P8160 Report - Bayesian Modeling of Hurricane Trajectories

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5/1/2023

Contents

1 Introduction

1.1 Background

A hurricane is a powerful tropical storm characterized by high winds, heavy rain, storm surges, and flooding. Hurricanes are also known as cyclones or typhoons, depending on the region where they occur.

Hurricanes typically form over warm ocean waters and can travel for thousands of miles, causing widespread destruction and disruption to communities in their path. They are categorized on a scale of 1 to 5 based on their wind speed and potential for damage, with Category 5 being the most severe.

Hurricanes can cause significant damage to infrastructure, homes, and businesses, and can also result in loss of life. As such, it is essential to take precautions and follow instructions from emergency management officials in the event of a hurricane.

1.2 Motivation

Climate researcher are interested in modeling hurricane trajectories for early warning and preparedness, resource allocation, planning and response, and scientific research. Overall, accurate modeling of hurricane trajectories is essential for mitigating the impact of hurricanes on communities, infrastructure, and the environment, as well as for advancing our scientific understanding of these powerful storms.

In this project, we are particularly interested in forecasting the wind speed of hurricanes.

1.3 Dataset

The dataset, `hurrican703.csv`, collected the track data of 702 hurricanes in the North Atlantic area from 1950 to 2013. For all the storms, their location (longitude & latitude) and maximum wind speed were recorded every 6 hours. The data includes the following variables:

- ID: ID of the hurricanes
- Season: In which year the hurricane occurred
- Month: In which month the hurricane occurred
- Nature: Nature of the hurricane ET: Extra Tropical

  DS: Disturbance

  NR: Not Rated

  SS: Sub Tropical

  TS: Tropical Storm
- Time: dates and time of the record
- Latitude and Longitude: The location of a hurricane check point
- Wind.kt Maximum wind speed (in Knot) at each check point

1.4 Data pre-processing

First we need to pre-process the data. We only kept observations that occurred on 6 consecutive hour intervals. Through this step, we found that some hurricanes had the same ID but were actually different ones (eg. ALICE). Hurricanes that had fewer than 3 observations were excluded. For the purpose of seasonal comparison, we defined August, September, and October as hurricane-active season, and the rest as hurricane-inactive season. After data cleaning, there are 21691 observations across 704 unique hurricanes.

2 Bayesian Model

2.1 Bayesian hierarchical model for wind speed

3 MCMC

3.1 Posterior distribution of the parameters

3.2 MCMC algorithm implementation

3.3 Parameter convergence diagnostic

3.4 Posterior summaries of gamma

3.5 Hurricane wind speed prediction

Given parameters γ and $\boldsymbol{\beta_i}$ which is the coefficients associated the ith hurricane, the predicted wind speed of the i-th hurricane at $t+6$ time stamp, denoted as $\hat{Y}_i(t+6)$ could be computed as:

$$\hat{Y}_i(t+6) = \boldsymbol{\beta_i}^T \mathbf{Z_i}(t) + \mathbf{X_i}\gamma$$

where $\boldsymbol{\beta_i} = (\beta_{0,i}, \beta_{1,i}, ..., \beta_{4,i})$, and $\mathbf{Z_i}(t) = (1,\ Y_i(t),\ \Delta_{i,1}(t),\ \Delta_{i,2}(t),\ \Delta_{i,3}(t))$.

Based on the burn-in number 8000 as concluded in MCMC parameter convergence diagnostic section, we calculated the parameters to be used to make prediction, and predict the wind speeds of each hurricane at each time stamp, except for the first two time stamps. We computed the RMSE and R-squared of each hurricane, as partly shown in the table 1.

The overall RMSE performance of difference hurricanes is shown in figure 1.

The overall R-squared performance of difference hurricanes is shown in figure 2.

The prediction performance on random chosen example hurricanes is shown in figure 3 and figure 4.

Furthermore, we examined the distribution of RMSE across various properties of hurricanes is shown in figure 5 and figure 6.

We observed that hurricanes belong to nature of "Not Rated" and "Tropical Storm" have an average higher RMSE than other hurricanes. Besides, hurricanes happening in summer from June to September, also have higher RMSE than other months.

4 Discussion

4.1 MCMC parameters convergence problem

4.2 Prediction latency of wind speed change

Group Contributions

Appendices

Figures and Tables

Table 1: Summary of RMSE and R-squared for selected hurricanes

ID	Year	RMSE	R-squared
ABBY.1960	1960	8.8804	0.7700
ABBY.1964	1964	9.6430	0.3033
ABBY.1968	1968	3.5043	0.9360
ABLE.1950	1950	3.6755	0.9813
ABLE.1951	1951	3.4802	0.9767
ABLE.1952	1952	4.5183	0.9583
AGNES.1972	1972	5.2483	0.8881
ALBERTO.1982	1982	8.0473	0.7499
ALBERTO.1988	1988	2.6121	0.7420
ALBERTO.1994	1994	4.3941	0.8807
ALBERTO.2000	2000	3.7896	0.9625
ALBERTO.2006	2006	4.3591	0.7882
ALBERTO.2012	2012	3.2193	0.8036
ALEX.1998	1998	2.9351	0.7289
ALEX.2004	2004	5.4552	0.9539

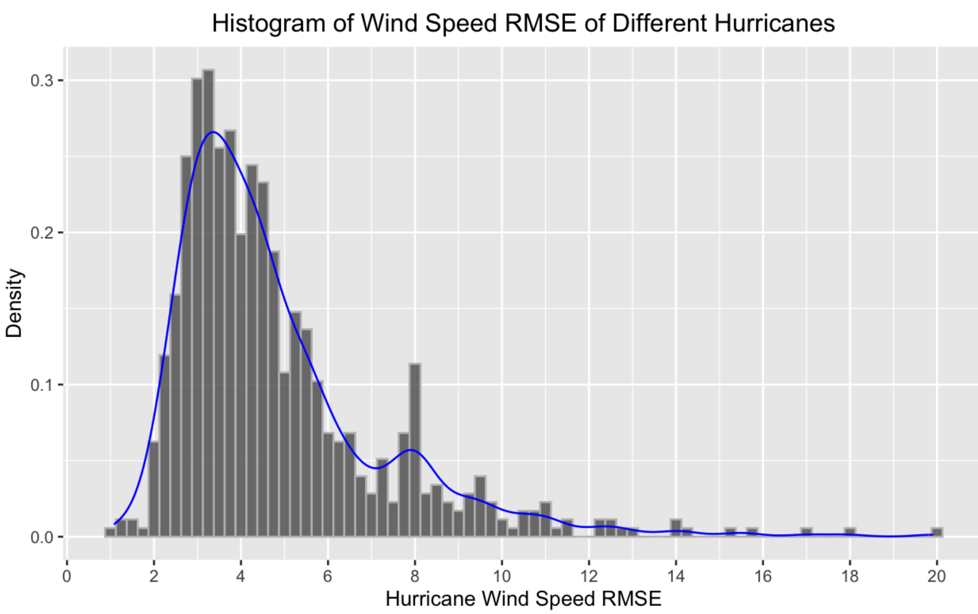

Figure 1: RMSE distribution

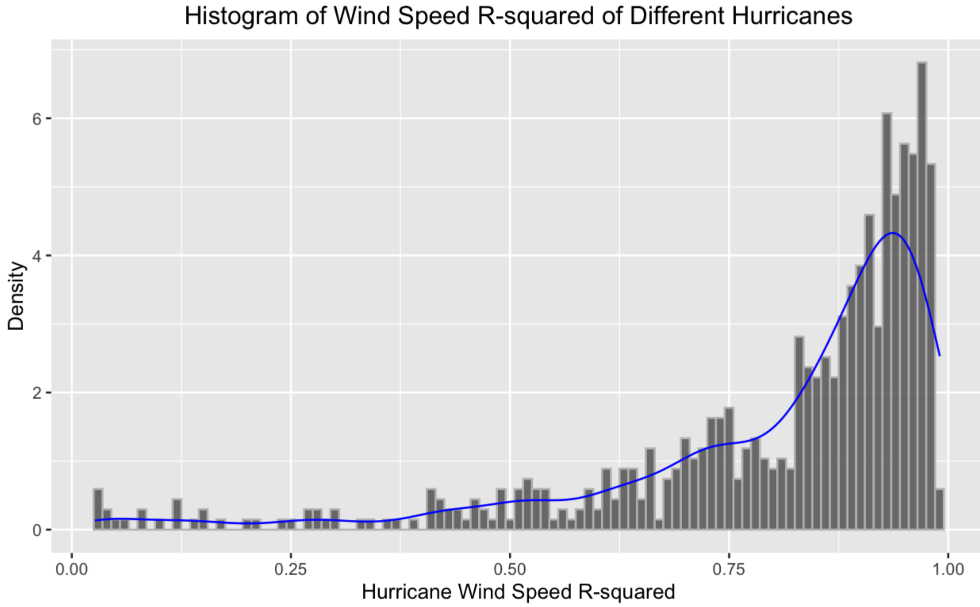

Figure 2: R^2 distribution

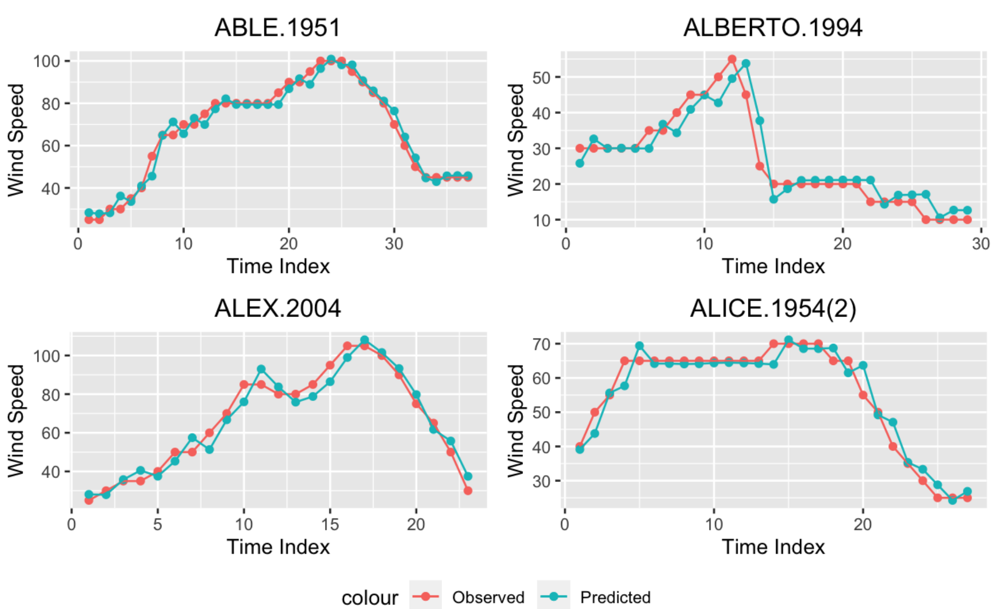

Figure 3: Time series prediction plot

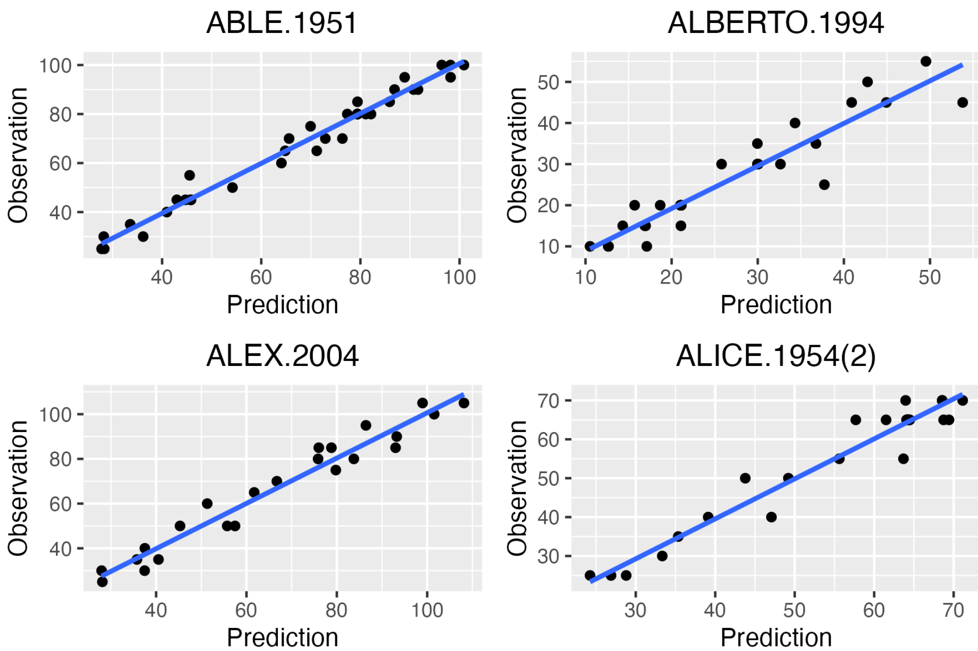

Figure 4: Prediction vs. observation

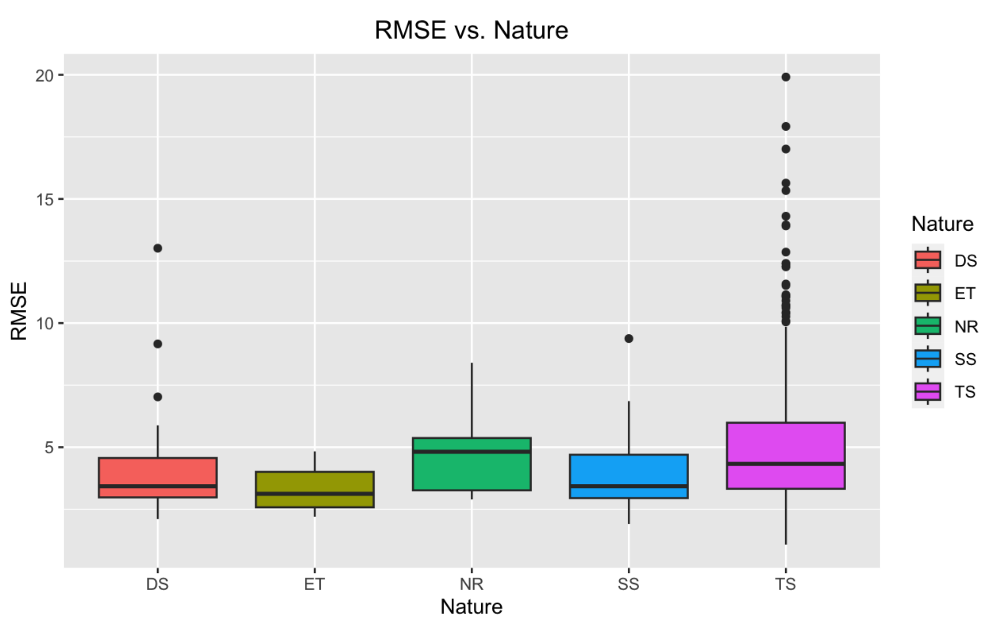

Figure 5: RMSE under different natures

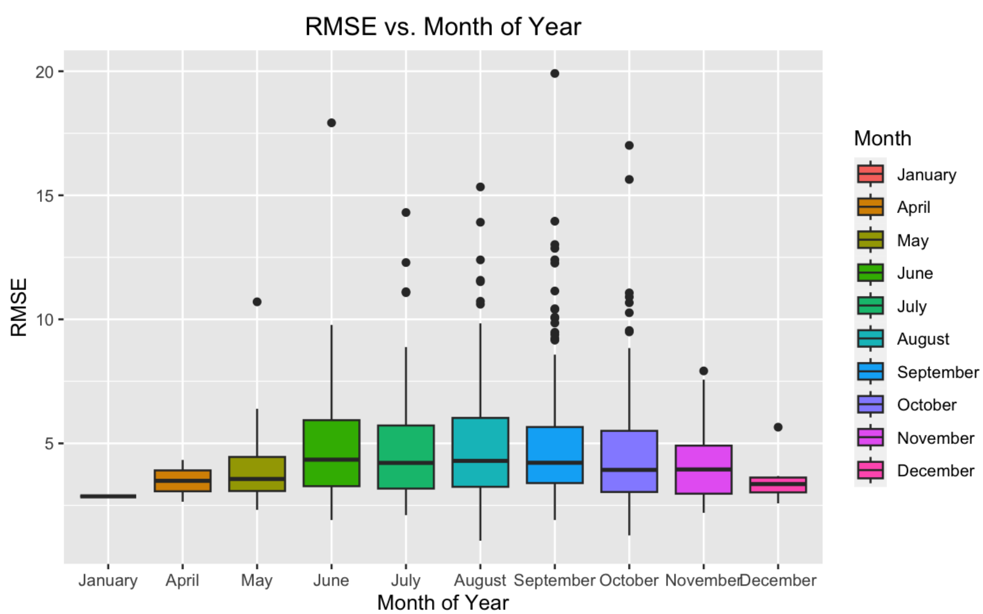

Figure 6: RMSE under different months