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Data Analysis of the Effects of Hurricanes on Ozone Concentration in Florida

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Abstract

The performance of air quality model is often plagued by extreme weather systems. In this paper, we propose a linear regression method that uses ozone data in Florida and hurricane data to study their relationship. Our experiments show that our model can generate predictions of ozone in Florida during hurricane activity. The model is simple and performs especially well for intense hurricane, which can be used to deepen understanding of extreme weather systems and air quality models.

Keywords

Air Quality Forecast; Tropical Cyclone; Ozone Concentration Prediction; Hurricane.

1. Introduction

Ozone is an allotrope of oxygen. Human and natural activities can produce ozone in the troposphere [1-3]. Tropospheric ozone is a serious hazard to human health [4-6]. Ozone has little effect on visibility, so it is difficult for citizens to observe it. Due to hazards of tropospheric ozone and its imperceptible nature, many countries or regions have established ozone standards. In the United States, the Environmental Protection Agency (EPA) established ozone standards and established the Air Quality Index (AQI) to convey ozone pollution level and its health risk level [7]. The EPA's air monitoring network uses the Air Quality System (AQS) to conduct ozone measurements at its air monitoring stations. In addition to establishing monitoring stations to report ozone conditions, increasing demand is for ozone forecasts. Researchers use ozone data from air monitoring sites to build and validate models [5, 8, 9]. However, predicting ozone is a difficult task. A challenge is that sudden changes in observations make it difficult for models to capture patterns and predict values. Sudden changes can be caused by abnormal conditions.

Tropical cyclones, that are, cyclonic circulations in tropical and subtropical regions, that occur in the North Atlantic are called hurricanes. Humans generally know that hurricanes can damage buildings and vehicles on land with high winds, flood coastal areas and kill humans with storm surges, and cause rivers to overflow and landslides with heavy rains. Due to their damage, many countries or regions have specialized branches to track and forecast tropical cyclones. In the United States, the National Hurricane Center (NHC) is responsible for tracking and predicting hurricanes, issuing hurricane watches and warnings, and collating hurricane data [10]. Florida is located on the southeast coast of the United States and is one of the areas most frequently affected by hurricanes. When people often pay attention to obvious effects of hurricanes, as a complex weather system, it has effects on other aspects, such as affecting air pollutants.

At the end of the last century, based on satellite total ozone observations, the process of interaction between tropical cyclones and the upper atmosphere was revealed [11]. Early this century, ozone events in Hong Kong related to typhoons were numerically simulated and analyzed [12]. Since about

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that time, ozone events occurred along the northwest Pacific coast were simulated and analyzed together with typhoon events [13-15].

This paper presents a new exploration, discusses the relationship between ozone in Florida and nearby North Atlantic hurricanes and attempts to predict ozone during hurricane impacts. Our approach utilizes ozone and hurricane data to explore the relationship. In order to predict ozone change, our algorithm collects data, and generates ozone forecast. Our findings can be used to improve air quality models that have traditionally been plagued by extreme weather systems and can 1) extend studies of ozone and tropical cyclone relationships, which are more confined to the Northwest Pacific coast, to the North Atlantic coast and 2) propose a ozone prediction model under hurricane impacts.

The rest of this paper is organized into five additional sections. Section 2 provides an overview of the data source. Section 3 describes our method. Section 4 introduces the experiment and the evaluation of the results. Section 5 introduces the related work. Section 6 summarizes this paper and discusses the future work.

2. Data sources

In general, our study and model use two data sets. The first is ozone time series data. The second is hurricane time series data. They are combined for training and validating the model.

2.1 AQS (Air Quality System) Data

Air quality data from the EPA for Florida are used. Ozone measurements for Florida can be downloaded from the EPA offcial website [7]. Ozone data include date, site ID, Daily Max 8-hour Ozone Concentration, site name, county, site latitude and site longtitude. The data is updated once a day.

2.2 Meteorological Data

Hurricane data in the North Atlantic are used. They are from National Hurricane Center *best track* data which can be downloaded from the National Hurricane Center official website [10]. The hurricane data include Year, Month, Day, Hours in UTC (Universal Time Coordinate), Minutes, Record identifier (e.g. Landfall), Status of system, Latitude, Longitude, Maximum wind (in knots), Minimum Pressure (in Millibars). Hurricane data typically have a temporal resolution of six hours. Special data are available to make up the landfall information.

3. Methodology

Our objective is to study the relationship between ozone and hurricane and to predict ozone when it is affected by a hurricane.

Each step of our method is explained in detail in the subsections. In Subsection 3.1, the air quality data are preprocessed. In Subsection 3.2, the hurricane data are preprocessed. In Subsection 3.3, the two kinds of data are combined for analysis.

3.1 Data Preprocessing of Air Quality

In practice, in the development of air quality prediction algorithms, air quality data are generally considered noisy and contain outliers, especially for stream data [16-18]. However, in the experiment, the relationship between ozone and hurricanes are analyzed. Dramatic changes in ozone can be related to hurricanes. So, the process of removing outliers is not applicable. However, ozone data on the previous observation day are added.

3.2 Data Preprocessing of Hurricane

The hurricane data are reorganized. Hurricanes that are far away from Florida may have little effect on ozone in the state. As tropical cyclones, hurricanes whose center positions are once between 20°N and 35°N, and between 70°W and 95°W are considered as the priority research hurricanes to establish and test the model of ozone change.

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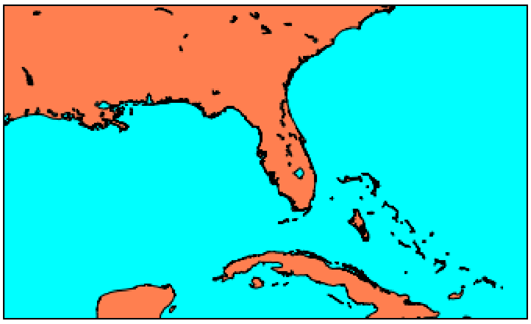

Figure 1. The area where hurricanes entering as tropical cyclones will be considered.

In order to reflect the characteristics of hurricanes, the peak and landfall date, and the peak and landfall intensity are marked. It should be noted that only the peaks and landfalls in Figure 1 are considered. It is because the peaks and landfalls cannot represent the characteristics of a hurricane if it is outside the area. For example, if a hurricane reaches a strong intensity far away, but weakens significantly as it approaches Florida, its characteristics should not be represented by its peak far away. Some hurricanes make no landfall in the area, and the center location being closest to Florida land is used as a *quasi* landfall point. Then, the days before or after the hurricane reaches peak intensity and makes landfall are calculated and marked, for example, (..., -3 , -2 , -1 , 0 , 1 , 2 , 3 ,...). In the study, the days within seven days before or after the peak or the landfall date are marked.

3.3 Data Analyzing of Air Quality and Hurricane

Ozone data after preprocessing are combined with hurricane data after preprocessing from the same date. However, using only hurricane data from the same day may not be enough to show the relationship between the two. For example, a hurricane's effect on ozone in Florida may occur a few days after it makes landfall, when the hurricane is about to dissipate or has already dissipated. So, the peak and landfall of the hurricane days before or after the day marked are used. After data preprocessing is complete, data analysis can be performed.

Predictors of hurricane parameters are included in the study to investigate possible correlations between ozone and hurricane parameters. To better predict ozone, it is common to use the previous day's ozone as an input. Linear regression models are used and they can generate ozone forecast given data from previous ozone observations and hurricane data.

4. Experiments and results

We used ozone and hurricane data to study the relationship between the two, build ozone prediction models, and evaluate our models. The models were implemented using Python 3.7. The models were executed on a CPU with only 4GB of memory.

4.1 Environmental Settings

In the experiment, we used ozone observations in Florida and hurricane data in the North Atlantic from 2016 to 2019 for training and testing. We performed data preprocessing of ozone and hurricane data as mentioned.

In the prediction part of the model, we used actual ozone data as the ground truth to evaluate the performance of our ozone forecasting model.

4.2 Experimental Results and Discussion

In the first part of the experiment, the relationship between ozone and hurricanes were studied.

Data from automatic ozone monitoring stations in Florida for the period from 2016 to 2019 were selected. When Daily Max 8-hour Ozone Concentration is greater than or equal to 0.055 ppm, it is defined as *Ozone Event*. When the Daily Max 8-hour Ozone Concentration rises by 0.030 ppm or more compared with the previous reading, it is defined as *Ozone Deterioration*.

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Table 1. Result for the number of reports of Ozone Event and Ozone Deterioration in Florida in the week before or after a hurricane peak or make landfall in the area shown in Figure 1.

Name	Ozone Event	Ozone Deterioration
Bonnie (2016)	201	1
Colin (2016)	56	6
Hermine (2016)	4	4
Emily (2017)	7	1
Irma (2017)	11	0
Philippe (2017)	2	0
Gordon (2018)	2	1
Michael (2018)	9	0
Dorian (2019)	47	3
Nestor (2019)	2	0

According to the table, when hurricanes are nearby, there can be a high probability of *Ozone Event* or *Ozone Deterioration* occurs in Florida. It is worth noting that there are only about a dozen reports of *Ozone Deterioration* in Florida each year. Thus, *Ozone Event* and *Ozone Deterioration* can in some cases be associated with hurricanes.

In the second part of the experiment, prediction models for ozone were built, and established models were evaluated through ground truth.

We trained multiple models based on each selected hurricane and ozone data. Models were built which can be described as *Daily Max 8-hour Ozone Concentration - Previous Daily Max 8-hour Ozone* Concentration = *k* * *Days away from the landfall* + *b*. For each model, the start time of training data is determined by referring to the day of the maximum ozone drop reported in the Florida station before landfall, and the end time of training data is determined by referring to the day of the maximum ozone rise reported in the Florida station after landfall. We used ground truth of ozone data to test our model. The result is that the correlation between prediction and ground truth is varied. We toke the hurricane landfall intensity as an independent variable, and multiplied *the days that the linear model can describe* by *the correlation coefficient of the model* as the dependent variable to describe the model performance, and the two are highly correlated. Stronger hurricanes can have more regular structures that make ozone changes to be described by linear models better.

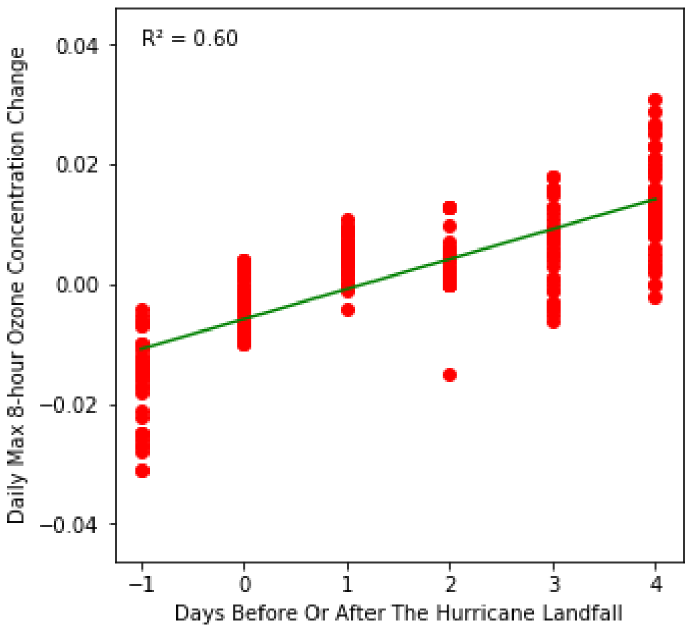

Figure 2. Under Hurricane Dorian, the predicted change value of Daily Max 8-hour Ozone Concentration in green and the ground truth change value in red.

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Table 2. Result for the effective days of the models and their correlation coefficients.

Name	Effective Days	Correlation Coefficient
Bonnie (2016)	5	0.15
Colin (2016)	3	0.34
Hermine (2016)	3	0.58
Emily (2017)	4	0.08
Irma (2017)	5	0.39
Philippe (2017)	3	0.52
Gordon (2018)	13	0.03
Michael (2018)	6	0.58
Dorian (2019)	6	0.60
Nestor (2019)	5	0.33

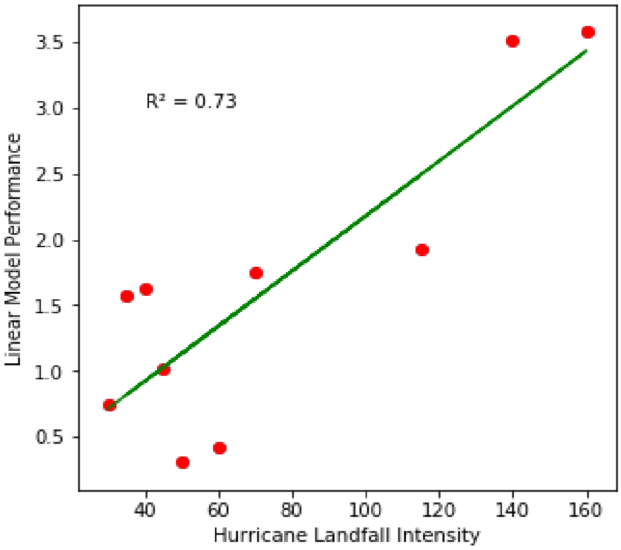

Figure 3. The hurricane landfall intensity in knots and the linear model performance defined in the text.

5. Related work

There are literatures on ozone simulation and prediction. The basic methods include support vector machines, neural networks, and other methods [5, 8, 9, 19, 20]. However, a challenge is that sudden changes in observations make it difficult for models to capture patterns. Activities of tropical cyclones, including hurricanes, are one of the reasons for dramatic changes. General mechanism by which tropical cyclones affect the total amount of ozone is described [11]. Simulation and analysis is made for some cases [12-15].

Our proposed model, using ozone data from Florida and hurricane data from the North Atlantic, explores their relationship, and try to predict ozone changes during hurricanes.

6. Conclusion

In this paper, we propose a data mining method to study the relationship between hurricane activity and ozone change. Advantages of our approach include that it could explain how active hurricanes affect tropospheric ozone concentration and try to make predictions based on that. Our algorithm performs particularly well for intense hurricanes, which may indicate the difference in structural regularity between strong and weak hurricanes can lead to the variation of change pattern of air pollutants. Possible future work is to upgrade the model to predict various air pollutants under the influence of tropical cyclones in different intensities and different ocean basins while maintaining the simplicity of the model. In addition, the mechanism of the impact of tropical cyclones on air quality can be further studied.

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