ANALYSING AND FORECASTING PRECIPITATION TRENDS IN VANCOUVER

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I. ABSTRACT

This study analyzed trends and forecasted monthly temperature and precipitation in Vancouver using time-series modeling. A dataset spanning several decades (1941 to 2024) was preprocessed to handle missing values and included derived features, such as lagged variables for precipitation. Prophet, a robust time-series forecasting model, was used to identify seasonality and long-term trends. Additional regressors, including rain intensity and relative humidity, were incorporated to improve precipitation forecasts.

The analysis revealed a steady upward trend in temperature, with an estimated rate of increase of 0.1°C per year, consistent with global warming patterns. Model diagnostics showed that the temperature model performed well, achieving a Root Mean Squared Error (RMSE) of 0.30 and a Mean Absolute Percentage Error (MAPE) of 4.03% when regressors were included. In contrast, the precipitation model exhibited significantly higher residual variability and error metrics, underscoring the challenges of forecasting this variable. A moderate correlation (0.50) was observed between temperature and precipitation, reflecting some seasonal alignment but highlighting the complexity of their relationship.

These findings contribute to understanding local climate dynamics in Vancouver and emphasize the need for more sophisticated modeling approaches, particularly for highly variable parameters like precipitation. This study provides a foundation for refining predictive models to support climate adaptation strategies.

II. INTRODUCTION

Climate change has emerged as one of the most pressing global challenges, profoundly impacting weather patterns, ecosystems, and human activities (Zhang et al., 2019). Understanding trends in temperature and precipitation is critical, as these variables are key indicators of climate variability. Their combined effects influence water resources, agricultural productivity, infrastructure resilience, and biodiversity. Vancouver, with its temperate maritime climate and distinct seasonal variations, serves as an ideal case study for analysing long-term climatic trends and forecasting future patterns (City of Vancouver, 2023).

This study focuses on time-series analysis of monthly precipitation and temperature data spanning multiple decades in Vancouver. The primary objectives were to identify long-term trends, seasonal variations, and potential relationships between these two climatic variables. By visualising how temperature and precipitation patterns align over time, the study sought to uncover potential correlations or shared influences, such as global warming or atmospheric circulation changes (Zhang et al., 2019). Additionally, predictive models were developed to forecast future trends, leveraging advanced machine learning techniques like Prophet (Taylor & Letham, 2018).

Prophet, a time-series forecasting model, was used to analyse both temperature and precipitation. Its ability to incorporate seasonality and external regressors made it well-suited for this analysis. The study explored the use of additional variables, such as rain intensity, humidity, and wind speed, to improve model accuracy. However, challenges such as multicollinearity among regressors and autocorrelations in model residuals were encountered, reflecting the complexity of modelling climate systems (WeatherStats, n.d.).

In addition to forecasting, this study aimed to investigate the relationship between temperature and precipitation. Visualisations such as scatterplots and overlaid trend lines were employed to reveal whether increases in temperature are accompanied by corresponding changes in precipitation. These insights could deepen our understanding of how climate systems are interconnected.

The research questions guiding this study were:

1. What are the long-term trends and seasonal patterns in Vancouver's precipitation and temperature data?
2. To what extent are these variables correlated, and how does their relationship vary over time?
3. Can external variables such as humidity, wind speed, and rain intensity enhance predictive accuracy for either variable?
4. What challenges arise in modelling and forecasting these climatic variables, and how can they be addressed?

By addressing these questions, this study contributes to understanding local climatic dynamics in Vancouver and the broader implications of climate change. The findings could inform policymakers and urban planners, providing evidence-based insights for sustainable resource management and adaptation strategies (City of Vancouver, 2023).

III. METHODS

Data Collection and Preprocessing

This study utilised a dataset of monthly weather data for Vancouver spanning multiple decades (1941 to 2024), obtained from WeatherStats Vancouver (WeatherStats, n.d.). The dataset included key variables such as maximum and minimum temperature, total precipitation, relative humidity, rain intensity, and wind speed.

Key preprocessing steps included:

1. Date Formatting:

- The date column was converted into a datetime format to enable proper time-series indexing.

2. Variable Selection:

- Average monthly temperature (avg_temperature_v) was calculated as the mean of max_temperature_v and min_temperature_v.
- Key variables, including precipitation_v (total precipitation), were selected for analysis.

3. Handling Missing Data:

- Missing values in numerical columns were filled with column averages to ensure a complete dataset for modelling.

4. Feature Engineering:

- Lagged variables for precipitation and temperature (e.g., one-month and twelve-month lags) were created to capture temporal dependencies.
- Rolling averages were calculated with a window size of 12 months to smooth short-term fluctuations and highlight long-term trends.

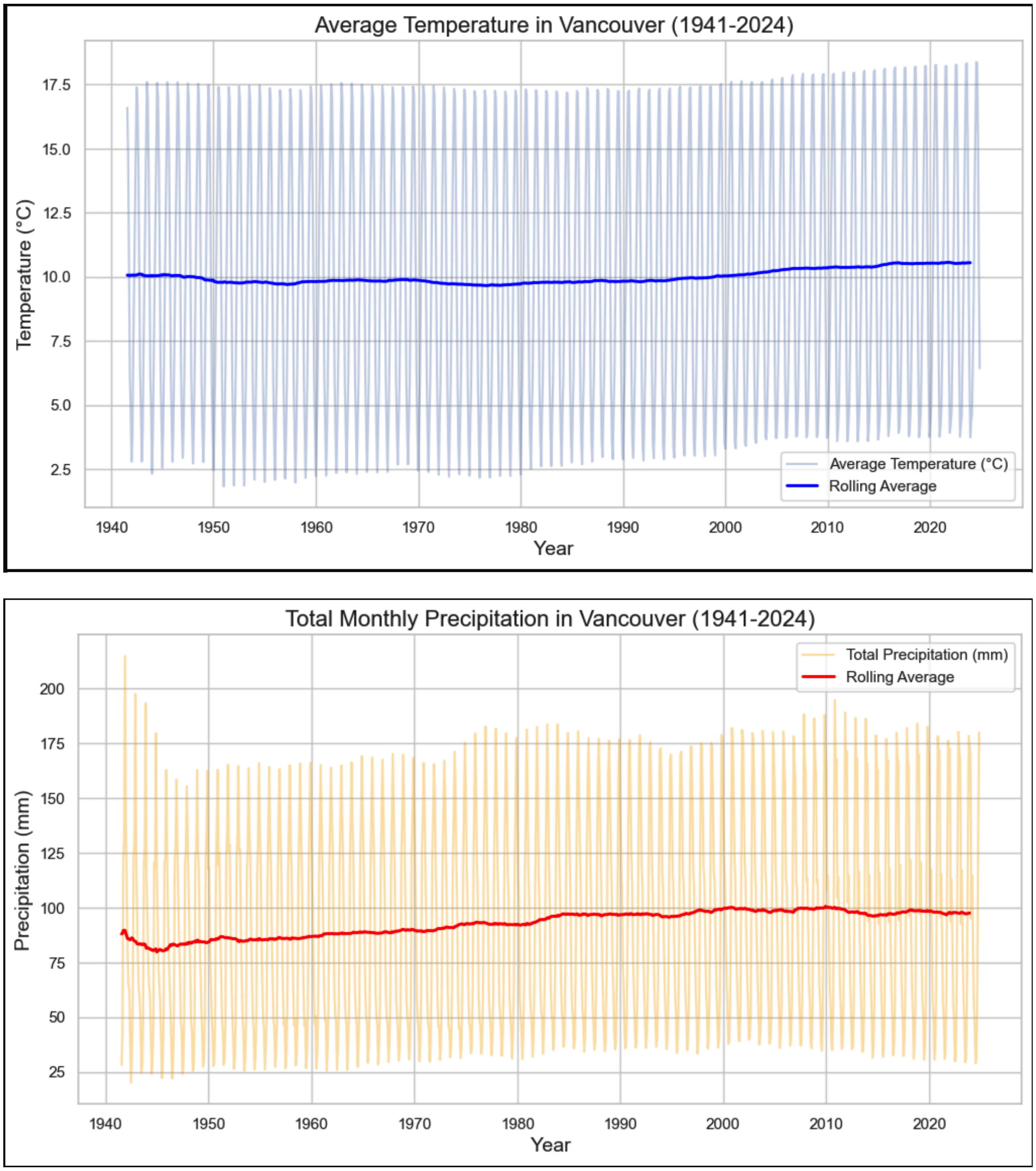


Figure 1: Time-series plot of raw temperature and precipitation data, showing rolling averages (provides an overview of the processed dataset).

Exploratory Data Analysis (EDA)

Exploratory analysis was conducted to identify patterns and relationships among the variables:

1. Trend and Seasonality Analysis:

- Seasonal decomposition was applied to temperature and precipitation data, separating the time series into trend, seasonal, and residual components.

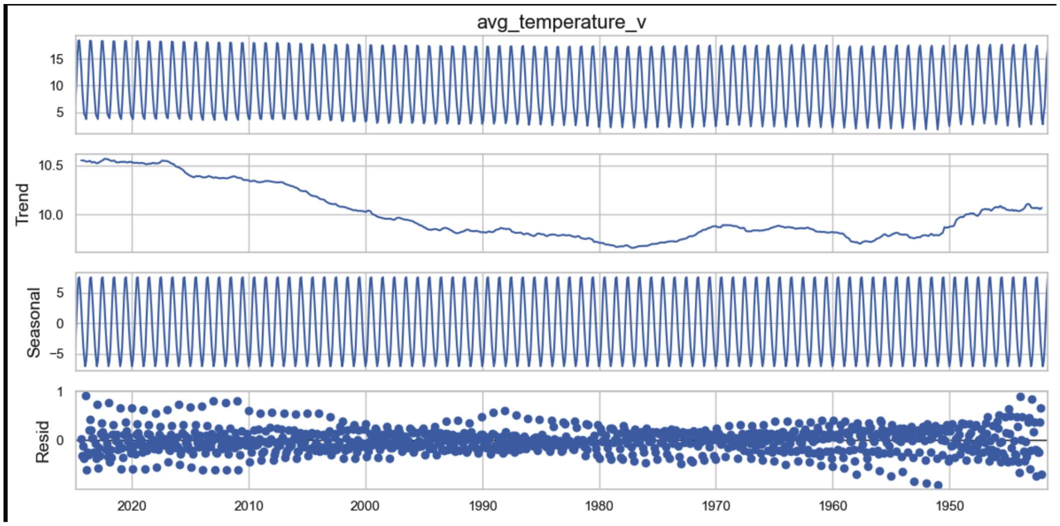


Figure 2: Seasonal decomposition for temperature highlights consistent annual cycles.

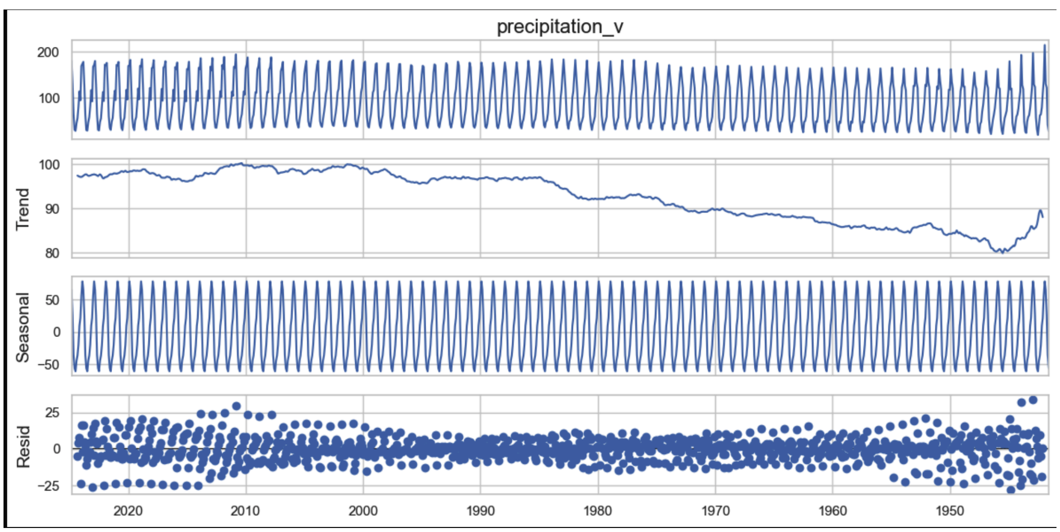


Figure 3: Seasonal decomposition for precipitation demonstrates recurring wet and dry periods with high variability.

2. Correlation Analysis:

- A correlation heatmap was generated to evaluate relationships among variables, including precipitation, temperature, relative humidity, and rain intensity.

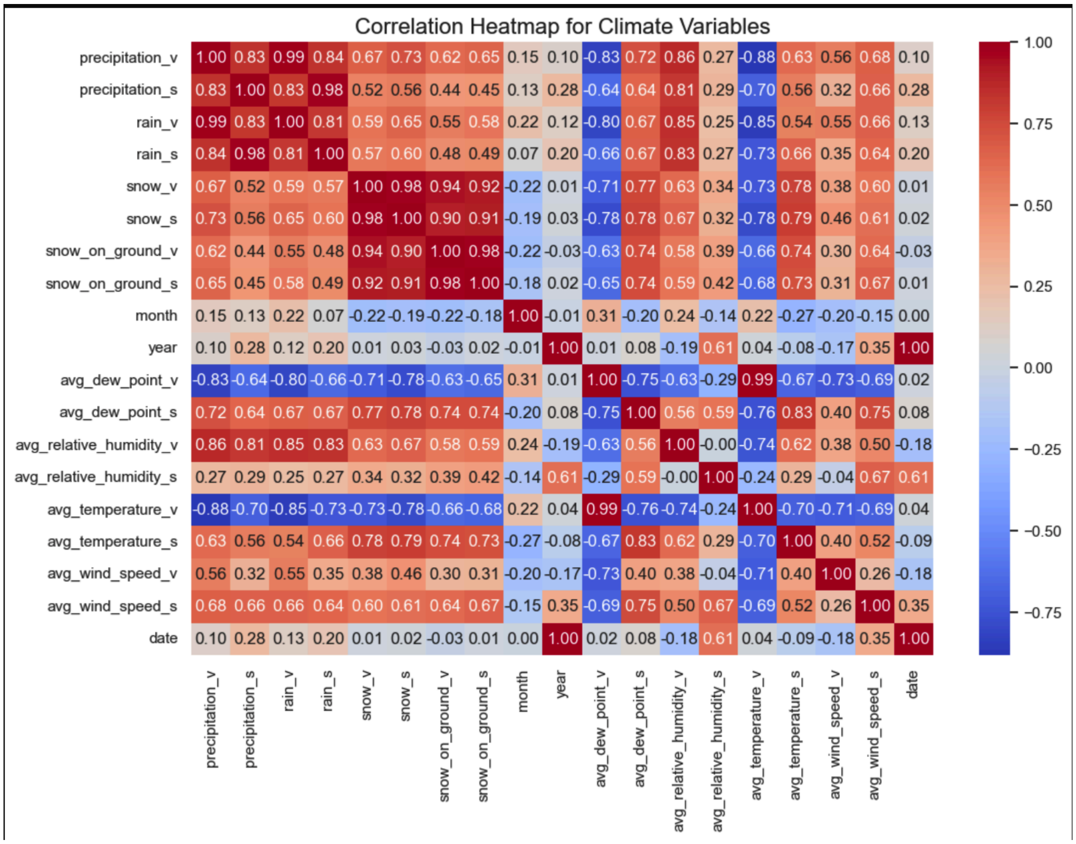


Figure 4: The heatmap shows strong correlations between some variables, aiding in regressor selection for forecasting.

Time-Series Forecasting

Prophet, a flexible time-series forecasting tool, was used to model and predict temperature and precipitation. Its ability to handle seasonality and incorporate external regressors made it suitable for this analysis (Taylor & Letham, 2018).

1. Model Configuration:

- Separate Prophet models were initialised for temperature and precipitation, with yearly and multi-year seasonalities added to capture both short-term and long-term patterns.

- External regressors, including rain intensity (rain_v) and average relative humidity (avg_relative_humidity_v), were added to the precipitation model based on their correlations with the target variable.

2. Model Training:

- Data was formatted for Prophet, with ds representing dates and y representing the target variable.
- External regressors were scaled to maintain consistency in variable ranges.

3. Forecasting:

- Future dataframes were created to extend forecasts by 60 months, with regressor values set to their historical means.
- The temperature and precipitation forecasts will be presented in the Results section.

Residual Analysis and Validation

Model performance was evaluated using residual diagnostics and error metrics:

1. Residual Plots:

- Residuals (the difference between observed and predicted values) were plotted to assess randomness and evaluate patterns not captured by the models.

2. Performance Metrics:

- Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE) were calculated for both temperature and precipitation models to quantify forecasting accuracy.

Relationship Analysis

The relationship between temperature and precipitation was explored using visual and statistical methods:

1. Dual-Axis Time-Series Plots:

- Overlaid time-series plots of temperature and precipitation were used to identify shared trends or divergences over time.

2. Scatterplots with Trendlines:

- Scatter Plots with fitted trend lines were created to visualise correlations between temperature and precipitation, annotated with the correlation coefficient.

IV. RESULTS

Observed Trends

The time-series analysis (Figure 1) reveals clear seasonal fluctuations in both temperature and precipitation over the study period. Temperature shows a gradual upward trend, consistent with global warming patterns, while precipitation exhibits high variability, with pronounced peaks during the wet season. Seasonal decomposition (Figures 2 and 3) confirms the presence of consistent annual cycles for both variables, with temperature exhibiting more stable patterns compared to the highly variable precipitation. The analysis estimated an average rate of temperature increase of 0.1°C per year, emphasizing the steady warming trend over the decades.

Model Forecasts

Prophet models were used to forecast temperature and precipitation for a 60-month period. The precipitation forecast (Figure 5) captures seasonal peaks, with confidence intervals reflecting the high variability of this variable. In contrast, the temperature forecast (Figure 6) shows a steady upward trend with well-defined seasonal cycles and narrower confidence intervals, indicating higher predictive accuracy.

- For temperature, the baseline model achieved a Root Mean Squared Error (RMSE) of 0.78 and a Mean Absolute Percentage Error (MAPE) of 8.47%, while the addition of regressors improved performance, reducing the RMSE to 0.30 and MAPE to 4.03%.
- For precipitation, both baseline and regressor models exhibited high RMSE and MAPE scores, reflecting the inherent challenges of forecasting such a highly variable climate parameter.

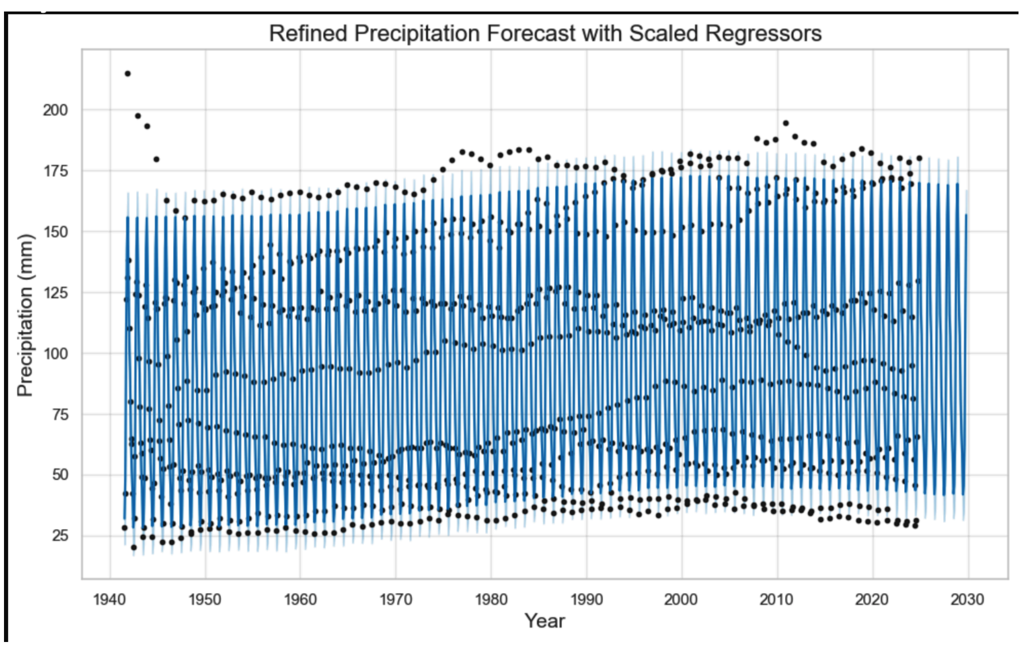


Figure 5: Prophet forecast for precipitation.

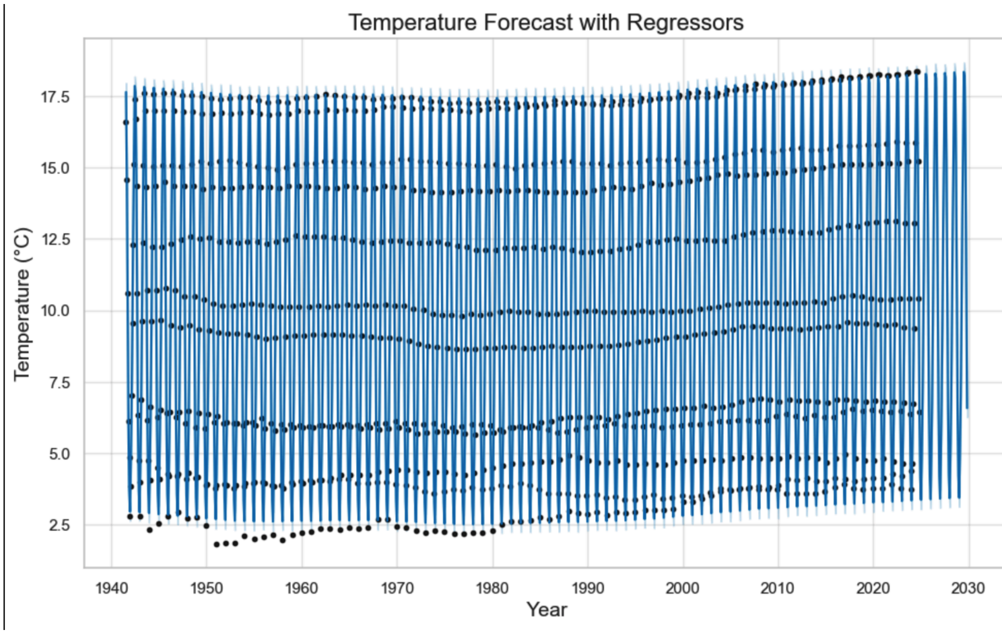
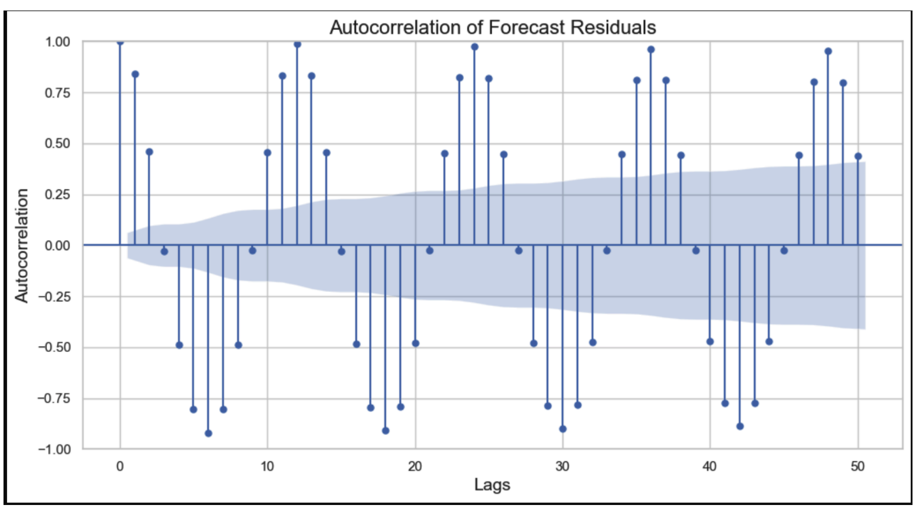


Figure 6: Prophet forecast for temperature.

Residual Analysis

Residual plots (Figure 7) indicate that the temperature model performed well, with residuals exhibiting minimal autocorrelation and low error metrics. However, the precipitation model showed higher residual variability and significant autocorrelation, suggesting that the model struggled to capture all temporal dependencies in precipitation patterns. RMSE and MAPE metrics confirm that temperature forecasts were more accurate compared to precipitation predictions.



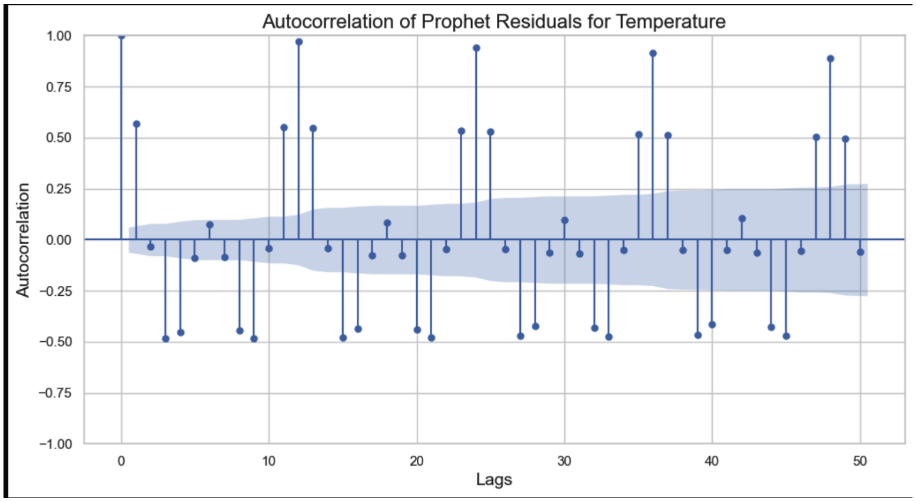


Figure 7: Residual plots for temperature and precipitation.

Relationship Between Temperature and Precipitation

The observed trends suggest some alignment between temperature increases and precipitation peaks, as seen in Figures 2 and 3. The correlation analysis revealed a moderate correlation of 0.50 between the two variables, indicating some degree of shared seasonal alignment, although precipitation variability limits the strength of this relationship. A detailed relationship analysis, including scatterplots, is discussed further in the Discussion section.

V. DISCUSSION

Interpretation of Trends

This study identified significant trends in Vancouver's temperature and precipitation patterns. The upward trend in temperature (Figure 1) aligns with global warming trends observed across Canada (Zhang et al., 2019). Seasonal decomposition (Figures 2 and 3) revealed recurring annual cycles for both variables, consistent with Vancouver's temperate maritime climate. Precipitation exhibited high variability, with pronounced seasonal peaks, reflecting the influence of wet winters and dry summers. Additionally, the analysis found an average rate of temperature increase of 0.1°C per year, suggesting a gradual warming trend over time.

While this estimated rate of increase is lower than values reported in global climate assessments, such as those in Canada's Changing Climate Report (Zhang et al., 2019), it represents a localized trend within the limitations of the model and dataset. Despite this discrepancy, developing predictive models for smaller scales like Vancouver is an essential step toward understanding and mitigating regional climate impacts. These models provide valuable insights and can be refined further as more accurate or high-resolution data become available.

Forecasting Insights

Prophet models captured key seasonal components and long-term trends for temperature and precipitation. The temperature model exhibited narrower confidence intervals and higher predictive accuracy, reflecting the relative stability and predictability of temperature trends. In contrast, the precipitation model displayed wider uncertainty intervals due to the inherent variability of precipitation data and the complexity of capturing its temporal dependencies.

As detailed in the Results section, the temperature model consistently outperformed the precipitation model in terms of error metrics, underscoring the challenges of forecasting highly variable climatic variables like precipitation. These findings align with other climate modeling studies that highlight precipitation as a more complex variable to predict due to its dependence on localized weather systems and external atmospheric drivers (Taylor & Letham, 2018; Zhang et al., 2019).

Model Performance

Residual diagnostics (Figure 7) demonstrated that the temperature model performed well, with low residual variability and minimal autocorrelation. The precipitation model, however, showed greater residual variability and significant autocorrelation, indicating that temporal dependencies were not fully captured. RMSE and MAPE metrics confirmed that temperature predictions were more accurate, underscoring the challenges of forecasting highly variable precipitation patterns.

Relationship Between Temperature and Precipitation

Scatterplot analysis suggested a moderate correlation of 0.50 between temperature and precipitation, with seasonal peaks in precipitation often coinciding with warmer periods. However, the high variability in precipitation limits the strength of this relationship. These findings align with studies suggesting that warmer temperatures can enhance precipitation intensity due to increased atmospheric moisture capacity (Zhang et al., 2019). However, the relatively weak correlation observed in this study suggests that local precipitation patterns are influenced by additional factors beyond temperature, such as atmospheric circulation.

Comparison with Literature

The findings align with broader climate trends reported in Canada's Changing Climate Report (Zhang et al., 2019), which documented rising temperatures and increasing precipitation variability nationwide. The variability in precipitation forecasts aligns with challenges reported in climate modelling literature, where external factors like atmospheric circulation patterns significantly influence predictions. While this study incorporated regressors such as rain intensity and humidity, multicollinearity may have reduced their predictive value.

Limitations and Uncertainties

This study encountered several limitations:

1. Multicollinearity Among Regressors:

- High correlation between regressors (e.g., rain intensity and humidity) may have affected the stability of the precipitation model. Variance Inflation Factor (VIF) analysis partially addressed this issue, but more robust feature selection techniques could improve future model performance.

2. Residual Autocorrelation:

- Significant autocorrelation in precipitation model residuals suggests that important temporal patterns were not fully captured. Incorporating lagged variables or alternative models, such as ARIMA or hybrid approaches, could address this limitation.

3. Model Simplicity:

- While Prophet effectively captures seasonality and trends, it may not fully account for complex interactions between climatic variables. Advanced machine learning models, such as Gradient Boosting or Long Short-Term Memory (LSTM) networks, could better capture these interactions in future studies.

4. Variability in Precipitation:

- Precipitation's inherent variability presents challenges for accurate forecasting. Integrating additional factors, such as global climate indices (e.g., El Niño Southern Oscillation), could provide greater insight into the drivers of precipitation patterns.

Implications and Future Directions

The findings have important implications for understanding Vancouver's climate. The increasing temperature trend underscores the urgency for local adaptation strategies, such as those outlined in Vancouver's Climate Adaptation Strategy (City of Vancouver, 2023). Understanding these trends is critical for anticipating the impacts of rising temperatures on precipitation patterns, particularly in the context of extreme weather events.

Future research should focus on:

- Incorporating global climate indices to enhance precipitation forecasts.
- Exploring advanced models, such as ARIMA, LSTM networks, or hybrid approaches, to handle autocorrelation and multivariable interactions.
- Expanding datasets to include real-time climate monitoring data for better temporal granularity.
- Conducting comparative studies with other regions to identify shared climatic patterns and unique local trends, providing broader context for localised findings.
- Investigating the impact of urbanisation on temperature and precipitation patterns, particularly in coastal regions like Vancouver.

VI. CONCLUSION

The study demonstrated clear seasonal and long-term trends in Vancouver's temperature and precipitation, with temperature showing a steady upward trend and precipitation exhibiting significant variability. While the estimated rate of temperature increase (0.01°C per year) is lower than global averages, it reflects localized patterns and highlights the importance of developing tailored models to address regional climate dynamics effectively.

VII. ACKNOWLEDGEMENTS

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VIII. CITATIONS

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