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Research on Climate Change Prediction based on ARIMA Model and its Impact on Insurance Industry Decision-Making

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Abstract: This research delves into the application of the Autoregressive Integrated Moving Average (ARIMA) model for predicting climate change and its subsequent implications for decision-making within the insurance industry. The study introduces a comprehensive approach to forecast climatic variables such as temperature, rainfall, and relative humidity, which are critical factors in assessing insurance risks and formulating underwriting strategies. The ARIMA model, recognized for its efficacy in time series analysis, is employed to capture the seasonal patterns and trends in climatic data. The model is calibrated using historical weather records from two distinct regions, Dali and New York, to account for geographical variability in climate sensitivity. By integrating the model's predictions with economic indicators and industry-specific data, the research constructs a Weather Composite Index (WCI) that quantifies the potential impact of climate change on local economies and insurance claims. The paper meticulously describes the model's parameters, including the order of differencing (d), the number of autoregressive terms (p), and the number of moving average terms (q), which are selected to optimize the model's fit and predictive accuracy. The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) are utilized to evaluate and compare the performance of different ARIMA configurations, ensuring that the chosen model minimizes the forecast error and provides the most reliable predictions.

Keywords: ARIMA Model; Climate Change Prediction; Insurance Industry Decision-Making; Time Series Analysis.

1. Introduction

In the face of global climate change, the insurance industry is confronted with unprecedented challenges. The increasing frequency and severity of extreme weather events pose significant risks to property and casualty [1-3], demanding a reevaluation of traditional underwriting practices [4]. This study aims to explore the utilization of the Autoregressive Integrated Moving Average (ARIMA) model as a predictive tool for climate change projections and its subsequent impact on insurance decision-making processes [5].

The ARIMA model, a robust statistical technique for analyzing and forecasting time series data, offers a promising approach to anticipate future climatic conditions. By understanding the historical patterns and trends in weather data, the ARIMA model can provide insights into potential future scenarios, which are crucial for insurance company in assessing and managing risks associated with climate variability.

This research focuses on the application of the ARIMA model to historical weather data from two distinct climatic regions, Dali and New York, to forecast temperature, rainfall, and relative humidity. The forecasts are then integrated into a Weather Composite Index (WCI), which serves as a metric to quantify the potential impact of climate change on insurance claims and the overall economic landscape [6].

The significance of this study lies in its potential to equip insurance companies with a data-driven framework for making informed decisions regarding underwriting policies, particularly in regions susceptible to extreme weather events. By leveraging the predictive capabilities of the ARIMA model, insurers can better anticipate and prepare for the financial implications of climate change, thereby enhancing their resilience and maintaining long-term viability in a dynamic and uncertain environment.

2. A Three-Factor Weather Composite Index Model under the Influence of Three Industries

2.1. Presentation of the Weather Composite Index Model

Weather insurance is usually a risk transfer for catastrophic risks, and once the level of catastrophic risks reaches the conditions specified in the policy, compensation can be obtained through the corresponding policy. Different from traditional insurance, weather insurance has the advantage of quick realization of compensation amount. Weather insurance has been developed to a certain extent worldwide, resulting in products such as typhoon insurance.

Different from traditional financial derivatives, weather insurance is generally traded on various weather indices. In this paper, three weather variables, cumulative rainfall RV, air temperature T and relative humidity RH, are introduced, and a three-factor weather composite index WCI is thus established.

$$WCI = e_1 * \Sigma|K_T - T_i| + e_2 * \Sigma|\Sigma RV_i - K_V| + e_3 * \Sigma|K_H - RH_i| \quad (1)$$

Combined with the climate characteristics of Dali and New York and the suitable temperature of various production and business activities K_T, K_V and K_H in this paper need to be determined according to the long-term historical data of the selected area.

Due to the large geographical span of each region, there are certain differences in the industrial structure of different regions, and the sensitivity to weather is also different. The adjustment of different industries to weather changes also reflects their demand for weather insurance on the other hand. Therefore, the determination of e_1, e_2 and e_3 in this paper needs to be combined with the regional GDP structure and its influence by temperature, rainfall and relative humidity.

2.2. Composite Weather Index Model for New York and Dali

In this paper, the Pearson correlation coefficients of temperature, rainfall and relative humidity and the annual data of local primary, secondary and tertiary industries in New York City and Dali City from 2013 to 2022 were selected respectively to be measured, and then combined with the proportion of the annual data of each industry to the GDP to determine the values of e_1, e_2, and e_3.

As shown in Table 2 the results of the according Pearson correlation analysis of New York City's primary, secondary, and tertiary industries with the average annual temperature, average annual rainfall, and average annual relative humidity numbers for the years 2013-2022, calculated using SPSS software.

Table 1. Analysis of the correlation between annual average temperature, annual average rainfall, annual average relative humidity and various industries in New York City

Correlation coefficient	Primary sector of industry	Secondary sector of industry	Tertiary sector of industry	e_i
Average annual temperature	0.094	0.055	0.045	e_1 =0.064
Average annual rainfall	0.294	0.054	0.082	e_2 =0.143
Average annual relative humidity	0.304	0.305	0.312	e_3 =0.307

The average air temperature of New York City over the period 1994-2023 was utilized as the baseline temperature, the average rainfall as the baseline rainfall, and the average relative humidity as the baseline relative humidity, as shown in Table 2

Table 2. Parameters Related to the New York City Weather Composite

K_T	K_V	K_H
12.2	104.07	0.2237

Similarly as shown in Table 3, it is also possible to calculate the results of the according Pearson correlation analysis between the primary, secondary and tertiary industries in Dali City and the average annual temperature, average annual rainfall and average annual relative humidity numbers from 2013 to 2022.

Table 3. Analysis of the correlation between average annual temperature, average annual rainfall, average annual relative humidity and various industries in Dali City

Correlation coefficient	agriculture	industry	servicing business	e_i
temperature	0.227	0.194	0.009	e_1 =0.143
rainfall	0.229	0.249	0.011	e_2 =0.163
relative humidity	0.307	0.482	0.887	e_3 =0.558

The average air temperature of Dali City during the period 1994-2023 was utilized as the baseline air temperature, the average rainfall as the baseline rainfall, and the average relative humidity as the baseline relative humidity, as shown in Table 4.

Table 4. Parameters Related to the New York City Weather Composite Index

Baseline air temperature	Baseline rainfall (months)	Baseline relative humidity
15.65	89.19	0.2427

Based on the above mentioned parameters related to the weather composite indexes of New York and Dali, it can be concluded that the formulas for the weather composite indexes of Dali and New York City, respectively, are as follows.

$$WCI_{NY} = 0.064 * \Sigma|12.2 - T_i| + 0.143 * \Sigma|\Sigma RV_i - 104.07| + 0.307 * \Sigma|0.2237 - RH_i| \quad (2)$$

$$WCI_{DL} = 0.143 * \Sigma|15.65 - T_i| + 0.163 * \Sigma|\Sigma RV_i - 89.19| + 0.558 * \Sigma|0.2427 - RH_i| \quad (3)$$

The greater the correlation coefficient e_i shows that as the weather changes, the greater the fluctuation of the GDP changes of the three industries, the more local insurance claims demand, and the greater the value of the WCI index. Therefore, by calculating the value of the WCI index, we can help insurance companies make decisions and evaluate the amount of claims of insurance companies, so as to determine whether to underwrite insurance policies in areas where the number of extreme weather times is increasing.

3. Time Series ARIMA Model

3.1. Presentation of the ARIMA Model

Time series plots are drawn for temperature, humidity and precipitation in Dali and New York over the past thirty years. By observing the time series plots, it can be concluded that the temperature, relative humidity and precipitation fluctuate and change greatly with time, showing obvious seasonality.

The traditional model is created by SPSS professional modeler, and it is found that the prediction result R^2 value is small, and the estimation effect is worse, so we choose to construct the ARIMA model to fit the time series, and get the predicted values of temperature, relative humidity, and precipitation for a single day in the next seven months as shown in Figure 2.

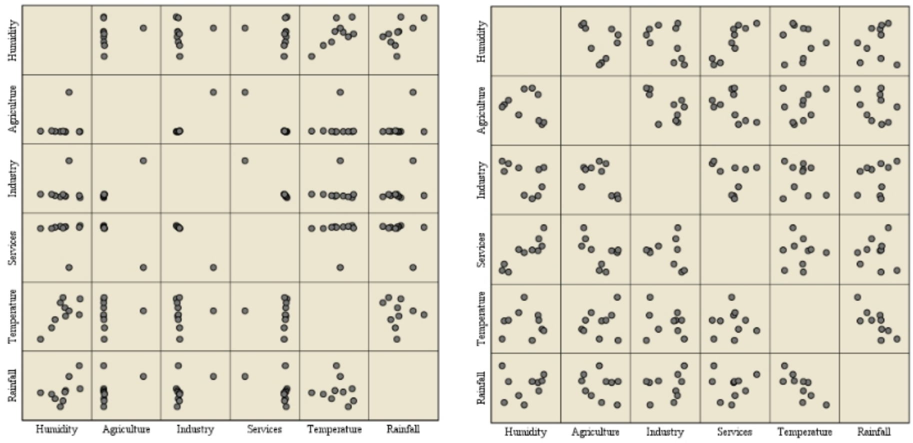

Fig 1. Scatterplot of New York and Dali Mean Temperature, Mean Annual Rainfall, and Mean Annual Relative Humidity vs. Matrix for Each Industry

For the large fluctuation of temperature, relative humidity and precipitation over time reflected in the time series plot, it is conjectured that the time series may be a unit root process of order d. For this reason, the data are first differentiated and transformed into a smooth time series before modeling, and here the $ARIMA(p,d,q)$ model is used.

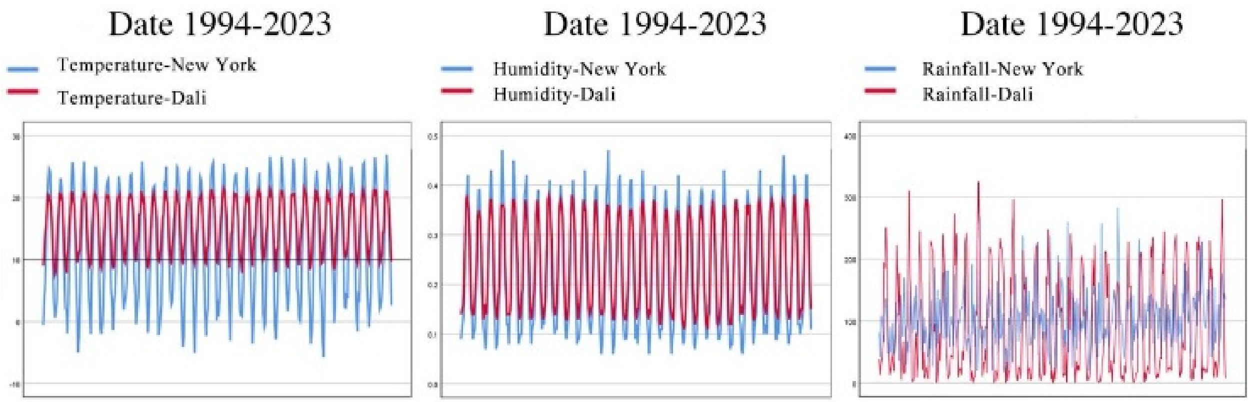

Fig 2. New York Dali related parameters time series diagram

$$y_t' = \alpha_0 + \sum_{i=1}^{p} \alpha_i y_{t-i}' + \varepsilon_t + \sum_{i=1}^{q} \beta_i \varepsilon_{t-i} \tag{4}$$

Among them:

$$y_t' = \Delta^d y_t = (1-L)^d y_t \tag{5}$$

$$\left(1 - \sum_{i=1}^{p} \alpha_i L^i\right)(1-L)^d y_t = \alpha_0 + \left(1 + \sum_{i=1}^{q} \beta_i L^i\right)\varepsilon_t \tag{6}$$

Where k is the number of model parameters, n is the number of samples and L is the likelihood function. By choosing the model that makes minimizes the values of AIC and BIC, it helps us to get a better fitting and more concise model.

3.2. ARIMA Modeling

According to the principle of selecting the smallest, the $ARIMA(p,d,q)$ model that minimizes the values of AIC and BIC is selected by the code loop step-by-step iteration method for the temperature, humidity, and precipitation of Dali and New York, respectively, over the past thirty years, and the results of the model fitting are shown in Tables 5.

Because the rainfall in New York is affected by some extreme weather, there is no obvious seasonal law. Therefore, the predicted value of the next seven months is replaced by the average value of the rainfall in the first half of the previous year. The results are shown in Figure 4 and Figure 5.

3.3. Results of WCI Index in Dali and New York

Assuming that the insurance period is half a year, the formula of the weather composite index is obtained.

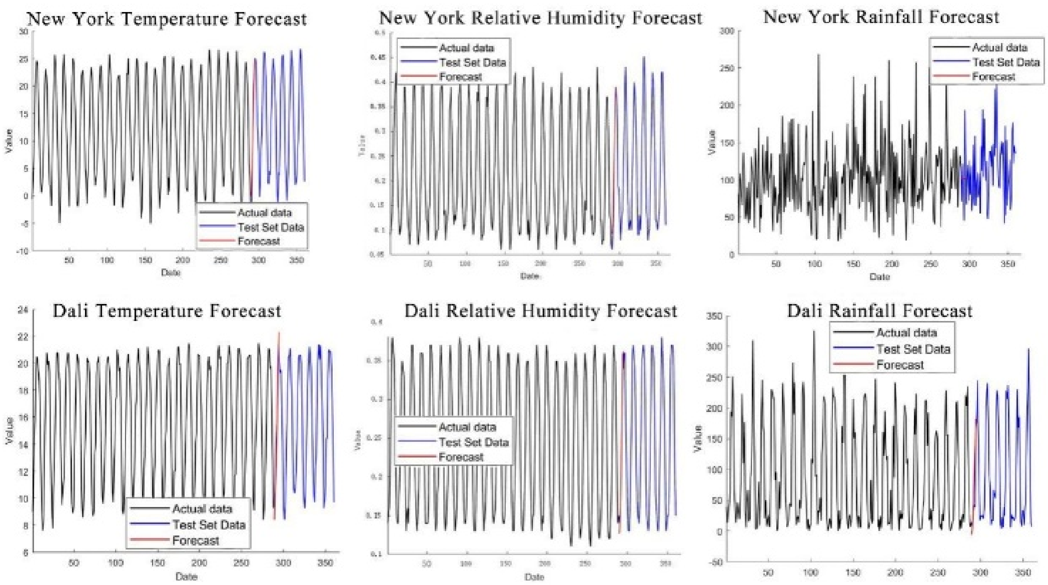

Fig 3. ARIMA time series model of temperature, rainfall, and relative humidity for New York and Dali

Table 5. AIC, BIC fitting results

REGIONS	Minimum AIC	Minimum BIC	Models used
Temperature in Dali	744.2249	784.5175	ARIMA (5,0,5)
Temperature in New York	1099.3541	1135.9837	ARIMA (5,0,4)
Relative humidity in Dali	-1220.2802	-1190.9765	ARIMA (5,0,2)
Relative humidity in New York	-1637.2016	-1604.2349	ARIMA (5,1,3)
Precipitation in Dali	2971.2565	2993.2342	ARIMA (2,0,3)
Precipitation in New York	3028.8224	3032.4853	ARIMA (0,0,0)

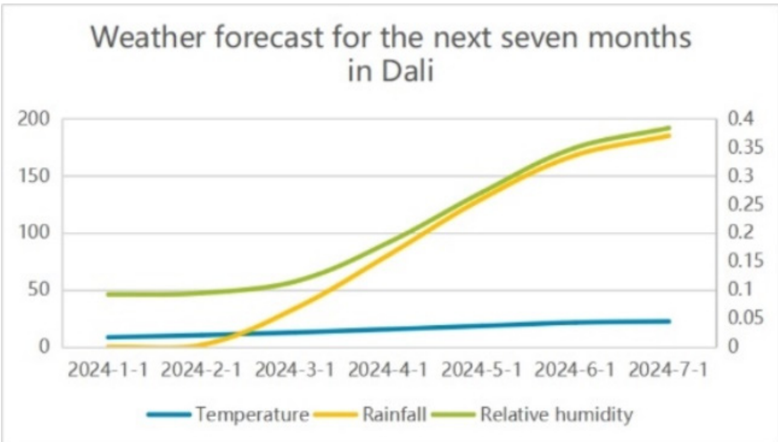

Fig 4. Forecast the main indicators of Dali area in the next 7 months

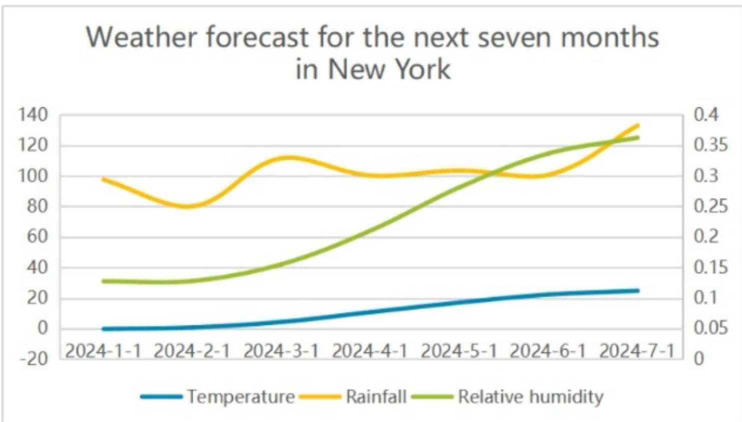

Fig 5. Forecast the main indicators of New York area in the next 7 months

$$WCI_{NY} = 0.064 * \Sigma|12.2 - T_i| + 0.143 * \Sigma|\Sigma RV_i - 104.07| + 0.307 * \Sigma|0.2237 - RH_i| \quad (7)$$

$$WCI_{DL} = 0.143 * \Sigma|15.65 - T_i| + 0.163 * \Sigma|\Sigma RV_i - 89.19| + 0.558 * \Sigma|0.2427 - RH_i| \quad (8)$$

The temperature, rainfall and relative humidity of the next seven months in 1.2 through the ARIMA time series model are substituted into the formula to calculate the WCI weather composite index of Dali and New York. The results are shown in Table 6.

Table 6. The weather composite index of Dali and New York during the insurance period in the next seven months

City name	WCI_{city}
New York	14.73932073
Dali	79.18836847

Through the above analysis, it can be found that the climate indicators of Dali City show a large degree of fluctuation with seasonal changes, and the three major industries in Dali are seriously affected by weather changes. In particular, the $Pearson$ correlation coefficient between relative humidity and weather reaches 0.558, which ultimately leads to the fact that the weather comprehensive index WCI_{DL} of Dali City is far greater than that WCI_{NY} of New York City.

Therefore, for insurance companies, if they need to choose between Dali and New York, New York City will be a better place to place underwriting policies. In general, insurance companies should choose cities with smaller values of the WCI weather composite index to ensure that they can best arrange property insurance, make the system flexible to pay for future claims, and ensure the long-term health of insurance companies.

4. Conclusion

The application of the ARIMA model in this study has demonstrated its efficacy in predicting climatic variables and assessing their impact on the insurance industry's decision-making processes. The model's ability to capture the intrinsic patterns and trends within historical weather data provides a valuable tool for anticipating future climate scenarios, which are critical for insurers when evaluating risk exposure and crafting underwriting strategies.

The ARIMA model's performance in forecasting temperature, rainfall, and relative humidity for Dali and New York has been commendable, offering a robust framework for the development of the Weather Composite Index (WCI). The ARIMA model has shown high accuracy in its predictions when compared to actual climatic data, as evidenced by the low values of the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). However, the model's reliance on historical data and its sensitivity to the choice of parameters highlight the need for careful calibration and validation.

Future research could combine ARIMA with hybrid models of other time series prediction methods, such as long short-term memory (LSTM) networks, to take advantage of the multiple approaches.

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