Uncertainty Quantification for a Climatology of the Frequency and Spatial Distribution of North Atlantic Tropical Cyclone Landfalls

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ABSTRACT.

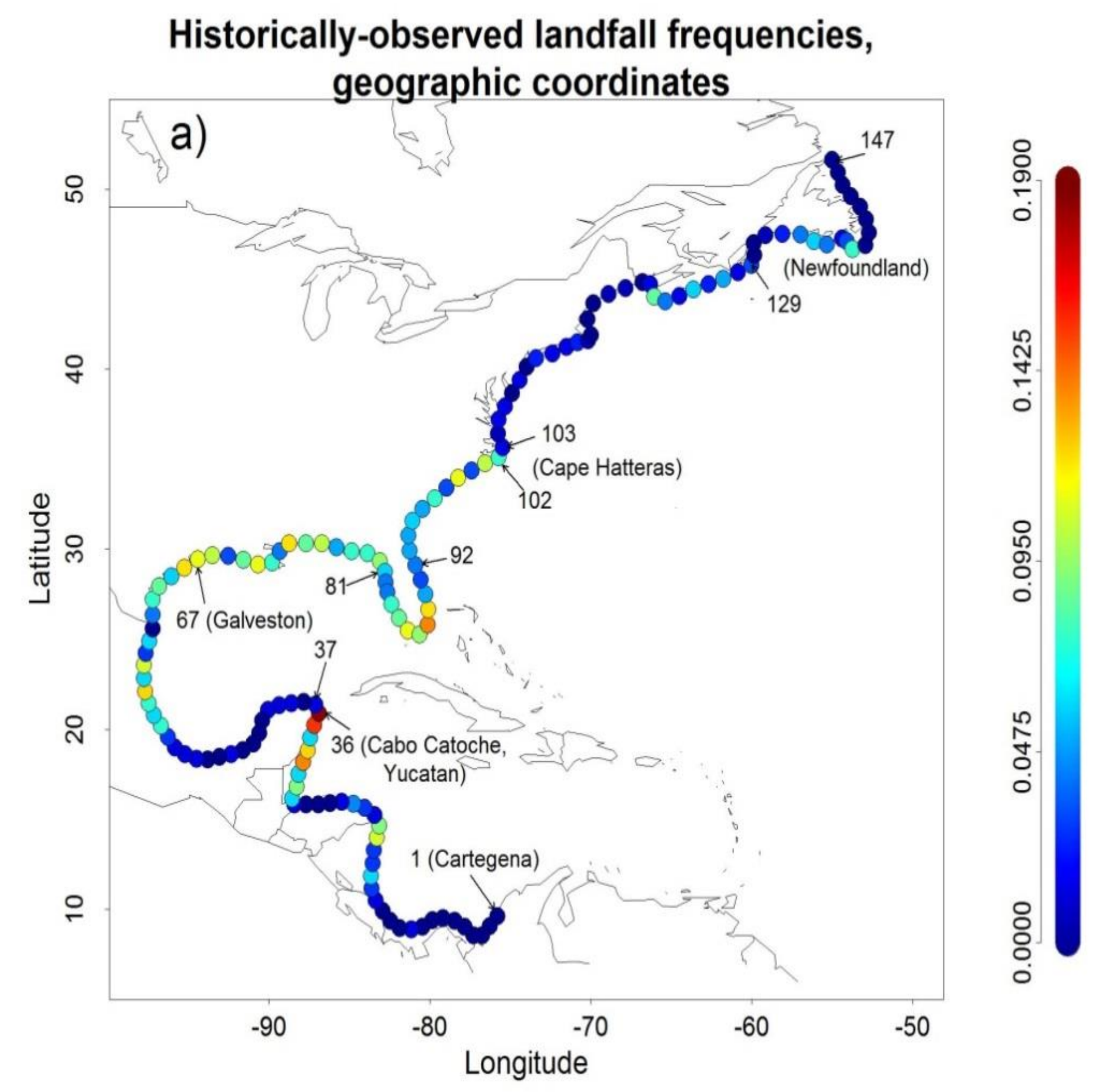
Estimating the climatology of tropical cyclone (TC) landfalls poses several challenges:

- Historical landfall locations contain uncertainty, esp. before modern obs. technology
- Only ~100 yr observational data available ➔ sampling variability!
- Length of available record differs across regions of coastline

Underutilized sources of information about landfall climatology include:

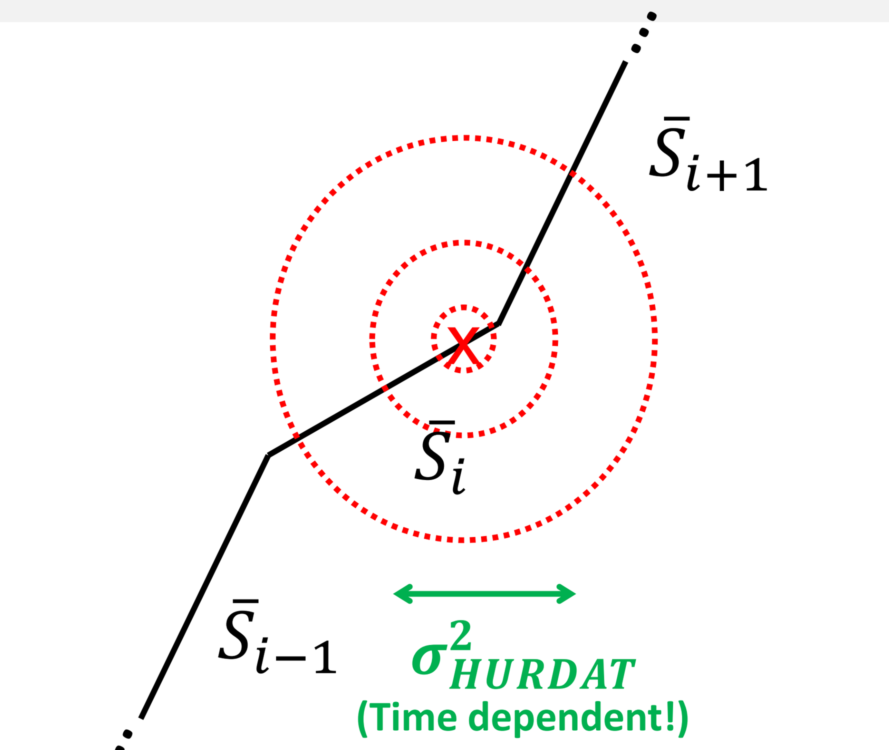
- Dependence of landfall on climate state through well-known physical relationships
- "First Law of Geography": The probability of landfall at nearby locations with similar coastal orientations should be similar

This work explicitly models these challenging aspects + incorporates these sources of information to produce a physically-consistent climatology for landfall activity along the east coast of North and Central America.



DATA & METHODS (and model in words)

- Domain: discretized Atlantic coastline from Newfoundland through Latin America
- Historical landfalls derived from HURDAT2 "Best Tracks" *(Jarvenin et al 1984, Landsea and Franklin 2013)*
- Time-dependent TC position uncertainties from literature



Cartoon: contours of probability density about a recorded landfall position (x). Probability then gets restricted to discretized coastal segments.

- Re-map to a 2D coordinate space: coast-following distances vs. mean onshore hurricane-season wind strength. Distances in this space incorporate "shadow effect" of coastline geometry.
- Sampling via MCMC returns an ensemble of estimates of each model parameter for rich uncertainty quantification.

BAYESIAN HIERARCHY (model in equations)

Random variables to learn:

y_k: Latent "true" landfall position of event k

$N_j(t)$: Counts in year t, coastal segment j

$\boldsymbol{\lambda}_t$: Vector of expected counts in yr t

θ: Statistical model parameters

Fixed data/predictors:

$\hat{\boldsymbol{y}}_t$: Recorded landfall positions

$\boldsymbol{Z}_t$: Climatic predictors

$$\prod_t \left[y_t, \{N_{k,t}(y_t)\}_{k=1}^{N_{coast}}, \boldsymbol{\lambda}_t, \theta \mid \hat{y}_t, \boldsymbol{Z}_t\right] \propto \prod_t \left\{[\hat{\boldsymbol{y}}_t|\boldsymbol{y}_t]\left(\prod_k \left[N_{k,t}(\boldsymbol{y}_t)\middle|\lambda_{k,t}\right]\right)[\boldsymbol{\lambda}_t|\theta, \boldsymbol{Z}_t]\right\}[\theta]$$

Data-level model — Process-level model — Parameter model

$$\hat{y}_k \sim N_{s_{coast}}\left(y_k, \sigma^2_{HURDAT2}(t_k)\right)$$

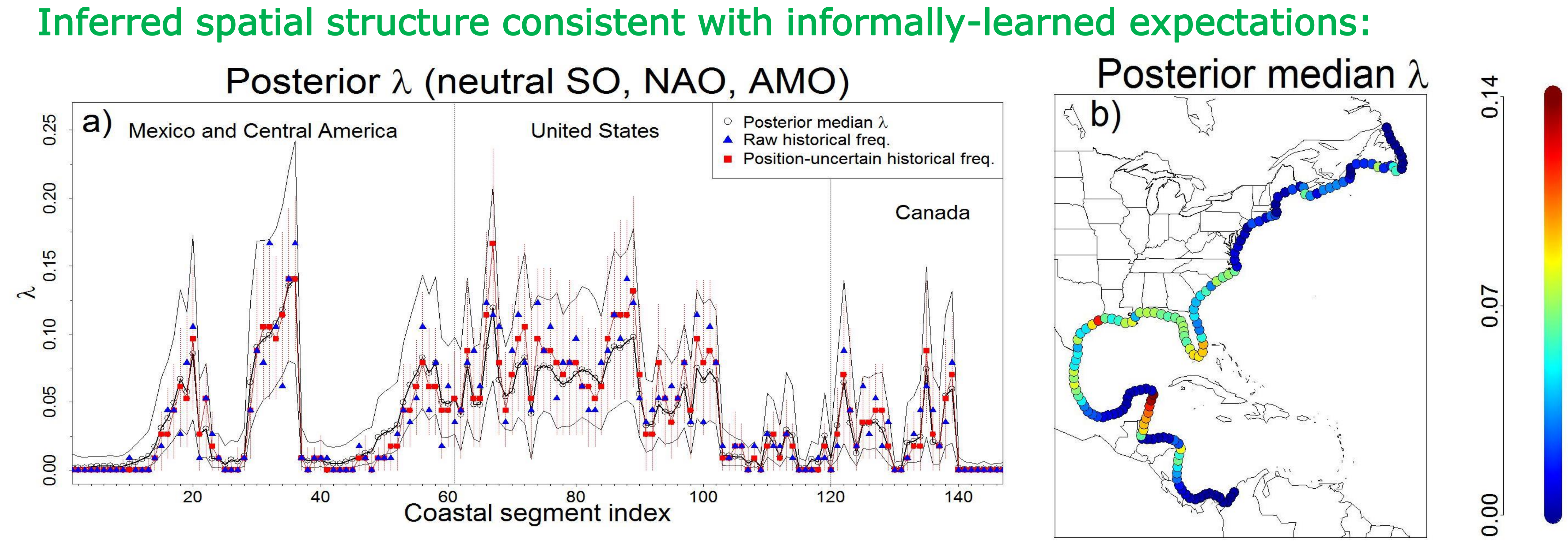
$$N_j(t) \sim Pois\left(\lambda_j(t)\right)$$

$$\log(\boldsymbol{\lambda}(t)) = \beta_0 + \beta_{SO} Z_{SO}(t) + \beta_{AMO} Z_{AMO}(t) + \boldsymbol{\beta}_{NAO} Z_{NAO}(t) + \boldsymbol{\epsilon}$$

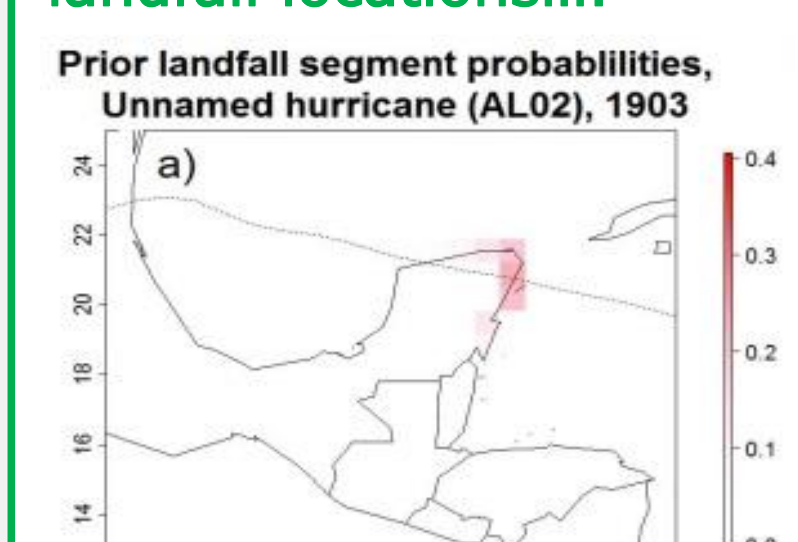
Noninformative priors for all parameters

RESULTS

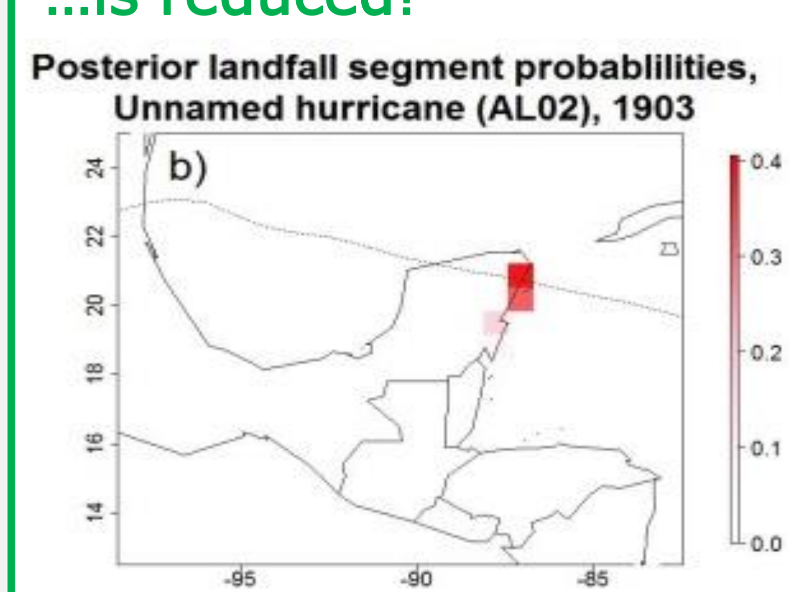
Inferred spatial structure consistent with informally-learned expectations:



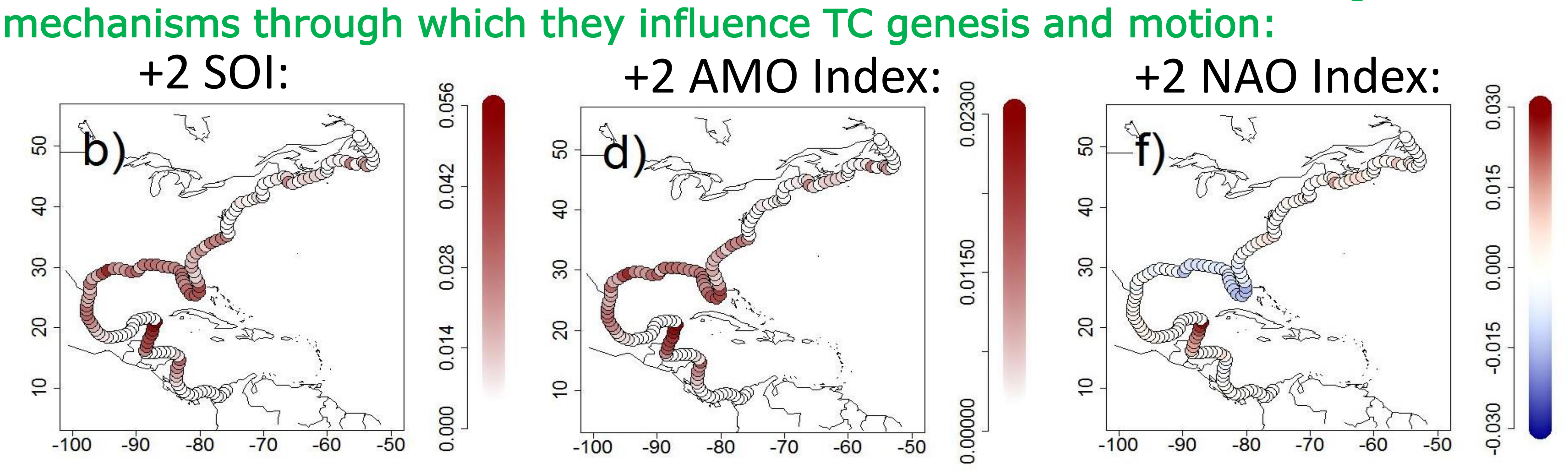
Uncertainty in historical landfall locations….



…is reduced!



Inferred effects of climate states consistent with current understanding of mechanisms through which they influence TC genesis and motion:



Climatological Uncertainty from:

1. Sampling variability due to short historical record (greatest contributor!)
2. Obs. error in TC position data
3. Nearly negligible contribution from uncertainty in underlying model params.

References

- Jarvenin et al (1984), *A tropical cyclone data tape for the North Atlantic Basin, 1886-1983: Contents, limitations, and uses*. NOAA Tech. Memo. NWS NHC-22
- Landsea and Franklin (2013), *Atlantic hurricane database uncertainty and presentation of a new database format*, Mon. Weath. Rev., 141, doi:10.1175/MWR-D-12-00254.1.
- Tolwinski-Ward (2015), *Uncertainty quantification for a climatology of the frequency and spatial distribution of North Atlantic tropical cyclone landfalls*, J. Adv. Mod. Earth Sys., doi:10.1002/2014MS000407