Analyzing North Atlantic Hurricane Behaviors

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The Atlantic coastal US had a 12-year period without hurricane landfalls of major intensity until Hurricane Harvey in 2017. Harvey is known as one of the costliest tropical cyclones on record, tied with Hurricane Katrina.

MOTIVATION

- How has the overall rate of movement from starting location to ending location changed with time?
- Are hurricanes moving further North?
- What factors led to the 12-year period between major hurricane landfalls?
- What environmental factors contribute to the changes over time?

DATA DESCRIPTION

We utilize satellite data in the form of NetCDF, recorded daily at 6-hour intervals from NASA Modern-era Retrospective Analysis for Research and Applications (MERRA 2) and Japanese Meteorological Agency – 55 year Reanalysis Data (JRA). We also combine the National Hurricane Center's North Atlantic historical hurricane data (HURRDAT2).

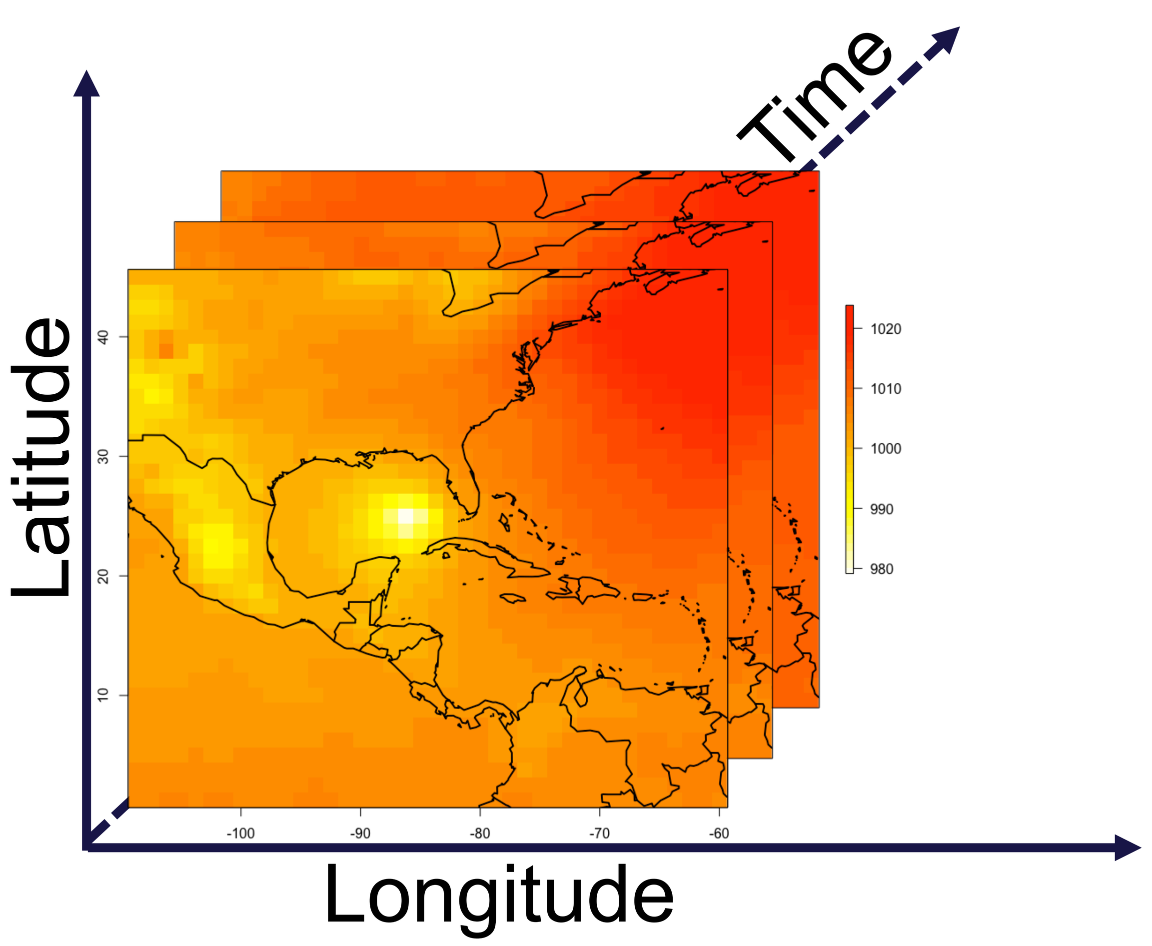

Figure1: NetCDF data showing the surface pressure level in the North Atlantic basin during Hurricane Katrina, August 28, 2005. This data is recorded at 6 hour intervals for 1979-2017.

APPROACH

To analyze hurricane movement we model the *overall average movement rate* (the rate at which a hurricane moves from starting point to finishing point, across the map, in miles per hour) for each hurricane as a function of time (seasons). We can then make inference about the changes in rate over time.

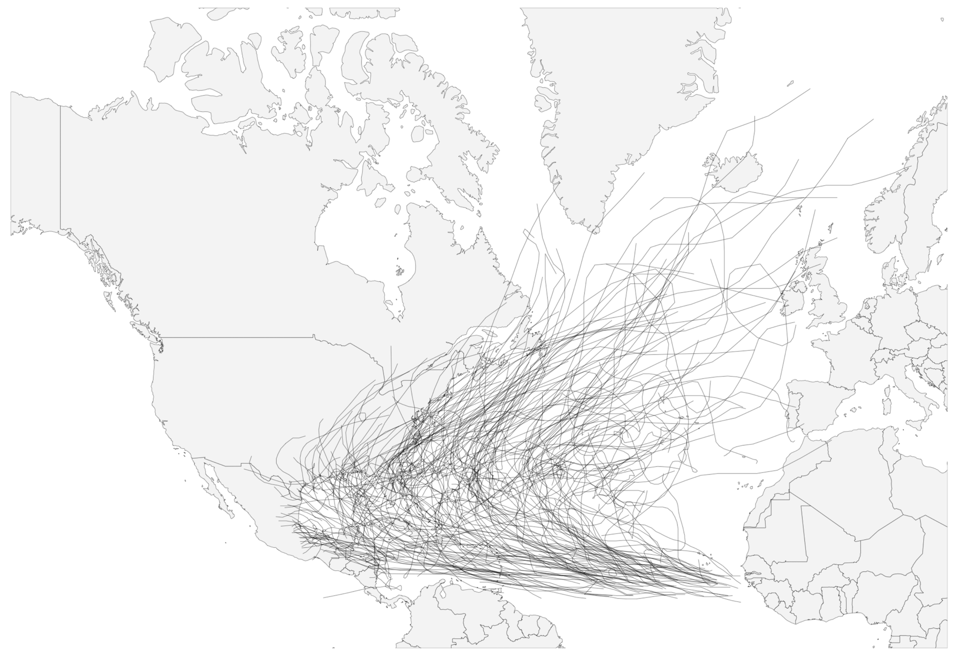

Figure 2: Hurricane tracks for seasons 2000-2017 extracted from the NetCDF files. We are interested in seeing if the overall rate and the total distance covered by each hurricane is changing over time.

Models

Model 1:

Let y_{tj} be the overall average movement rate of hurricane j in season t. Then let θ_t be the average rate of hurricane movement for all hurricanes in season $t,\ t = (1980, \dots, 2017)$. We set up a Bayesian hierarchical model to explore the changes in average rate across each year.

$$y_{tj}|\theta_t, \sigma^2 \sim N(\theta_t, \sigma^2) \quad t = 1, \dots, T; j = 1, \dots, m_t$$

$$\theta_t|\mu, \tau^2 \sim N(\mu, \tau^2) \qquad \sigma^2|v_0, s_0^2 \sim IG\left(\frac{v_0}{2}, \frac{s_0^2}{2}\right)$$

$$\mu \sim N(\mu_0, \omega). \qquad \tau^2 \sim IG(a_\tau, b_\tau)$$

We have assigned conjugate priors and select hyperparameters $v_0, s_0, \omega, a_\tau, b_\tau$ so that θ_t reflect the data. We apply a Gibbs sampling algorithm to draw from the full posterior distribution.

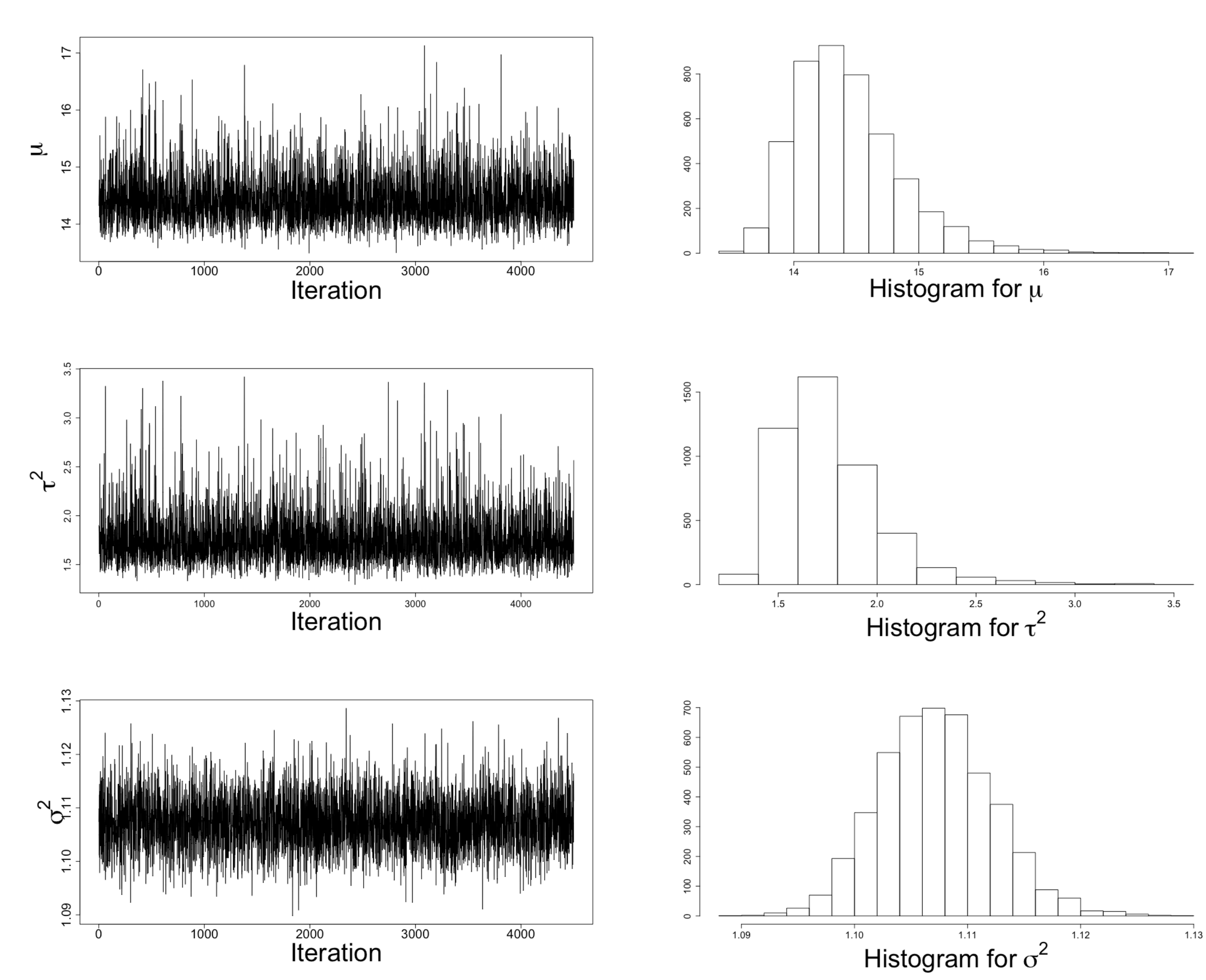

Figure 3: Trace plots for model 2 shows that the Gibbs sampling algorithm is converging with no problems. We obtain the posterior estimates for $\mu, \tau^2,$ and σ^2

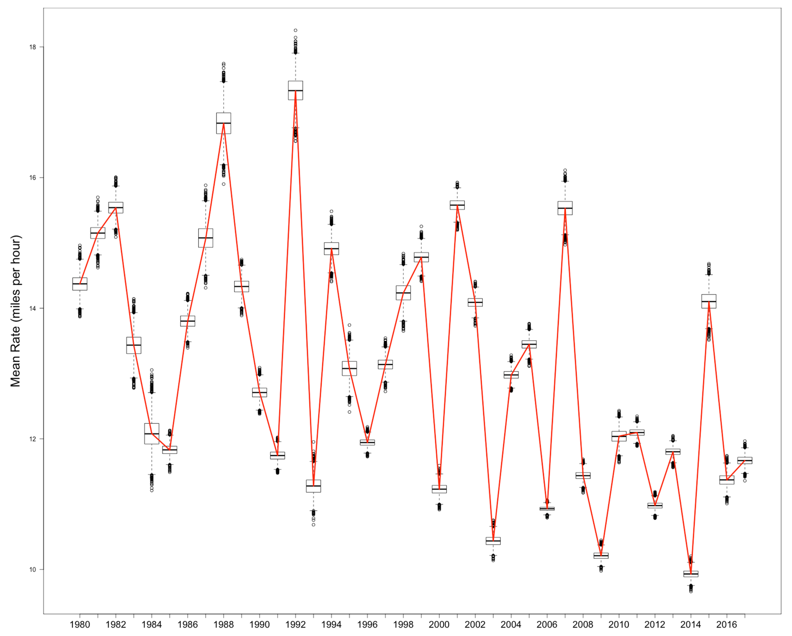

Figure 4: The posterior estimates for the average movement obtained from Gibbs sampling from the full posterior. Overall, it appears the hurricane rates are decreasing by year (i.e. hurricanes are moving slower each year).

Model 2:

Note that model 1 relies on the hurricane count for each year, m_t. Thus, we also seek to analyze the changes in hurricane counts over time. Let m_t denote the total hurricane count for hurricane season t. Let λ_t be the rate of hurricane occurrence for season t.

$$m_t \sim Pois(\lambda_t) \quad t = 1, \dots, T$$
$$\lambda_t \sim Gamma(\alpha, \beta)$$
$$\beta \sim Gamma(a, b)$$

We assign non-informative values to a, b and α and apply a Gibbs sampling algorithm to explore the posterior distributions.

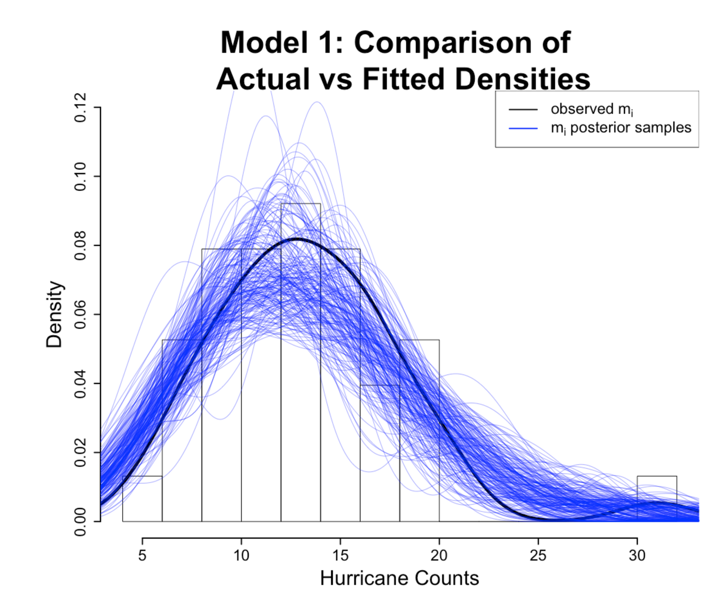

Figure 5: Posterior predictive samples for Model 2 plotted against the observed values. The model captures the general shape of the observed values. Note that there is a lone year in which 31 hurricanes occurred—this corresponds to the 2005 hurricane season.

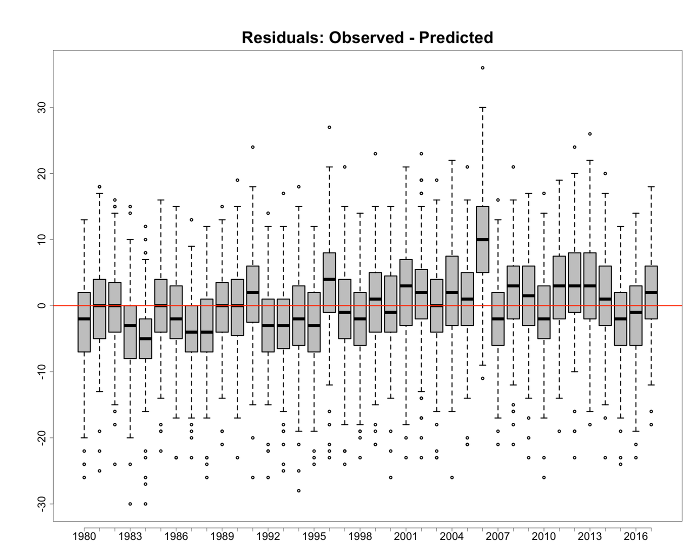

Figure 6: For model 2, the fitted vs predicted difference is close to zero except for the later years which correspond to 2005-2017.

CONCLUSION & FUTURE WORK

We hope to explore the factors contributing to the decrease in the *overall average movement rate* (Figure 4) by incorporating pressure, wind speed, El Niño-Southern Oscillation Index, and other variables. From figures 5-6, predicting a year in which an abnormally high number of hurricanes occurs, such as in 2005, would be useful.

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