Hurricane Winds Over the North Atlantic: Spatial Analysis and Sensitivity to Ocean Temperature

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Poster Presentation for IASCLiP Virtual Workshop, September 2015

Abstract: Hurricanes pose serious threats to people and infrastructure along the United States Gulf and Atlantic coasts. The risk of the strongest hurricane winds over the North Atlantic basin is analyzed using a statistical model from extreme value theory and a tessellation of the domain. The spatial variation in model parameters is shown, and an estimate of the limiting strength of hurricanes at locations across the basin is provided. Quantitative analysis of the variation is done using a geographically weighted regression with regional sea surface temperature as a covariate. It is found that as sea surface temperatures increase, the expected hurricane wind speed for a given return period also increases.

Research Objectives:
1. Map latent extreme value model parameters across the North Atlantic Ocean basin; 2. Relate those parameters to sea surface temperature

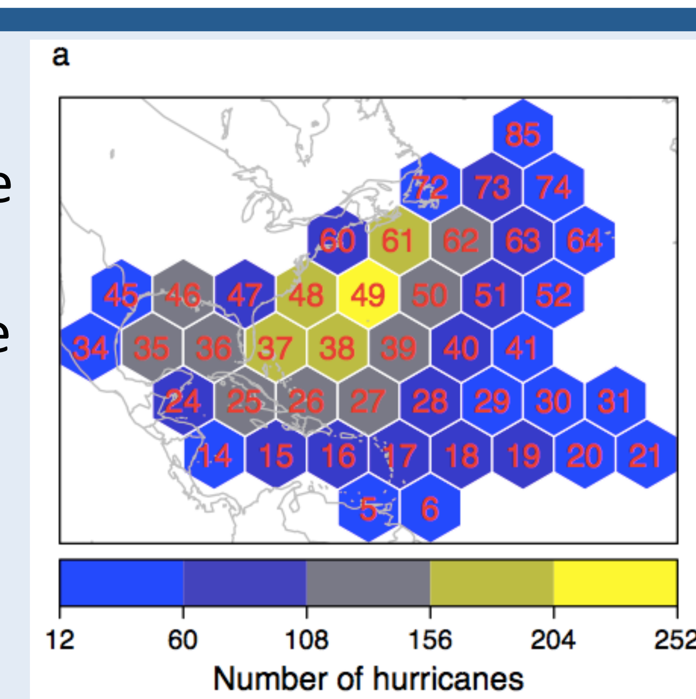


Figure 1a: Shows the number of hurricanes from 1854–2010 per hexagon as taken from the National Hurricane Center's HURDAT database.

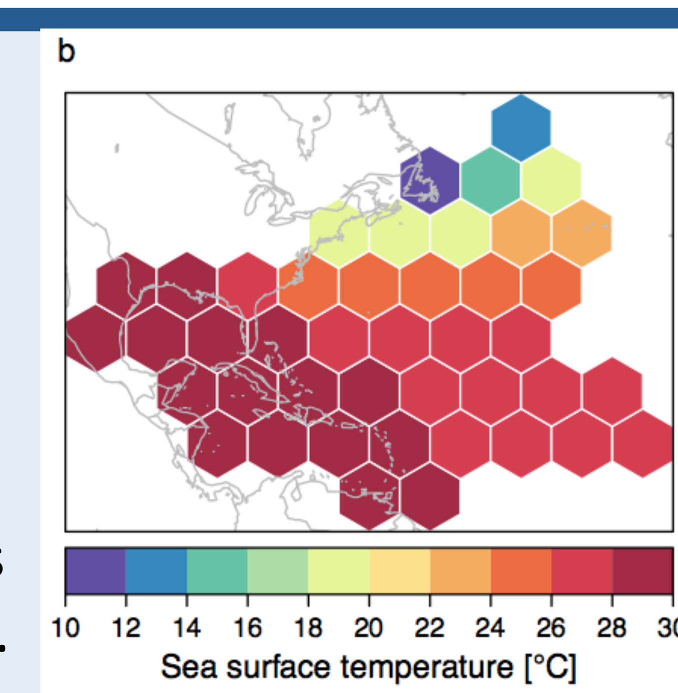


Figure 1b: Average August–September sea surface temperature values per hexagon from 1854–2010 as taken from the NOAA ERSST V3b dataset.

Extreme Value Analysis

A Peaks-Over-Threshold Approach

Goal: an extreme value model that provides a continuous estimate of the return level (threshold intensity) for a set of return periods. This model is useful because it gives an estimate of the return level for a return period longer than the data record.

Statistical Model: The Generalized Pareto distribution (GPD) describes the set of fastest winds above some high intensity threshold. The threshold choice is a compromise between having enough values to estimate the distribution parameters with sufficient precision, but not too many that the intensities fail to be described by a GPD. Specifically, given a threshold wind speed u, the exceedances are modeled, $W - \underline{u}$, as samples from a GPD family so that for an individual hurricane with maximum winds W, the probability that W exceeds any value v given that it is above the threshold u is given by

$$\Pr(W > v | W > u) = \left(1 + \frac{\xi}{\sigma}[v - u]\right)^{-1/\xi} = \mathrm{GPD}(v - u | \sigma, \xi)$$

Since the number of storms exceeding any wind speed v is a Poisson process, the return period for any v has an exponential distribution, with mean $r(v) = 1/\lambda_v$. By substituting for λ_v in terms of both λ_u and the GPD parameters then solving for v as a function of r the corresponding return level for a given return period can be estimated as

$$\mathrm{rl}(r) = u + \frac{\sigma}{\xi}\left[(r \cdot \lambda_u)^{\xi} - 1\right]$$

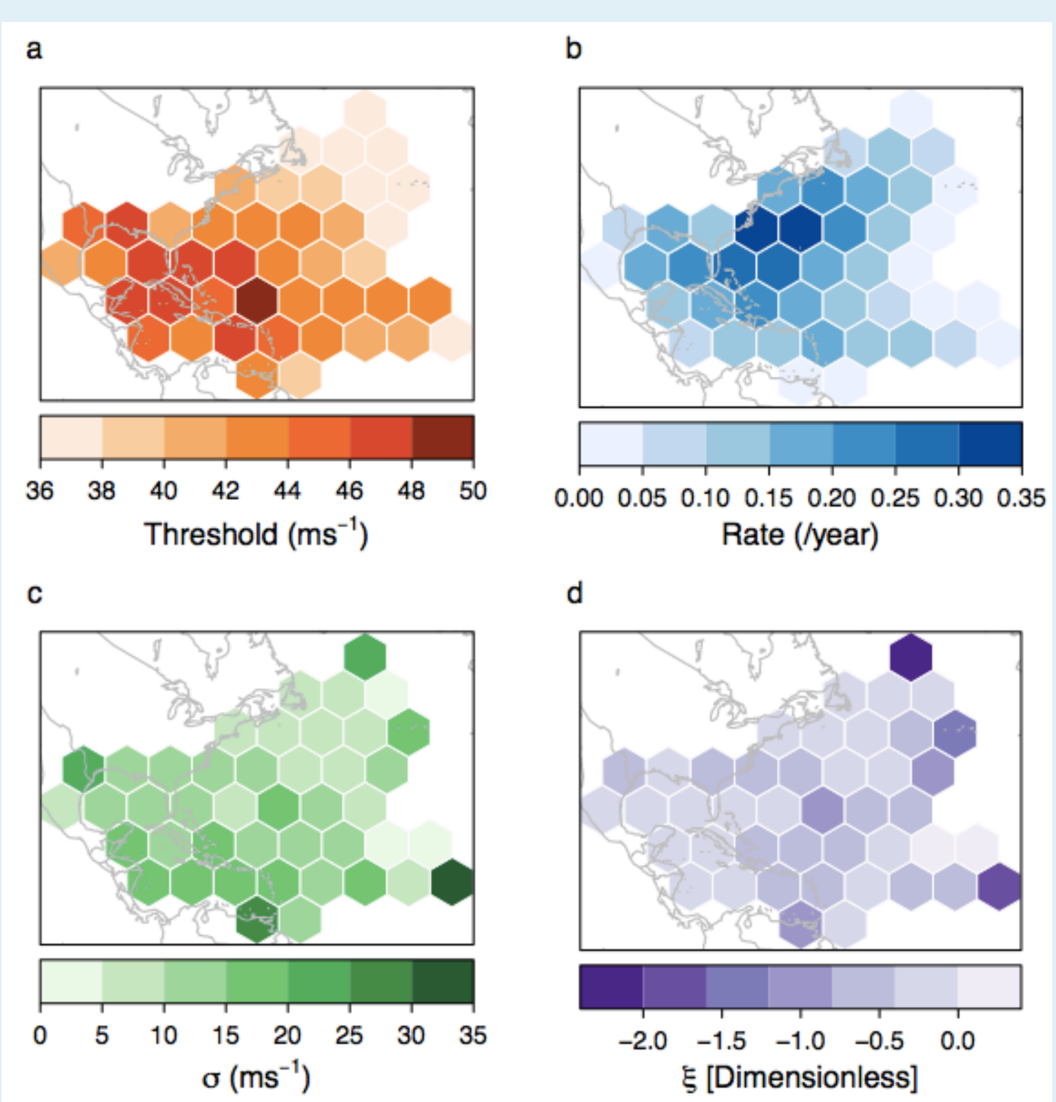
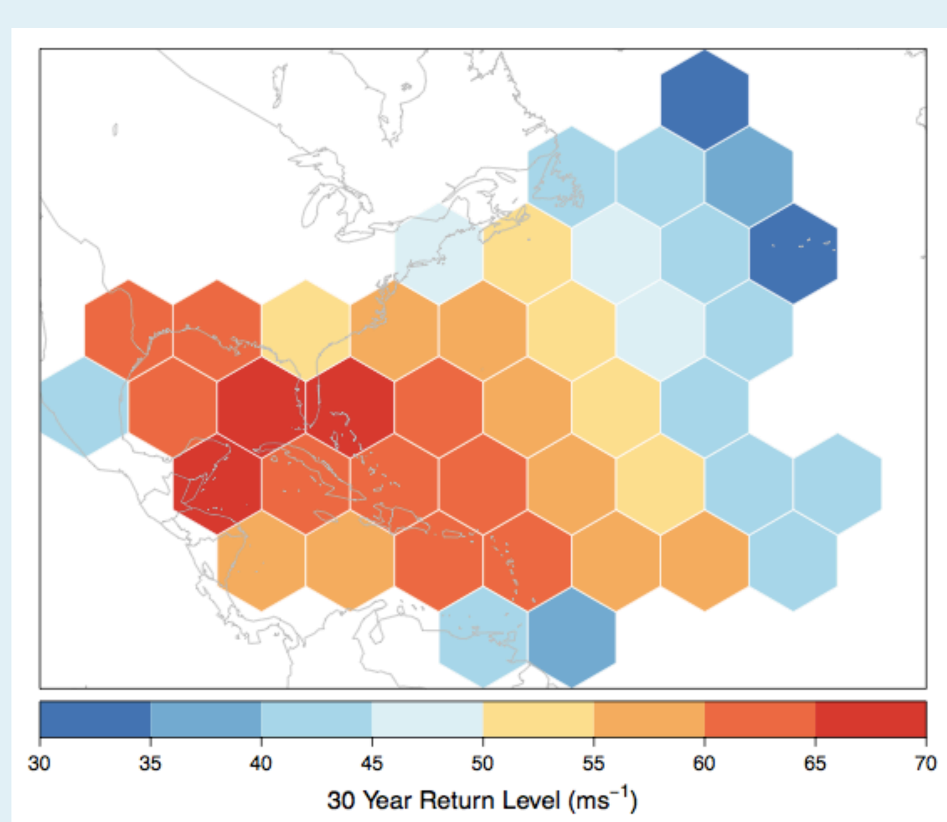


Figure 2: a) Model threshold (50th percentile wind speed), **b)** Rate of hurricanes over threshold per year, **c)** Sigma or scale of hurricane winds, **d)** Xi or shape of the tail of the distribution. **Figure 3 (below)**: 30 year return level



Sensitivity to Sea Surface Temperature

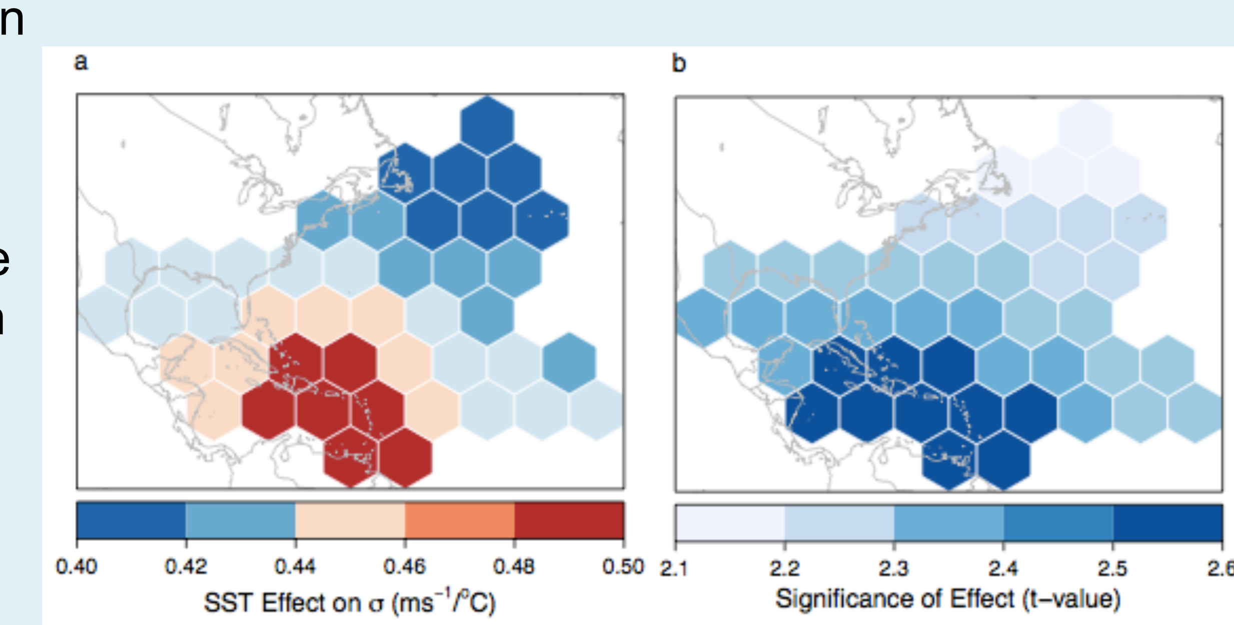
Using Geographically Weighted Regression

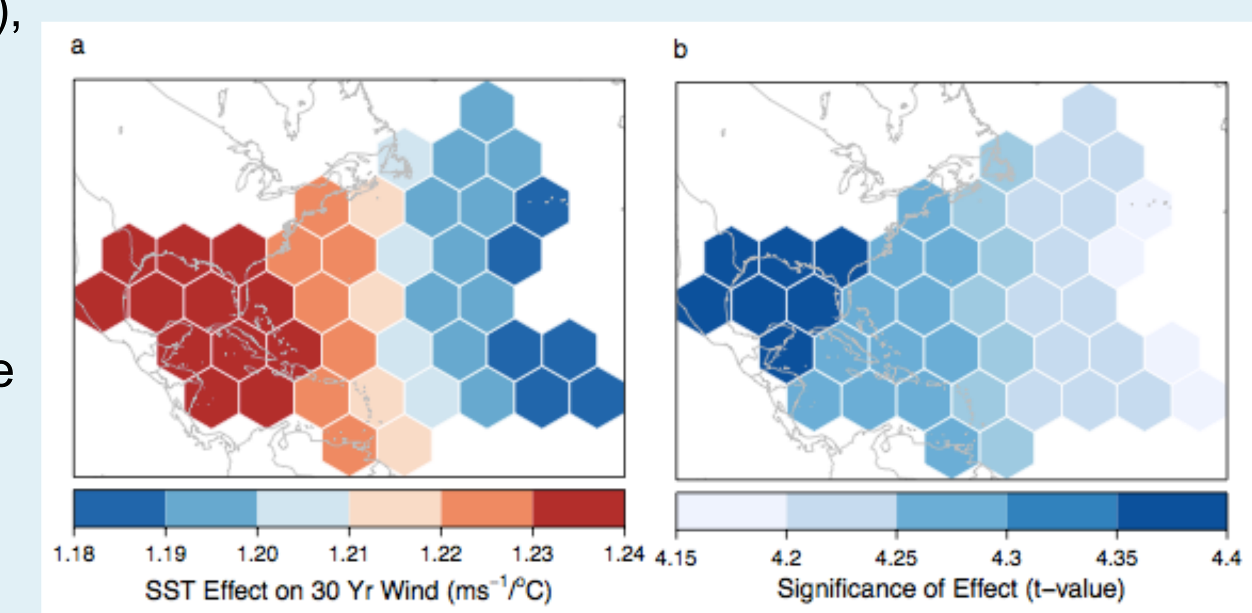
Goal: to visualize the spatial differences in sensitivity of the model parameters to sea surface temperature.

Statistical Model: With GWR, the SST parameter is replaced by a vector of parameters (i.e., λ_u, σ, ξ, or the return level estimates), one for each hexagon. The relationship between the response vector and the explanatory variables is expressed mathematically as

$$y = X\beta(g) + \epsilon$$

Here, an adaptive kernel is chosen that allows the estimates to vary depending on the location of the samples. The percent change in the intercept values of each variable across the hexagons provides information showing how sensitive the latent variables are to SST. There is a 22.1% change in the λ, a 18.3% change in the σ, a −50.6% change in the ξ, and a 4.1% change in the 30-year return level per degree SST. This suggests that the ξ parameter is the most sensitive to SSTs. The ξ parameter represents the most extreme events (negative values corresponding to more extreme events), so these results suggest that the maximum intensity of hurricanes is most sensitive to a changing SST value. Local significance of the coefficients is found by dividing the SST coefficient by its standard error. The ratio, called the t value, has a t-distribution under the null hypothesis of a zero coefficient value. Regions of high t values (absolute value greater than 2) denote areas of statistical significance. Only the significant parameters are shown to the right.





Citation: Trepanier, J. C. 2014, Hurricane winds over the North Atlantic: spatial analysis and sensitivity to ocean temperature. *Natural Hazards*, 71: 1733–1747.