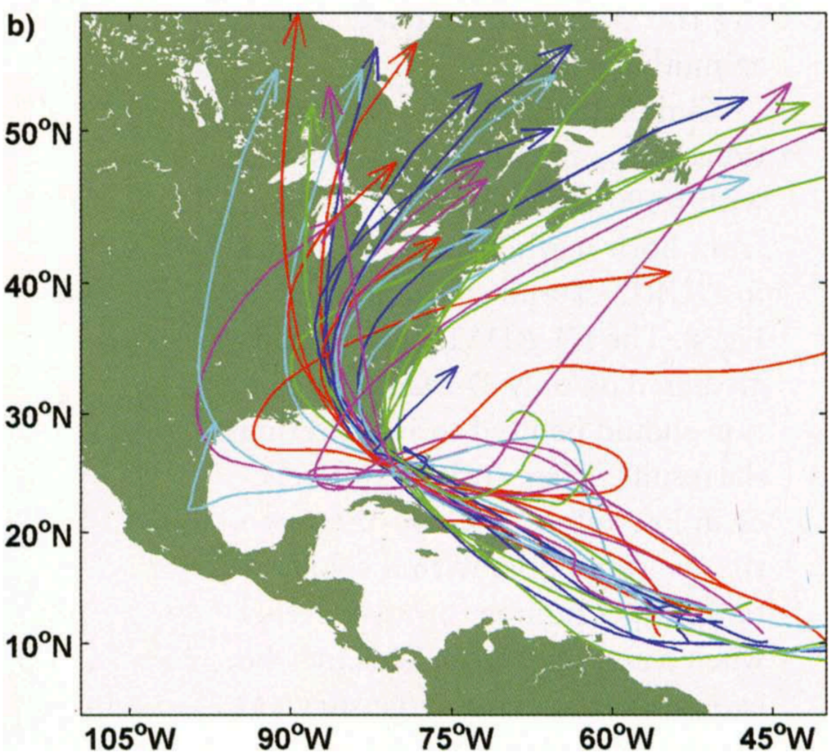
We utilize physics-based models to simulate TCs and their hazards

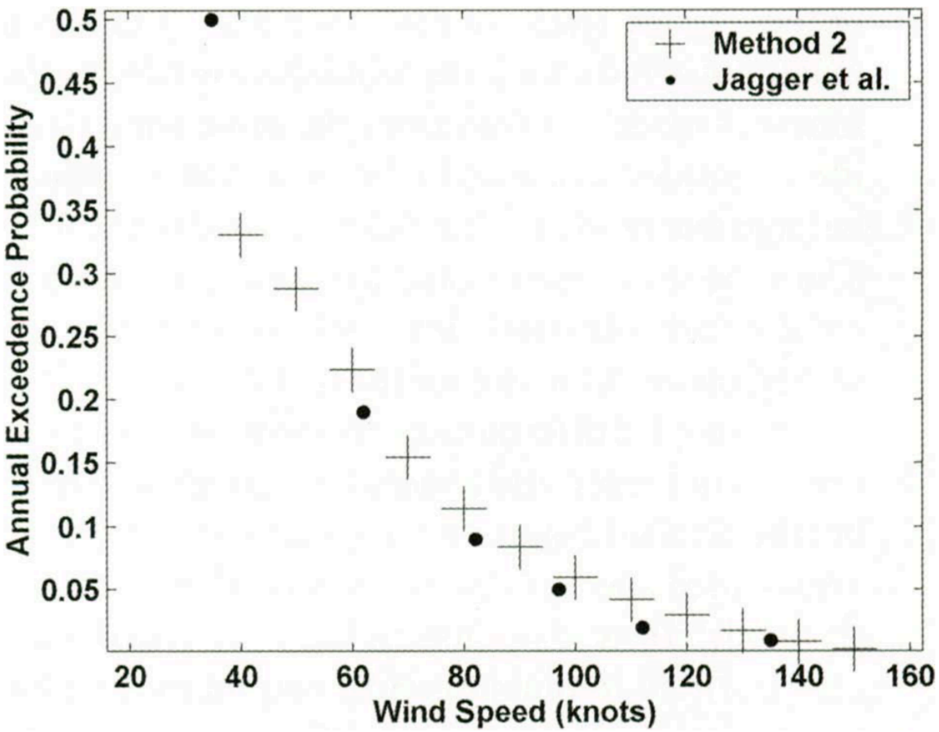
- NCEP reanalysis data represents historical period (1980-2005)
- 8 CMIP6 GCMs incorporated in future analysis (2070-2100) and bias corrected based on historical period
- Composite projection weighted average of 8 models
- Probabilistic SLR incorporated in hazard analysis



Synthetic TC Tracks

- Obtained 6200 synthetic TCs (track, intensity, size) generated from the statistical-deterministic TC model for each GCM in each period





Emanuel et al. (2006), *Bull. of the AMS*

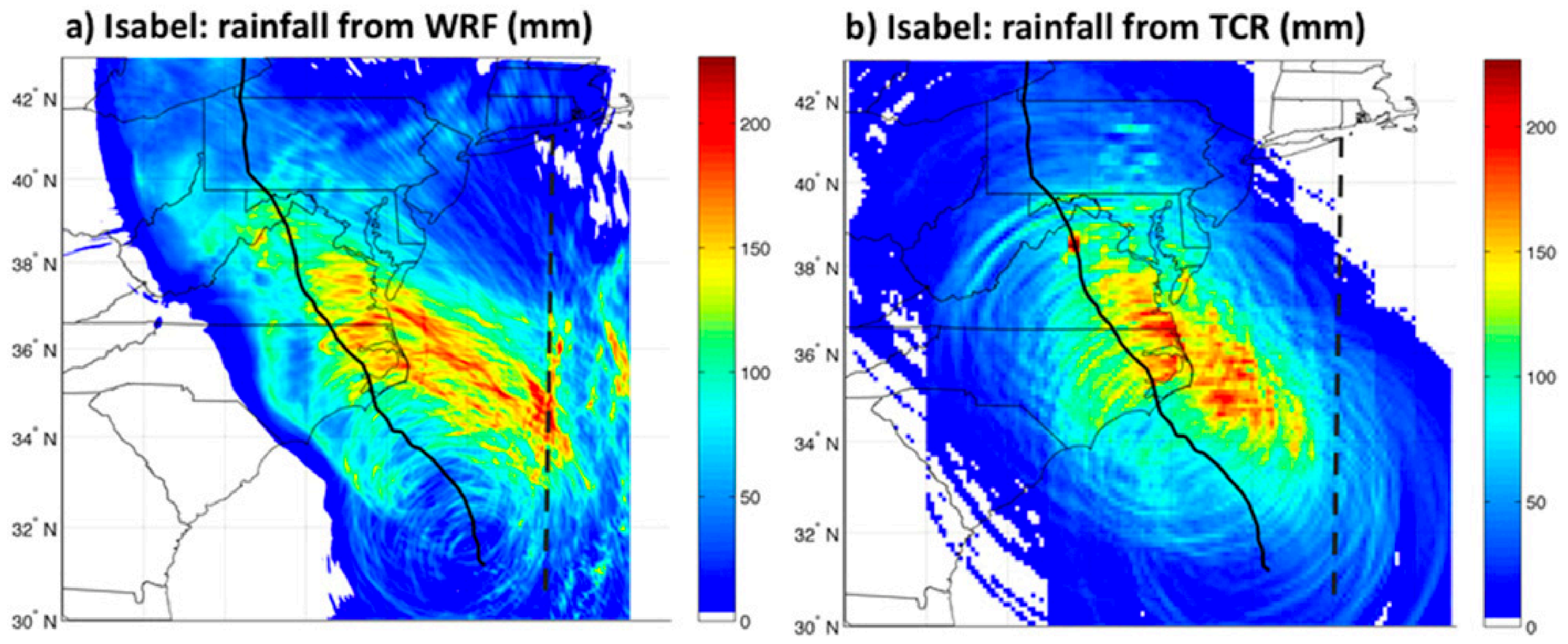
TC rainfall (TCR) model

$$P_{\text{rate}} = \epsilon_p \frac{\rho_{\text{air}}}{\rho_{\text{liquid}}} q_s (w_f + w_h + w_t + w_s + w_r)$$

Frictional (w_f), **Topographic** (w_h), **Stretching** (w_t), **Shear** (w_s), **Cooling** (w_r)

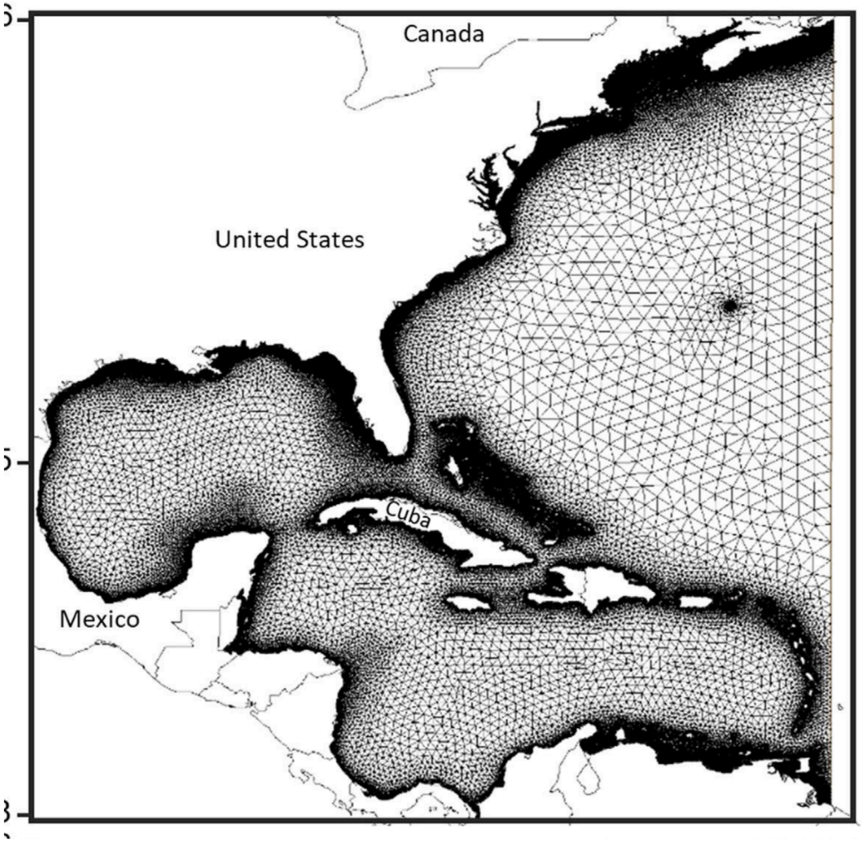
More recently, Xi et al. (2020) compared TCR against historical TC rainfall for entire US

Lu et al. (2018), *J. of the Atm. Sci.*



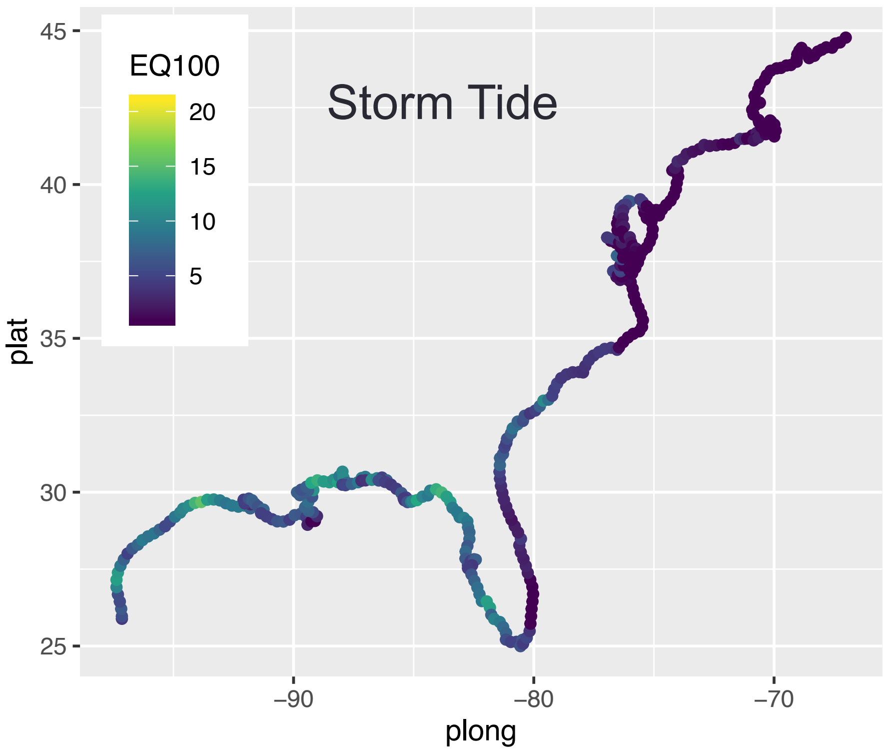
Hydrodynamic storm tide model (ADCIRC)

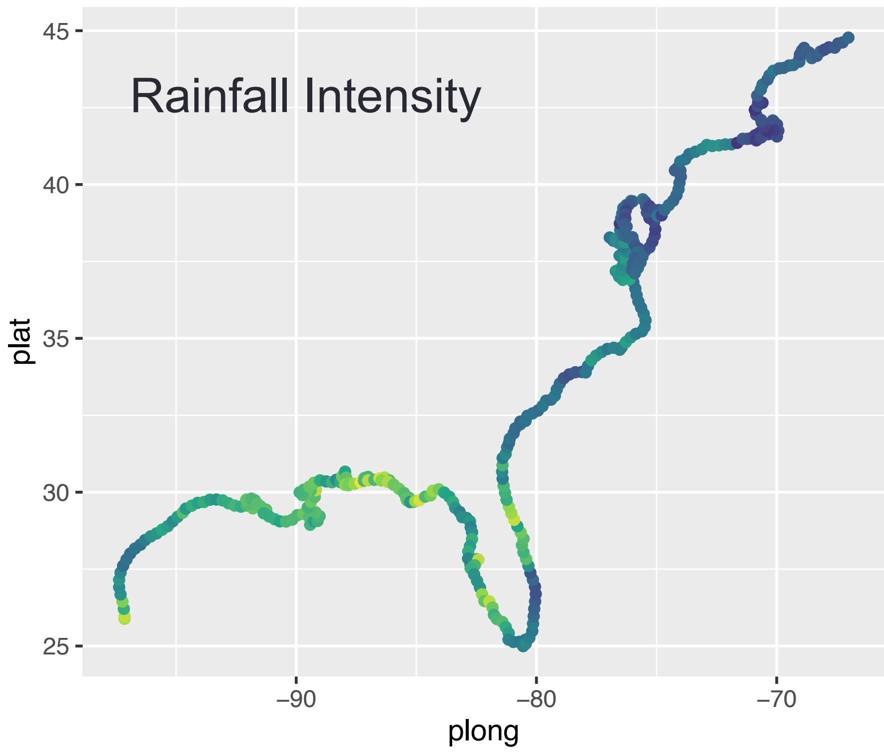
- 2D depth integrated shallow water model developed by Luettich and Westerink
- North Atlantic basin scale mesh developed in Marsooli & Lin (2018)
- 8 tidal constituents
- Pressure: Holland (1983)
- Wind: Emanuel & Rotunno (2011)



Marsooli & Lin (2018), *JGR Oceans*

Future storm climatology and SLR cause the 100yr storm tide to become ~1yr event and 100yr rainfall to become <5yr event in some locations





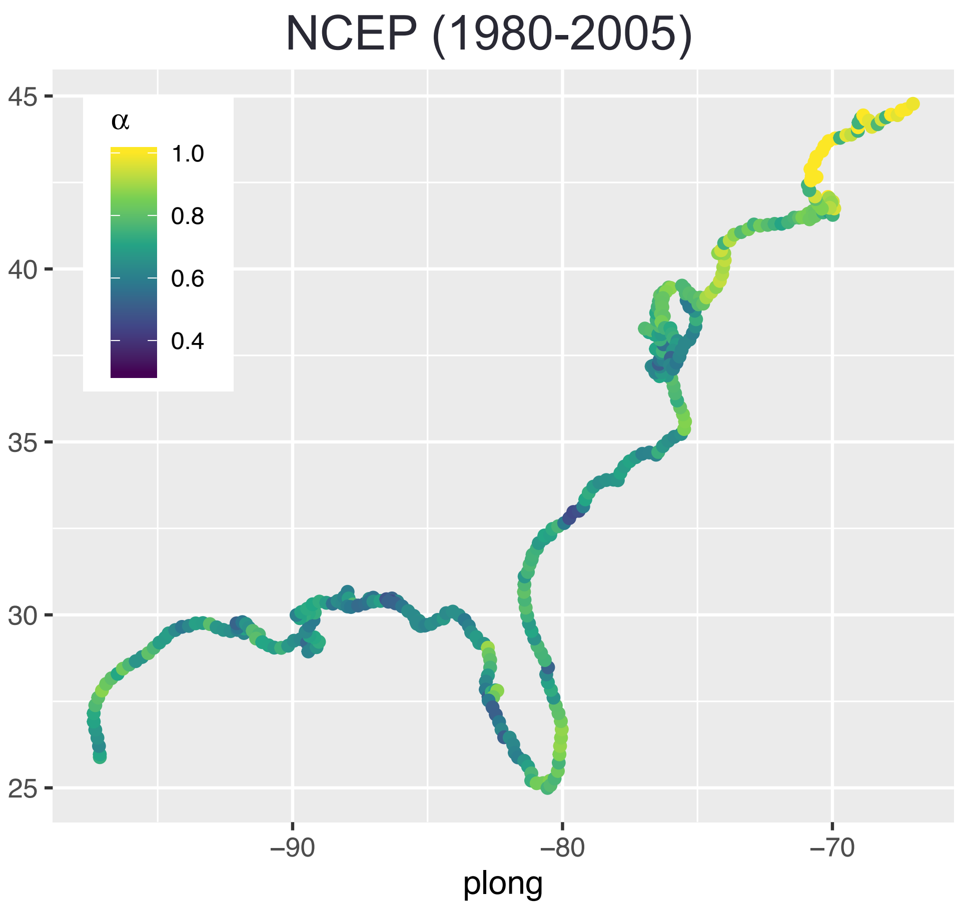
Quantifying statistical dependence between storm tide and rainfall

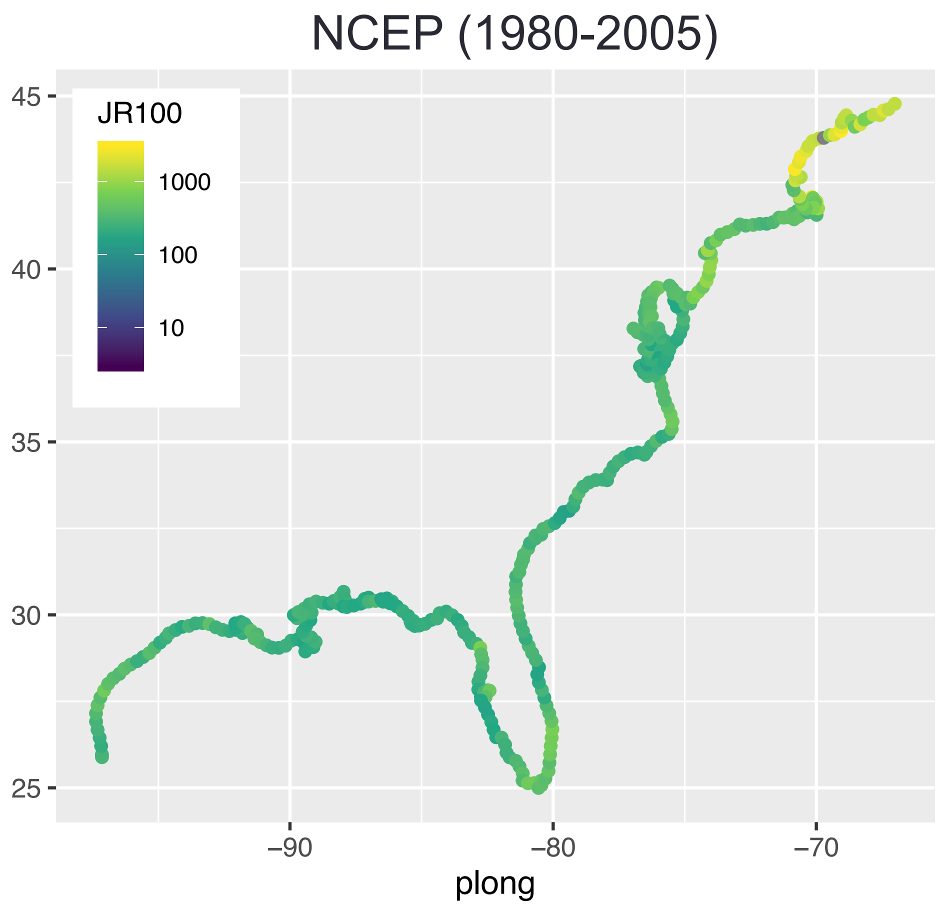
Bivariate Threshold Excess Model (Coles, 2000)

- Joint exceedances are modeled with bivariate logistic model
    - $G(x,y) = \exp(-(x^{-1/a} + y^{-1/a})^a)$
    - a → 1 : Complete Independence
    - a → 0 : Complete Dependence

- We define critical thresholds of storm tide (x) and rainfall intensity (y) as their 100-year levels during the historical period
    - What is the return period of joint exceedance in the historical period?
    - Considering future sea level rise, future storm climatology, and their combination

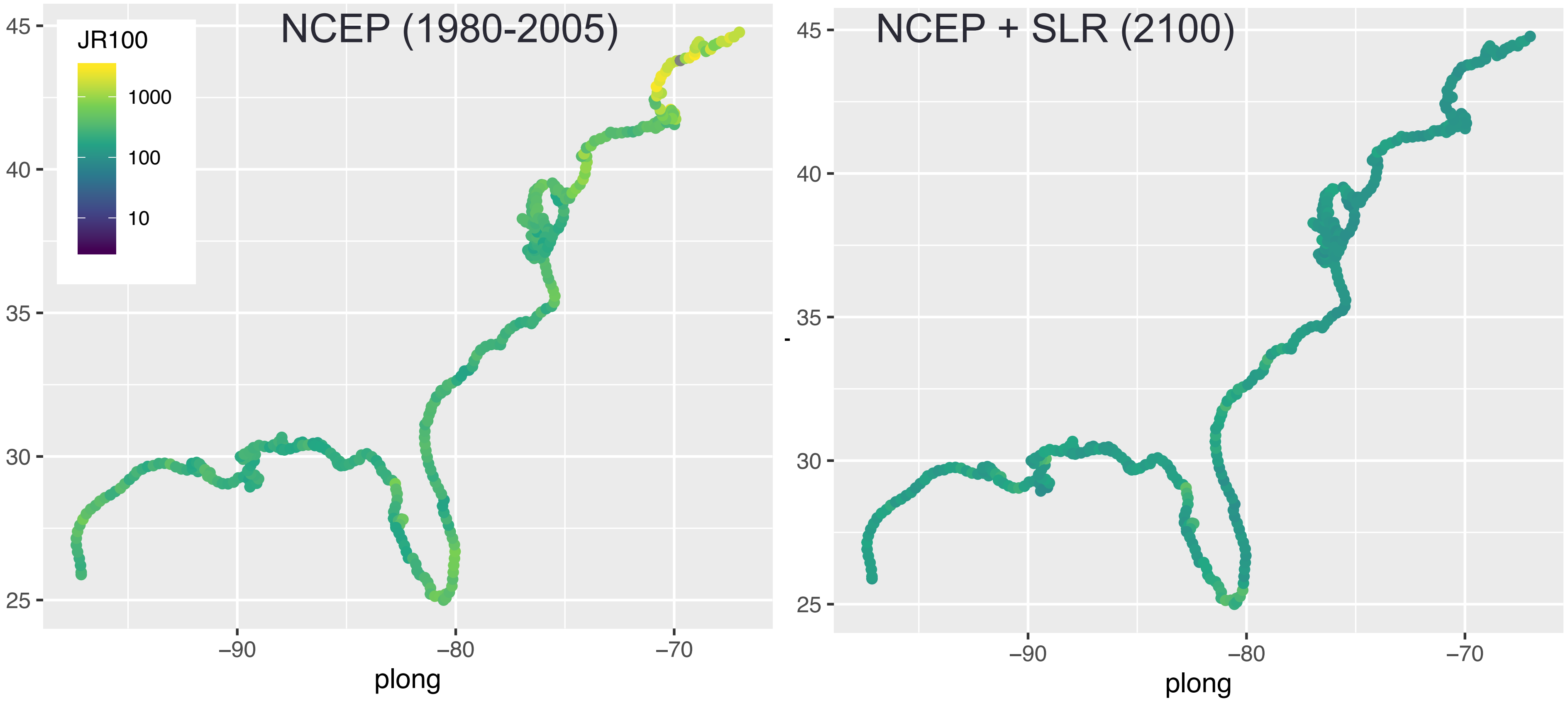
High rainfall-surge dependence along GoM and low dependence along NE coastline in historical period





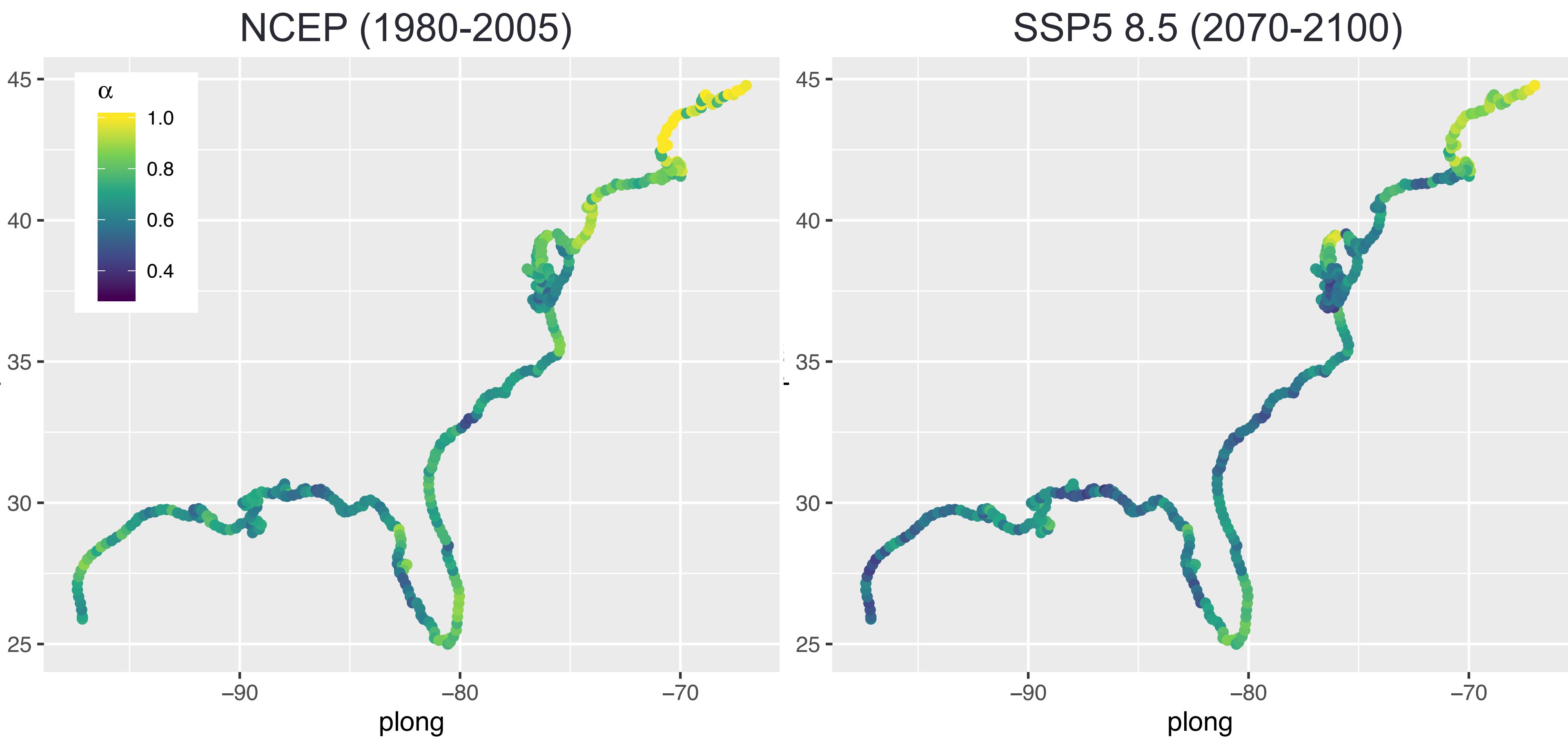
Impact of SLR alone increases frequency of joint exceedance events

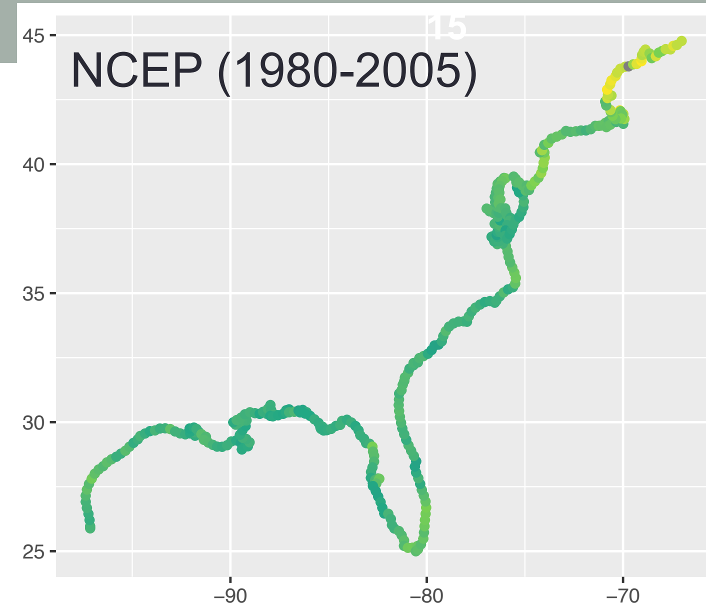
- We use a standard Monte Carlo approach to randomly perturb each storm tide – rainfall pair according to the SLR distribution (as in Mofthakhari et al. 2017)



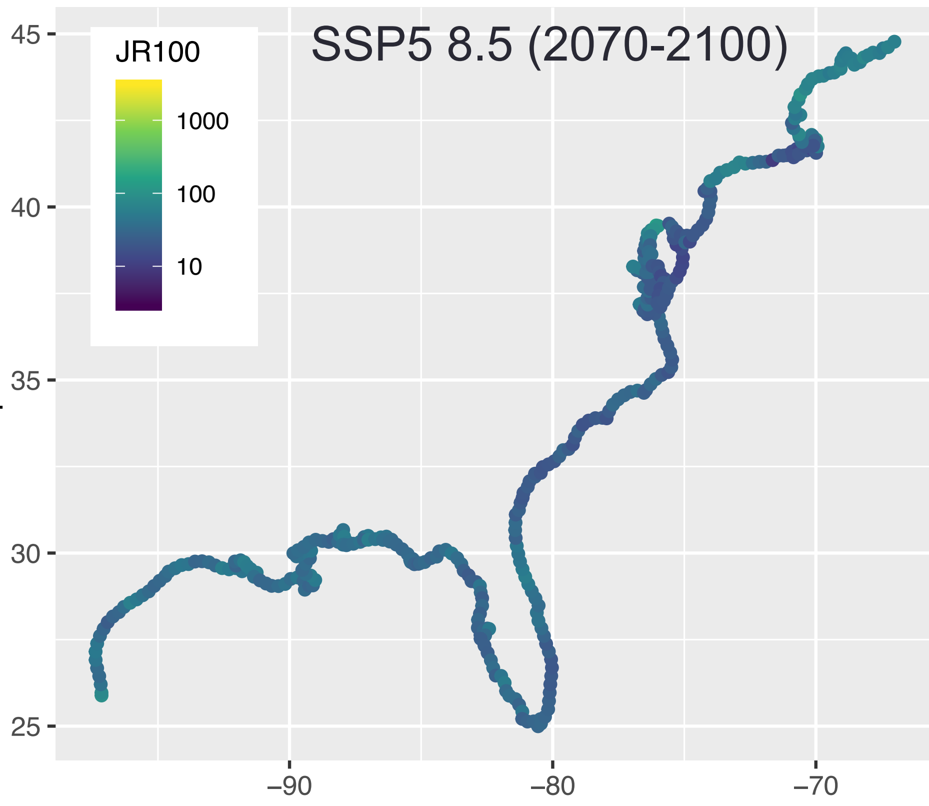
How do changes in storm climatology exacerbate joint hazard?

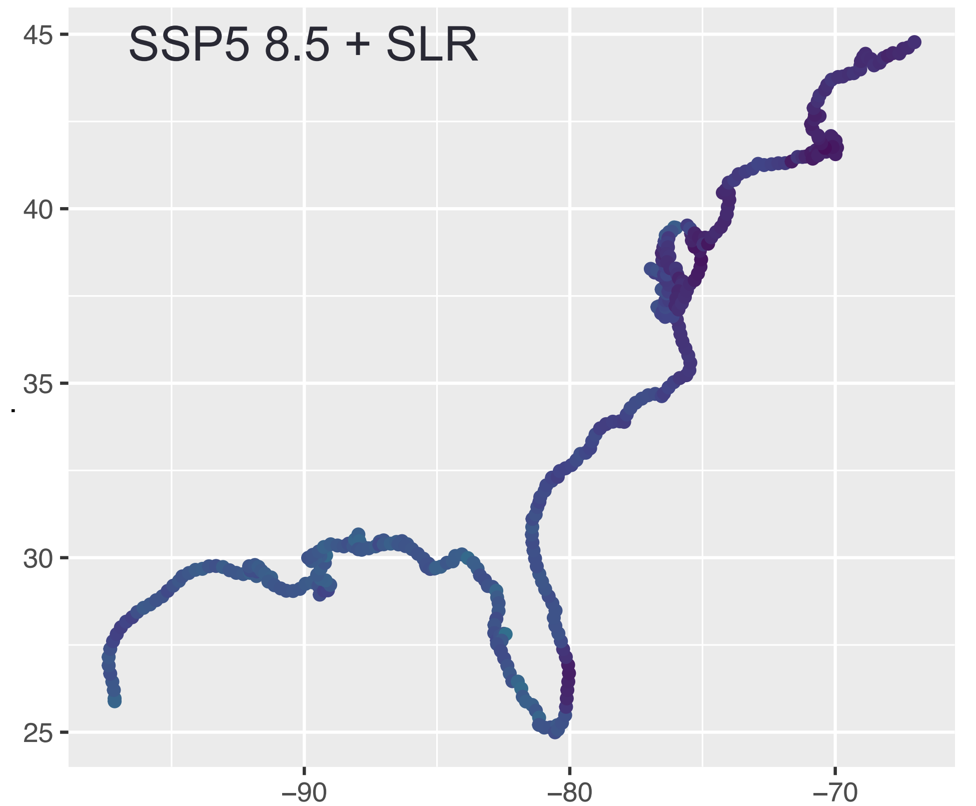
- Increase in either (or both) hazards (similar to impact of SLR)
- Increase in statistical dependence between hazards

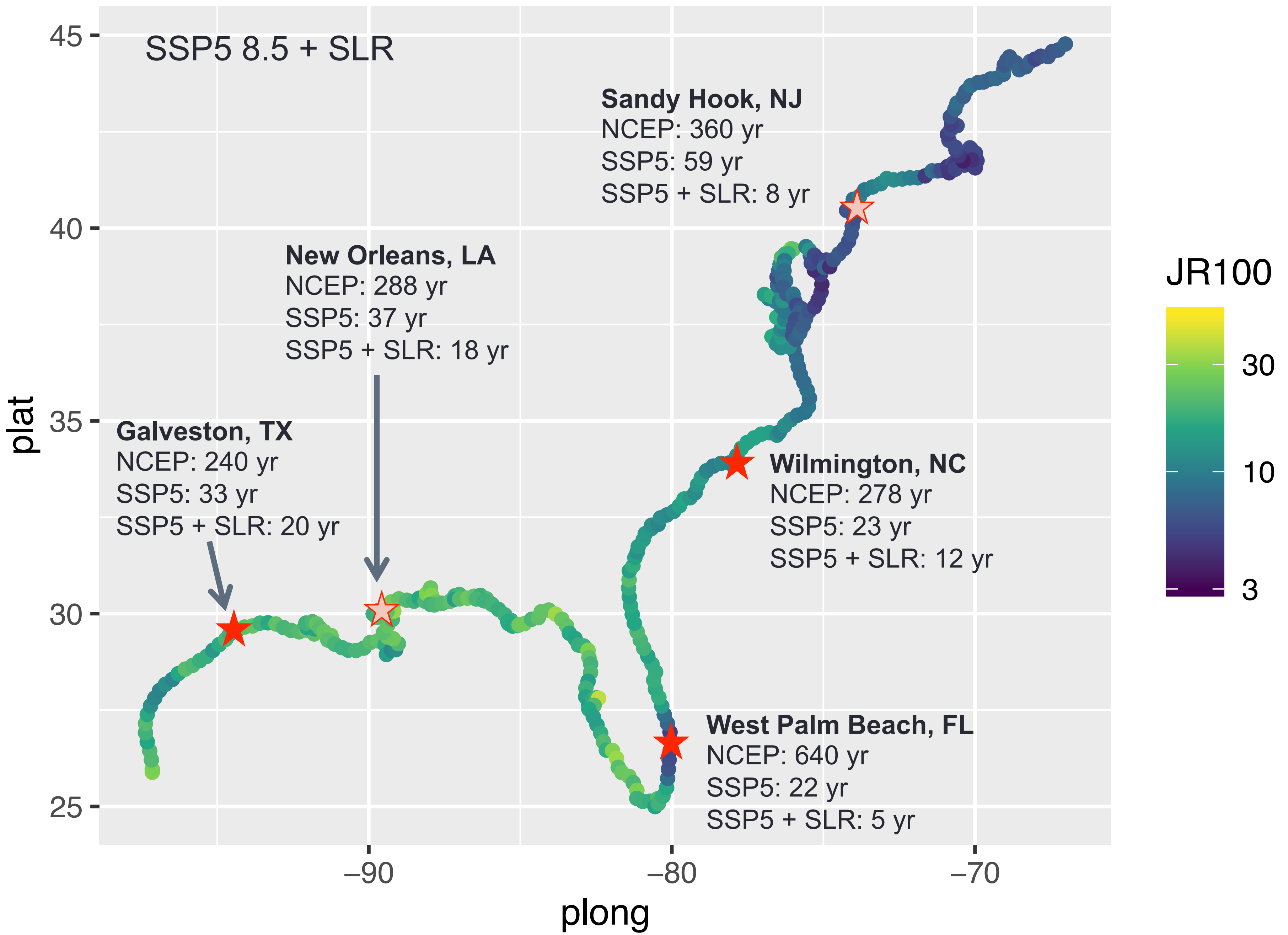




Under the combined impact of future storm climatology and SLR, the average return period of joint 100yr rainfall and surge (defined in the historical period) could shrink to less than 10 years






SSP5 8.5 + SLR
Sandy Hook, NJ
NCEP: 360 yr
SSP5: 59 yr
SSP5 + SLR: 8 yr
New Orleans, LA
NCEP: 288 yr
SSP5: 37 yr
SSP5 + SLR: 18 yr
Galveston, TX
NCEP: 240 yr
SSP5: 33 yr
SSP5 + SLR: 20 yr
Wilmington, NC
NCEP: 278 yr
SSP5: 23 yr
SSP5 + SLR: 12 yr
West Palm Beach, FL
NCEP: 640 yr
SSP5: 22 yr
SSP5 + SLR: 5 yr
JR100
30
10
3
45
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35
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25
plat
−90
−80
−70
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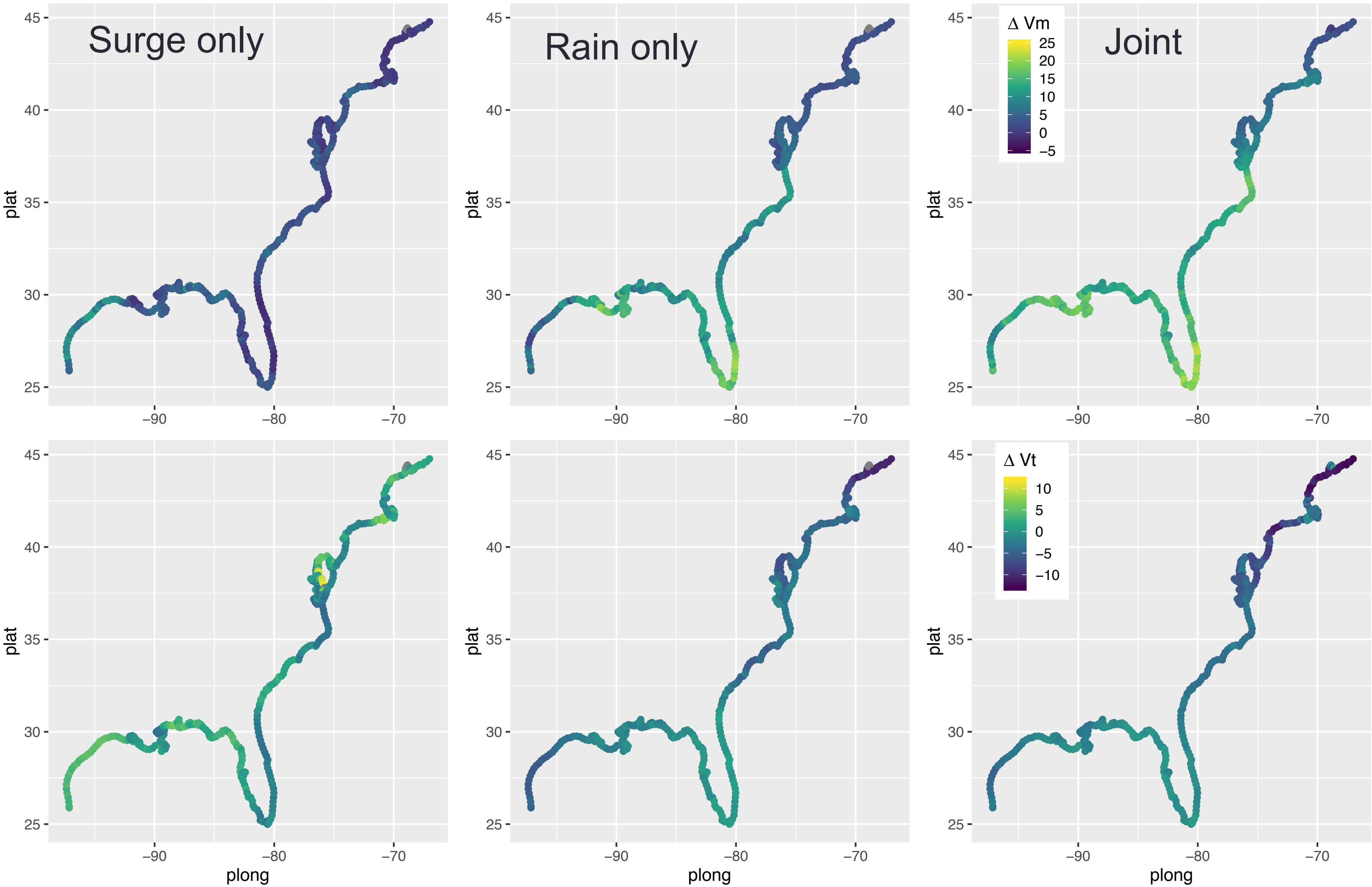
What storm characteristics are associated with rain and/or surge hazard?



Limitations and Future Work

- How can we account for antecedent rainfall and/or interaction with other weather systems?
- Does non-linear interaction of SLR and storm tides significantly impact total water levels?
- How does increase in joint hazard severity translate to coastal flood impacts?
    - Our work can be used to develop boundary conditions for local-scale flood models