



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

S.E. Tolwinski-Ward (STolwinski-Ward@air-worldwide.com), AIR Worldwide Corporation, Boston, MA, USA
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ABSTRACT.

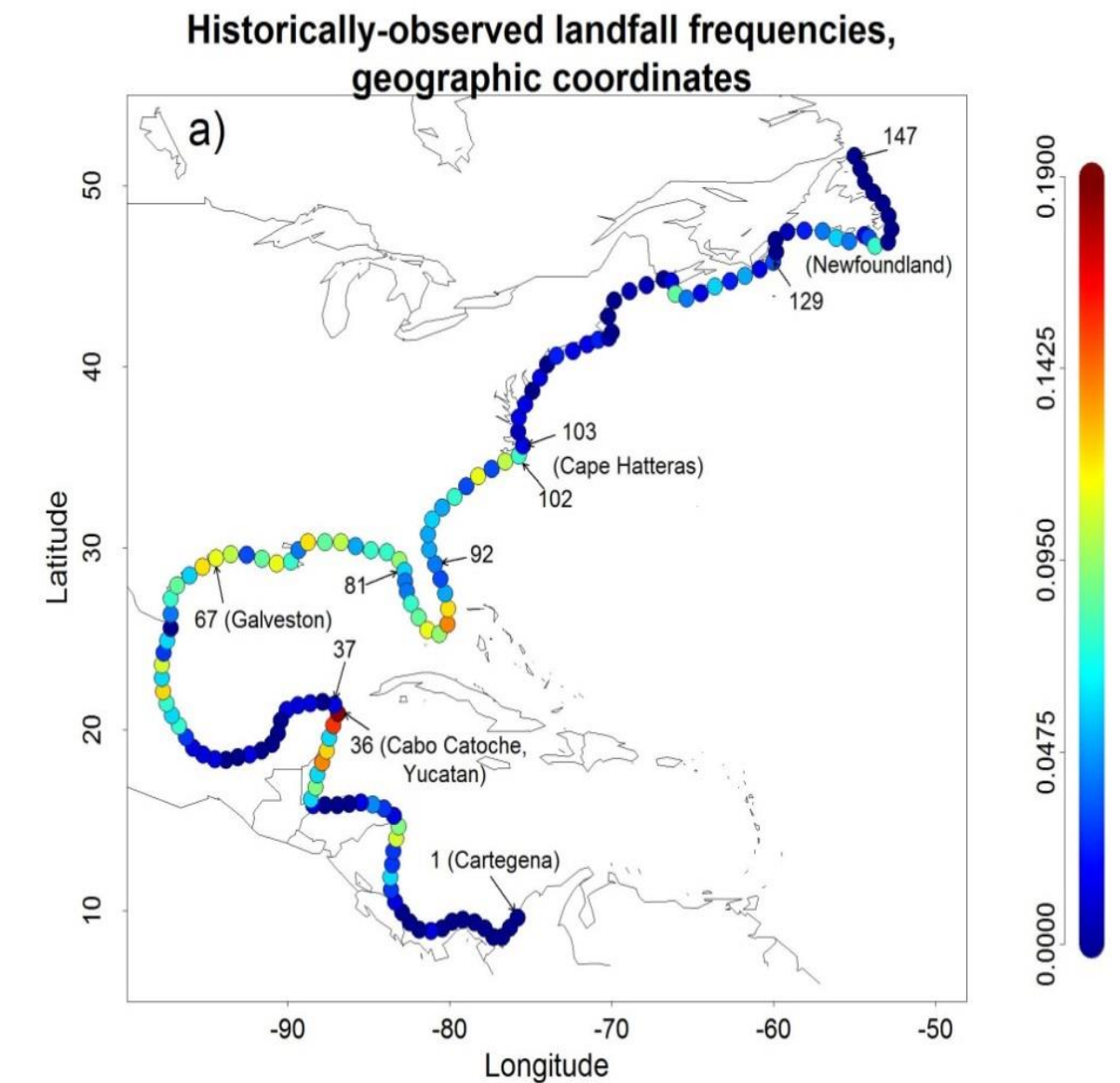
Estimating the climatology of tropical cyclone (TC) landfalls poses several challenges:

- 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:

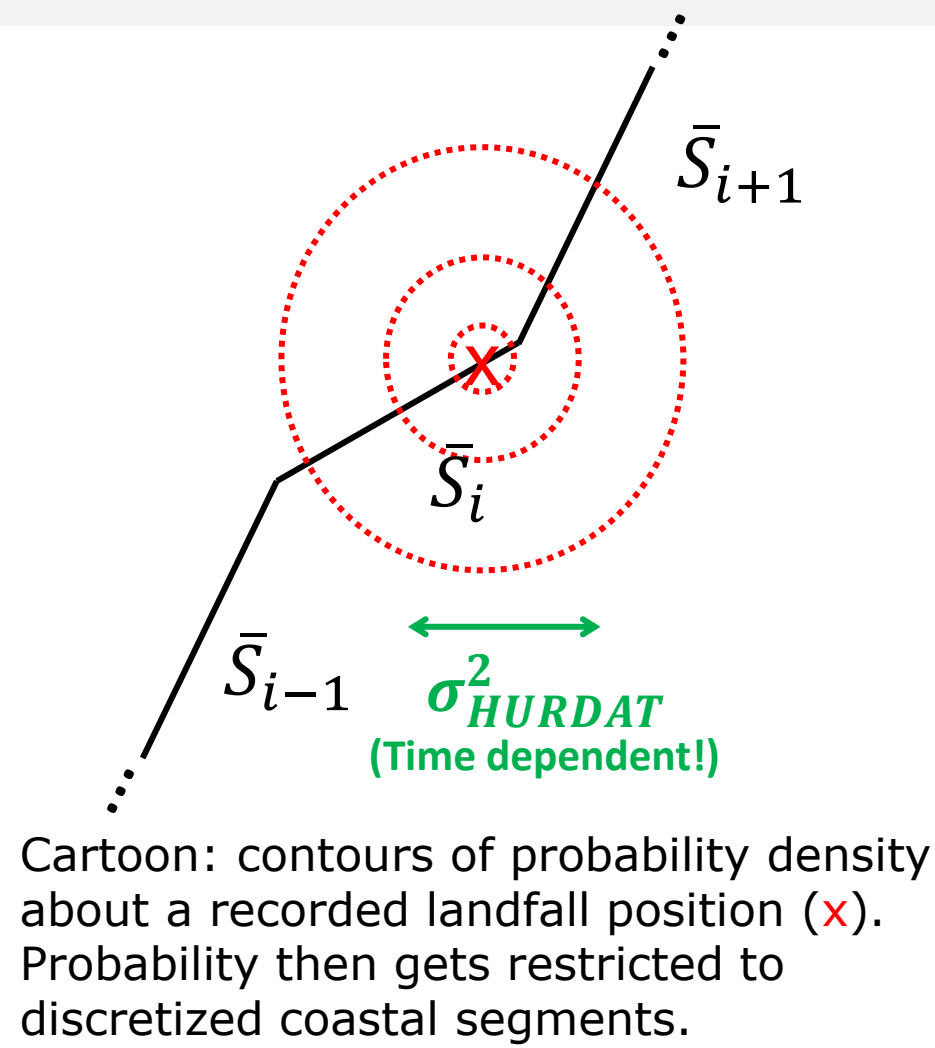
- Dependence of landfall on climate state through well-known physical relationships
- "First Law of Geography": The probability of landfall at nearby locations with similar coastal orientations should be similar

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
- 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
- λ_t : Vector of expected counts in yr t
- θ : Statistical model parameters

Fixed data/predictors:

- \hat{y}_t : Recorded landfall positions
- Z_t : Climatic predictors

$$\prod_t [y_t, \{N_{k,t}(y_t)\}_{k=1}^{N_{coast}}, \lambda_t, \theta | \hat{y}_t, Z_t] \propto \prod_t \{ [\hat{y}_t | y_t] (\prod_k [N_{k,t}(y_t) | \lambda_{k,t}]) [\lambda_t | \theta, Z_t] \} [\theta]$$

Data-level model

Process-level model

Parameter model

$$\hat{y}_k \sim N_{S_{coast}}(y_k, \sigma_{HURDAT2}^2(t_k))$$

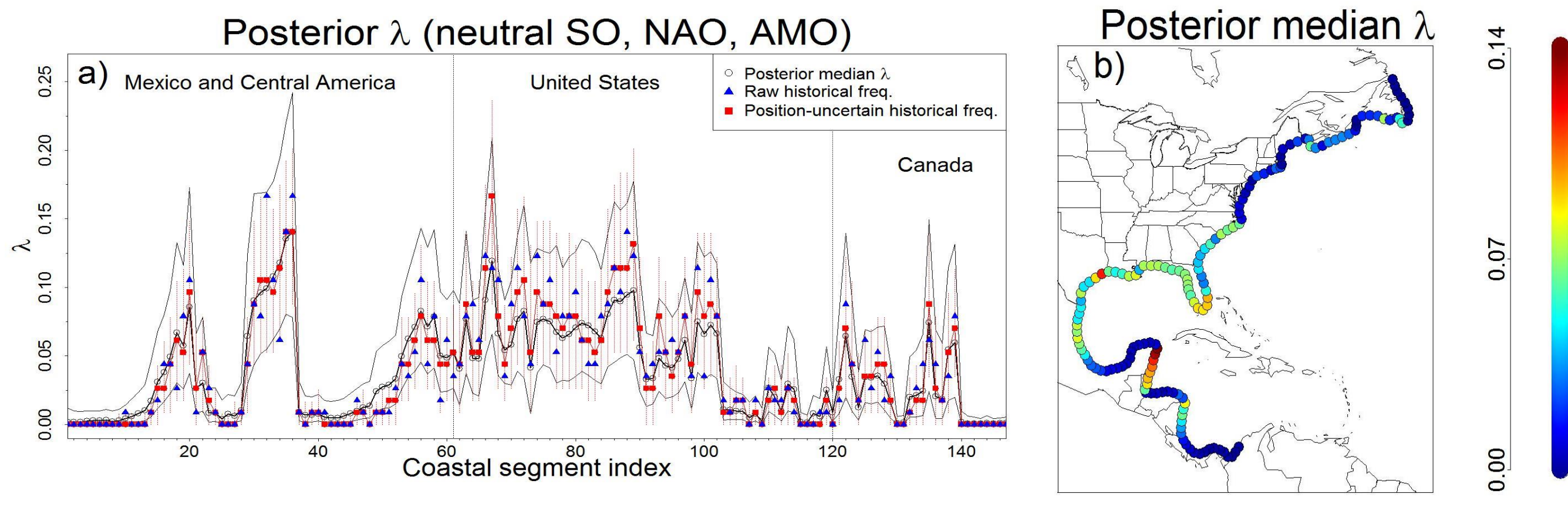
$$N_j(t) \sim Pois(\lambda_j(t))$$

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

Noninformative priors for all parameters

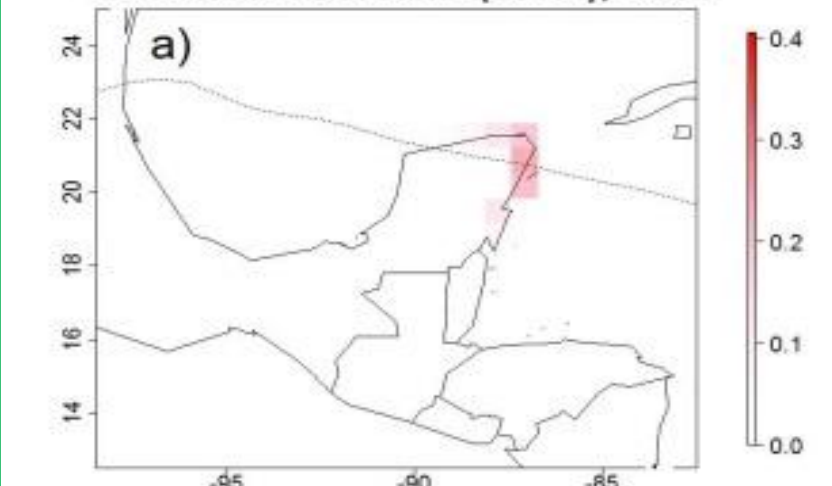
RESULTS

Inferred spatial structure consistent with informally-learned expectations:



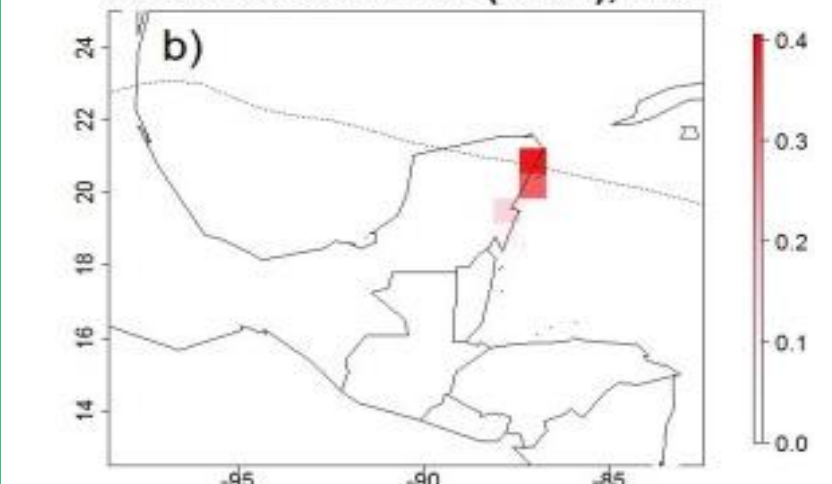
Uncertainty in historical landfall locations....

Prior landfall segment probabilities, Unnamed hurricane (AL02), 1903

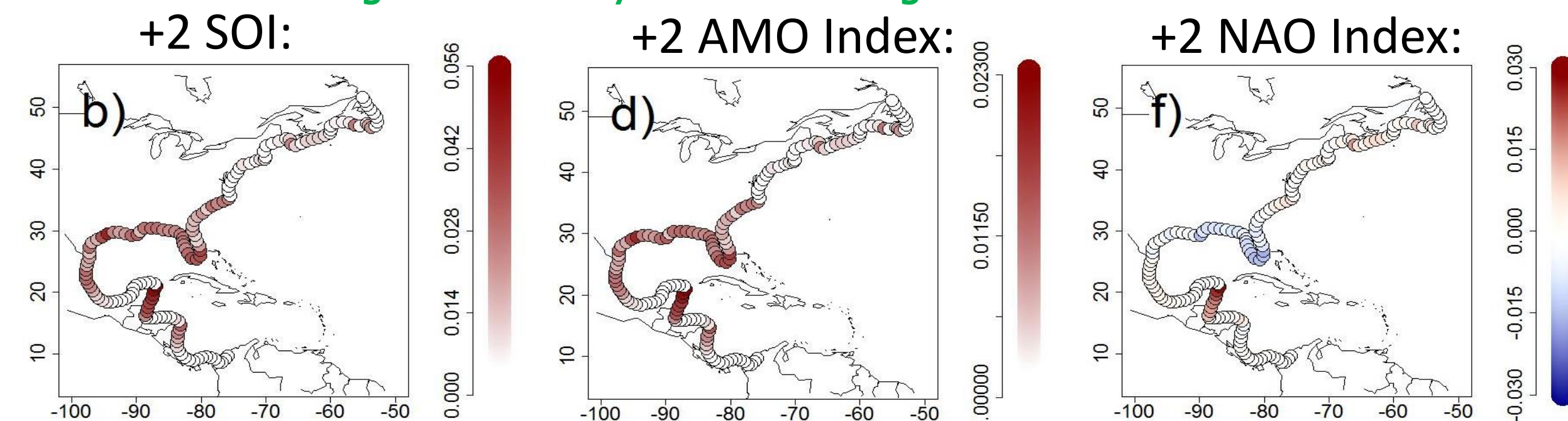


...is reduced!

Posterior landfall segment probabilities, Unnamed hurricane (AL02), 1903



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