DETECTION AND PREDICTION OF CLIMATE CHANGE WITH TEMPERATURE



Submitted by Adnan Ahmed to the University of Exeter as a dissertation for the degree of Master of Science in September 2020

I certify that all material in this dissertation that is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

Signature: <insert your signature here @Adnan>

Table of Contents

[1 Introduction 3](#_Toc115034284)

[2 Literature review 6](#_Toc115034285)

[2.1 General Analysis and Pre-processing 6](#_Toc115034286)

[2.2 Time Series Analysis (ARIMA) 8](#_Toc115034287)

[2.3 LSTM 9](#_Toc115034288)

[2.4 ANN 11](#_Toc115034289)

[2.5 RNN 13](#_Toc115034290)

[2.6 Statistical Significance Tests 13](#_Toc115034291)

[2.7 Linear Regression 13](#_Toc115034292)

[3 Data and Methodology 14](#_Toc115034293)

[3.1 Introduction 14](#_Toc115034294)

[3.2 Dataset Description 14](#_Toc115034295)

[3.3 Exploratory Data Analysis 15](#_Toc115034296)

[3.3.1 Distribution of Variables 15](#_Toc115034297)

[3.3.2 Missing Value Analysis 15](#_Toc115034298)

[3.3.3 Outlier Analysis 15](#_Toc115034299)

[3.3.4 Univariate Analysis 15](#_Toc115034300)

[3.3.5 Relation with Target Variable 15](#_Toc115034301)

[3.3.6 Distribution of variables with respect to Temperature 15](#_Toc115034302)

[3.3.7 Probability Distribution using KDE 15](#_Toc115034303)

[3.4 Methods 15](#_Toc115034304)

[3.4.1 Data Split 15](#_Toc115034305)

[3.4.2 Encoding 15](#_Toc115034306)

[3.4.3 Implementation 15](#_Toc115034307)

[3.5 Model Results 16](#_Toc115034308)

[3.5.1 Baselines 16](#_Toc115034309)

[3.5.2 Model Results 16](#_Toc115034310)

[3.6 Summary 16](#_Toc115034311)

[Conclusion 17](#_Toc115034312)

[Reference 17](#_Toc115034313)

# Introduction

'Weather' is a blanket term under which there are many components to consider. Be it the temperature, humidity, rainfall, air pressure, wind speed, wind direction, and a multitude of factors that play a role in the overall atmospheric conditions of a region, taking this into consideration; it is a safe assumption to say that it is improbable that the weather of a particular region is the same two days in a row. This makes it a challenge to predict the conditions one might face when actively taking part in an activity. It could be argued that the weather of a region is one of the essential features of the place's development in terms of infrastructure and the foundations of society. For example, if a site is prone to extremes in weather conditions that make it inhabitable by most communities, then obviously, the prosperity of that community living there is also severely affected. Weather is something that has an influence on all living beings daily and cannot be avoided or ignored under any circumstances. Thus, the underlying motive of weather forecasting could be considered one of the ways we can ensure the safety, evolution, and growth of the human species.

Weather forecasting is the science of predicting the weather of a particular region with the help of statistical principles and models that are based on significant and historical data about a place. This and the principles of physics that we know influence the weather combined are the foundational principles of weather forecasting. In most prediction models in weather forecasting, we must leave some room for error as it isn't feasible to assume an accurate prediction with no flaws, primarily because of the numerous factors that play a role in the weather. The data that we use tends to have significant factors, but there are multiple factors that could be directly correlated to the weather, such as geographical location, wind speed, moisture, air pressure, seasonality, and a wide range of subsequent features. Now there is a spectrum of variables that indirectly affect the weather, such as calamities like earthquakes, landslides, tsunamis, and other rare occurrences or phenomena that happen so rarely that they may be considered outliers and not considered whilst doing our analysis and predictions, which leads to less accurate results.

Science and technology have made a substantial improvement in this field, and so what we can expect is nothing short of sufficient in terms of predictions. Climate change is a phenomenon that is in direct correlation to weather and may be considered as the periodic modification of Earth's climate brought about as a result of changes in the atmosphere as well as interactions between the atmosphere and various other geologic, chemical, biological, and geographic factors within the Earth system (Jackson, S. T., 2017). Thus, the main aim of this report is to accurately interpret and predict the change in the average temperature of various regions in the world to determine a trend and estimate if the temperature of the planet is increasing or decreasing over time. This is significant and plays a vital role in the well-being of not just the human species but all the living beings on the planet. Ecosystems around the world, both marine as well as land-dwelling creatures as well as plants and microorganisms, live in a delicate balance with each other, and a tiny change in this ecosystem could cause detrimental damage to it. Thus, climate change growing at a rapid pace is dangerous and has already led to the extinction of multiple species that have been recorded.

It is hard to say the damage it has caused as we do know the possible undiscovered species and environments that have been damaged or destroyed. One this is for certain, and that is that climate change growing at such a rapid pace does not have any positive impact on our planet, and many studies have shown how climate change can directly lead to natural calamities such as the melting of the polar caps in the north pole which leads to the increase in the water levels of the planet which subsequently has led to many communities being displaced from their homes as the land has been captured by the ocean. This is just one of the infinite use cases that prove that climate change is real, and we use real-life data to come to our own conclusions as well. We use the average temperature of different cities across the world from the time period 1995 to 2019 and asses to see if there is an increase in the overall temperature or not; we do this using the average temperature of the place.

We implement various statistical data modelling techniques, such as time series analysis, long-term short memory, which is an application of artificial intelligence, and a few other models, after which we pass them through a few agnostic models that are specifically designed to test the interpretability of each model and check to see which gives us the best results. The dissertation may be broken down as follows.

Chapter 2 consists of a literature review and all the ways, methods, and techniques that have been used in the past to determine the weather forecasting and climate change calculations, followed by Chapter 3, which includes a description of the data we use as well as the methodologies implemented by us to determine our results and finally in chapter 4 we discuss the results and the conclusion we have come to and the significance it beholds.

# Literature review

As discussed in the introduction section, we can see that weather forecasting is essential not just for convenience but rather for the well-being and safety of a region. Climate change can be accurately measured with respect to changes in the temperature of a region over a period. There are various statistical techniques that have been implemented to determine the change in temperature as well as predict it. In this literature review, we are going to delve deep into the ways that it has been done in the past. We may also compare to see the most common methods used and their effectiveness. Using these techniques, we are able to compare and see the interpretability of each model as well as the statistical significance and accuracy they tend to produce. Some of the methodologies used are as follows.

## General Analysis and Pre-processing

This is usually the first stage of most projects, where we analyze the data to search for missing values, outliers, and any trends that may occur over a period. In the case where we use variables such as temperature, snowfall in cms, and amount of rainfall, which are numerical, we usually clean the data by either eliminating the missing values if they are insignificant, or we may also use the mean or median of the column to fill in the missing data from the previous and next day. There are various libraries in R and Python which are designed to combat this, such as MICE, tidyr, Pandas, and many more. As the temperature is primarily the variable that we used to determine this climate change, we see that in the analysis of climate change in Switzerland by M. Beniston et al. The evolution of daily minimum temperatures at the four stations from the beginning of the century to the end of 1992. Based on the daily temperature values, mean annual statistics have been established; a five-year running mean has been applied in order to filter out some of the high-frequency modes inherent to the inter-annual variability. (Beniston, M., Rebetez, M., Giorgi, F. , 1994). The temperature has a pattern that shows that it has increased by 2K over the year it has been observed. This, along with several other variables individually, is what the analysis was conducted on. Similarly, we see that M.S Shekhar et al., in the paper Climate-change studies in the western Himalayas used seasonal temperature over a significant period of time where they noted that the maximum temperature, as well as the minimum of the region, has increased by 2.8 degrees Celsius and 1 degree Celsius respectively. This, in turn, leads them to believe there will be anomalies in the other climatic conditions of the region, such as the snowfall in the region, and after careful analysis, they were able to see a significantly less amount of snowfall over the same period. It was observed that there was around 280 cm of snowfall less than the previous years. (Shekhar, M. S et al. (2010)). Another important feature of general analysis and preprocessing is to determine if two or more variables are correlated with each other in any way and try to spot any trends if possible. There are different ways that the correlation can be measured, such as Pearson's Correlation coefficient, which is used to quantify the linear relationship between two variables that are random in nature. (W. Xie, M. He et al., '2020') uses Pearson's correlation coefficient as well as Spearman's Rank coefficient to understand the type of relationship that exists between wildfire and drought severity, we let the random variable X denote the number of forest wildfires, and the random variable Y denote the Palmer Modified Drought Index (PMDI) which can be used to measure the drought severity. Using the formulas of each correlation coefficient, they observed that Pearson's correlation coefficient is 0.712. Spearman's correlation coefficient has a numerical value of -0. 714. These numerical results indicate that these two variables are highly correlated in this case study. The major drawback, in this case, is that sometimes we may find that the variables are not correlated with each other, which is why we need to conduct this analysis multiple times with different variables taken into consideration. The other major setback is that correlation does not necessarily mean causation. This means even if they are very much correlated, we cannot assume that they are dependent on each other in any way. Thus, further analysis must be done, and this can be considered the initial step of analysis in climate change forecasting but definitely not the final step of the process.

## 2.2 Time Series Analysis (ARIMA)

Models Time series analysis, to its name, is a statistical modelling technique that is used for analysis and prediction over a period of time. From the term climate change, we can see that change is a process that occurs over a period of time. Thus, this technique would seem apt for climate analysis. According to (Kaufmann, R.K. et al., '2016'), the evidence of the effect of human activity on the climate is mainly evident from two sources: The experiments run by climate models and also the statistical analysis of historical data. In general, there are various ways to analyze and predict data over a period of time, but the most common way to go about it is using the principle of Regression; the three most popular models that are used as AR, MA, and ARIMA models. These represent Auto-Regression, Moving Average, and Autoregressive Integrated Moving Average. These are of different orders and have different kappa values that are used to measure which is the best-fitted model for a particular dataset with respect to the time series. The Auto Arima function is used to determine which is a good model to fit, after which we can use the appropriate model to generate predictions. (Dmritri, T. Ahmad, S. et al. '2020') used the precipitation and the maximum as well as minimum temperature from the years 1901-2000 by monthly means to generate a time series dataset and conduct the analysis. They also fit a separate SARIMA model on the precipitation and temperature time series. They then did the following steps to make sure that they had the best model to fit the time series data to find an accurate and reliable prediction.

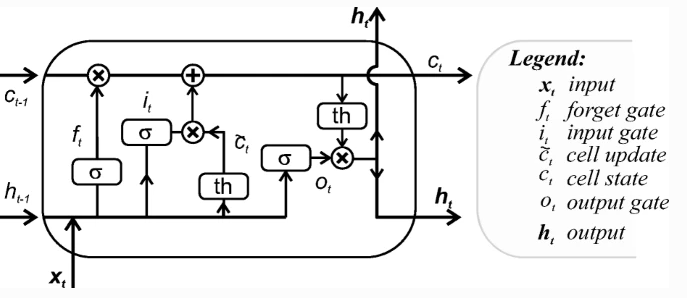
Initially, the first and foremost step was to determine which order of the series was best suited to make the series stationary. Different ARIMA models were fitted with different orders but had a constant coefficient. Now that the differenced series exists, it is considered to be stationary, although it may still have auto-correlated errors.

The next step undertaken was to identify the AR(p) and MR(q) components. This can be done by generating an Autocorrelation function (ACF) as well as a Partial Auto Correlation function (PACF) which can show us how well the present value of the series is related to that of the past values. By seeing if there is a sharp cutoff of the differenced series on the PACF graph, we can observe that AR needs to be added to the model, and if the same occurs on the ACF graph, we know that MA needs to be added to the model.

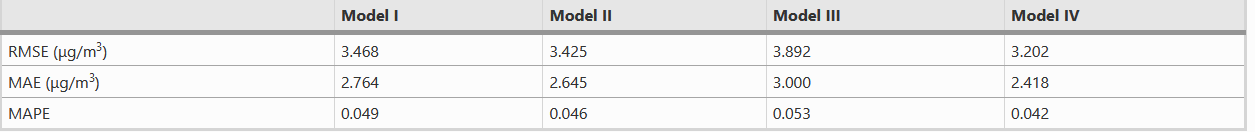
Following this, they have made some estimations using appropriate p,d, and q values which are fitted to the ARIMA models with appropriate residuals. Then the seasonality is removed for the models, and the best SARIMA model needs to be selected. After which, the forecasting is done, and the results are tested under the Akaike Information Criterion, which is an estimate of a constant and the relative distance between the unknown true likelihood and function of the data fitted on the model. Thus we can see that the lower the AIC value, the closer it is to the truth. Lower values indicate that the less information the model loses, the higher the quality of the model. The Bayesian Information Criterion (BIC) is also a criterion used with the same principle of the lower value, the better, and is based on the likelihood function. Using this method, they were able to observe the maximum and minimum temperature of the regions, respectively but also were able to forecast predictions for the precipitation, which showed a constant trend in values.

## 2.3 LSTM

Air Long term short memory is a type of Recurrent Neural Network which has a long-term dependency which means that it can retain information for a long period of time due to the internal memory it possesses. It is diagrammatically represented in figure 2.2, as shown below.



As we can see, the mechanics revolve around gates. Primarily these gates are comprised of gates, which are structures through which information is added or removed in the cell state; and also has weights Wj, where j signifies the state name. It contains sigmoid neural, σ, net layer, and a point-wise multiplication operation. The sigmoid layer is called a forget gate denoted by ft. This element decides what information will be thrown away from the cell state. Its decision is made by looking at xt and ht−1. It consists of two property values; one is the hidden state H(t) which is primarily responsible for the long-term memory, and the forget gate F(t) adjusts the connection of the input with that of the previous hidden state to the cell state, which then allows it to forget when needed (Pak, U. et al. 2018) In the prediction of ozone concentration uses LSTM and CNN models to determine the concentration by implementing the following methods. In the project undertaken by Pak, U. et al., they combine CNN and LTSM network in different ways to create four models which has a simple combination of the convolution layer and the layer of LSTM in different combinations, such that Model I is a simple combination of the convolutional layer with one layer of LSTM. Model II is a combination of the complete convolutional and pooling layers with one layer of LSTM. Model III is a combination of the convolutional layer with two layers of LSTM. Model IV is a combination of the complete convolutional and pooling layers with two layers of LSTM. They then run all four models with respect to RMSE, MAE, and MAPE, and we find that Model IV has the lowest values amongst the four, and thus we can figure that it is the best fit model for predicting the ozone concentration. As shown in the table below, we can see the values of Model 4 is much better than the rest on all accounts.



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## 2.4 ANN

Agent There are three types of neural networks: recurrent neural networks, multilayer neural networks, and single-layer neural networks. Feed-forward networks with a single layer: The information only moves forward in the network, where the neurons are stacked in layers. The output layers of computational neurons are referred to as the single layers.

Multilayer Feed-forward network: This is different from one layer in that it has one or more hidden layers. Since these layers don't directly communicate with each other, they are referred to as "hidden" in the network's perimeter because their values are not tracked during training.

Recurrent network: Its existence of feedback loops sets it apart from feed-forward neural networks. An example of a recurrent neural network would be neurons that send back their output signal to the input.

Artificial Neural Networks are based on the human brain. In an ANN, the nodes are mostly structured in layers. These layers come in three different types: input, hidden, and output. They are designed to take in a collection of inputs, carry out intricate calculations, and provide an output. The weight of each synapse makes up the ANN's collection of synapses. These weights (wjm) specify how the input will affect a neuron. An adder (additive junction) is a component of the ANN that contributes to adding the weighted signals. A selection criterion may be imposed by the adder based on the architecture. Among these conditions are minimum, maximum, average, and so forth (Kubat, M., 1999). The basic structural element of ANN is called perceptron, and the transfer function for neuron m is given by yj = ϕ(vj ) = ϕ Xm i=1 wjixj + bj ! with vj = z = Xm i=1 wjixj + bj where {x1, x2, .., xm ∈ R} represents the inputs, w1m, ..., wjm ∈ R are the respective weights of the m neuron. bj ∈ R is the bias that has the effect of increasing or decreasing the net input of the activation function. There exist different kinds of activation functions in machine learning, namely sigmoid, hyperbolic tangent (tanh), and rectified linear unit (ReLU) (Kubat, M., 1999). This is diagrammatically represented below in figure 2.1.

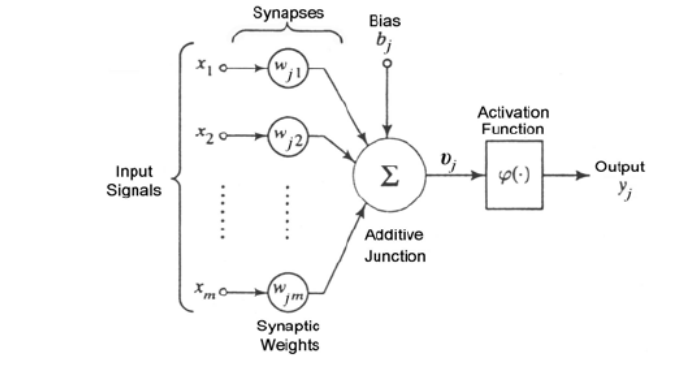


Figure 2.4.1 Artificial Neural Network Mechanics (Kubat, M., 1999)

(Chithra, N.R., Thampi, et al. '2015') used ANN-based models were developed for obtaining projections of monthly mean maximum and minimum temperatures at the station scale. The capability of the model was assessed by applying it to the Chaliyar river basin in Kerala, India. In the case of the prediction of T max, data pertaining to the predictors and the prediction were divided into three seasons, viz. dry period (January–May), wet period (June–November), and the month of December. Although in the case of the prediction of T min, they divided it into two seasons (wet and dry), and the networks were split and trained separately for each season. They used the correlation coefficient between the predictors and the predicted values. They found that the ANN model is feasible to downscale the climate data and generate appropriate results, which in this case was they found both the maximum as well as the minimum value have increased. The main drawback of this model and approach is that there is a certain level of uncertainty that may be present in the result. This could be combatted using ensemble models.

## RNN

## Statistical Significance Tests

## 2.7 Linear Regression

# Data and Methodology

The aim of Chapter 3 is to explore the dataset, understand all the latent and visible relationships and model on top of the data. This chapter will detail out the process of building out the models, along with the distribution of variables, missing value analysis, imputation of missing values, outlier analysis, univariate analysis and probability distribution. This analysis will help us understand the data. Post this, the focus will be on modelling the data to see what future trends will look like, we will use baseline as well as more advanced methods of timeseries analysis for the same. Interpretation of the results is key and we will summarize our learnings to bring a holistic end to Chapter 3.

## 3.1 Introduction

The primary objective of this project is to determine and predict the change in the surface temperature of the Earth. We use a felicitous dataset that has been obtained from the University of Dayton in the United States of America. Based on our learnings from the Literature Review performed in Chapter 2, we will work to build on top of the work done by authors of other papers. We will use baseline as well as advanced techniques leveraging a wide variety of models to ensure that the dataset exploration, analysis, modelling and interpretation is carried out in a holistic manner.

## 3.2 Dataset Description

The dataset that we will be using is from the University of Dayton, which has data from the year 1995 up to the 2019 and is regularly updated by the university. The National Climatic Data Center's Global Summary of the Day (GSOD) database serves as the files' primary source of information (NCDC). The Global Summary of the Day (GSOD) data's 24-hourly temperature observations are used to calculate the daily average temperatures. The dataset consists of eight columns, namely,

* **Region**: Information indicating the region from where the weather data is gathered
* **Country**: Indicative of the country from where the data has been gathered
* **State**: Indicative of the State from where the data has been gathered
* **City**: Indicative of the City from where the data has been gathered
* **Month**: This column indicates the month in which the data has been collected
* **Day**: This column indicates the day in which the data has been collected
* **Year**: This column indicates the ear in which the data has been collected
* **Average Temperature**: This data has been computed as a function of the average of 24 hourly readings from the Global Summary of the Day (GSOD) data

We have the data of over 324 cities which consist of 157 cities in the US and 167 cities from across the world. Since we are looking at data from 1995, we have 2,885,424 rows of information under these columns, this is a particularly large dataset, and thus we filter and sort out different regions and cities to conduct our analysis as an effective way to measure the average temperature and determine if it is changing over a period of time or not.

We see that the data that denotes the respective area in which we use as the basis of our analysis is found to be in the object format and the month, day, and year are integers where the average temperature is in float format as it has decimal values. There are very few missing values that can be easily rectified by using the mean of the previous and next day's temperatures, as it is an accurate assumption to make that the missing value is not too varied from the previous and next day in a season. There are a few outliers that were easily determined with the help of basic boxplots. Although the data is not perfect, and there may be a few discrepancies, we are able to clean it to the point where the dataset is suitable to carry out multiple different statistical calculations using machine learning and artificial intelligence algorithms to make predictions and forecasts.

## 3.3 Exploratory Data Analysis

In this section, we will explore the data from the National Climatic Data Center. We will analyze the distribution of the variables, perform missing value analysis, necessary transformations, feature engineering, outlier analysis and also look at the probability distribution using KDE. The data is 769 MB has 2.88 million rows. We perform the preliminary preprocessing such as typecasting the Month, Day and Year to integer and typecasting the average temperature to float to ensure that there is no discrepancy. In the next section let us go over the steps of preprocessing that have been carried out.

### 3.3.1 Preprocessing of the dataset

We start off by removing the ambiguous vales in the data frame that will not add value to the analysis. In the year column, we have values such as 200, 201 that do not make sense as it is not a valid year. We will also drop the State column, as it is specific to the United States of America, as it does not add value to the analysis and increases computation time. We will deal with different levels of aggregation for various visualizations in order to analyze the data that we will discuss in the proceeding sections.

### 3.3.2 Missing Value Analysis

We look at the percentage of missing values by grouping the data by country. Certain countries such as Burundi and Guyana have missing value percentages such as 80.5% and 57.8% respectively. These countries will not add value to the dataset, In general, we learn that there is missing data from the countries of Africa, Latin America and Asian countries. In the data dictionary, it is specified that missing values are indicated as -99, so we convert them to NaN (Not a Number), which is a NumPy data type to work better with the data. A sum of all of the missing values, there are 79,164 data points missing in the given data. We try to keep as much as the data possible by performing imputation of the missing values with the mean temperature of the same city and date from all the years. This exercise, in turn brings the missing values to 25,627 data points. Post this, we analyze the missing values by city to see what the feasible cities are we can analyze in detail. The rest of the missing values are imputed with the average overall mean temperature of the city. Now, the number of missing values is zero.

### 3.3.3 Distribution of Variables

It is critical that we analyze the distribution of the variables in a variety of permutations and combinations so that we have a good intuition of the data. In this sub-section, we will analyze what the distribution of the data looks like. First, we will look at the distribution of the yearly global average temperature in Figure 3.3.3.1. Note that the data present here is in degrees centigrade.

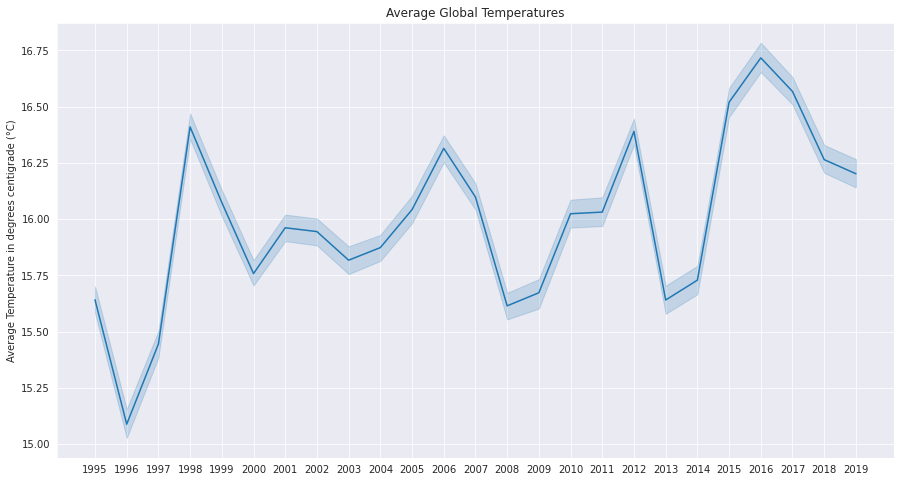


Figure 3.3.3.1: *Distribution* of average global temperatures by year

Here, we see varying trend across the years, but if we were to extrapolate the data, we see an increasing trend in the global average temperature. To further support our case study, we use the plotly express library to plot the temperatures via an interactive graph from 1995 to 2019. Let us now have a look at the extreme instances of the graphs.

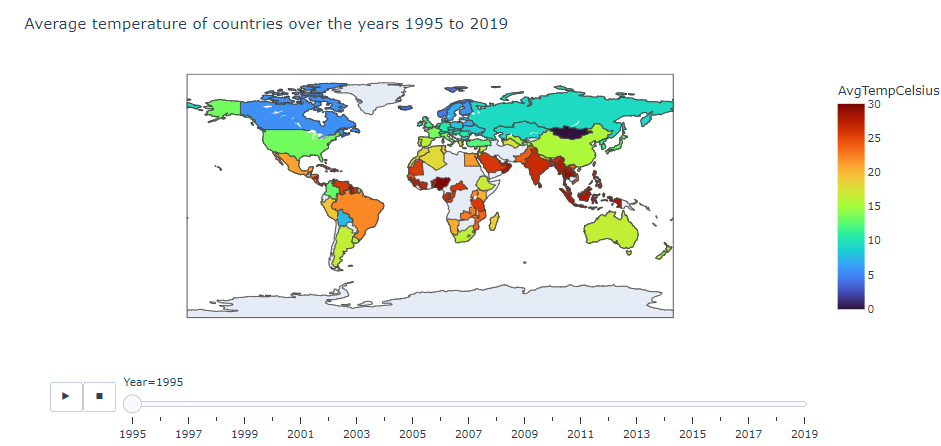


Figure 3.3.3.2: Plot of Average Temperature in the Year 1995 by Country

Here, in Figure 3.3.3.2, we have plotted the average temperature in the year 1995 in a graph of the globe. In Figure 3.3.3.3, we will now plot the average temperature in the year 2019. If our interpretation of Figure 3.3.3.1 is correct, we should see an increasing trend of global temperatures.

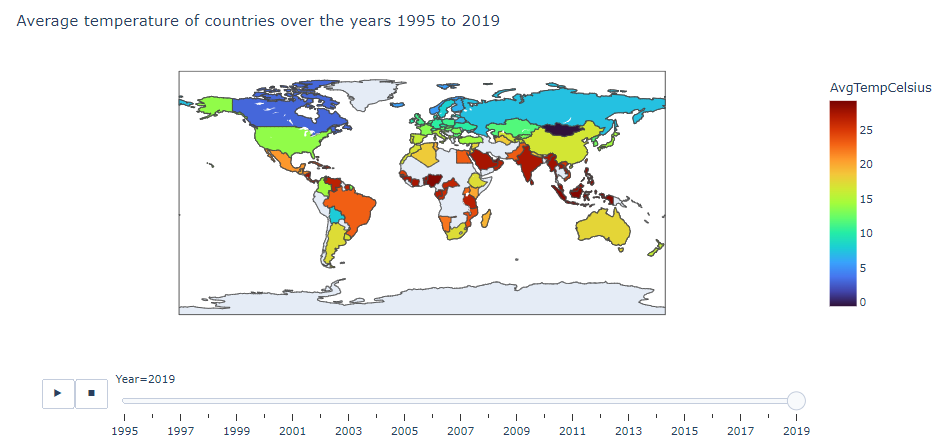


Figure 3.3.3.3: Plot of Average Temperature in the Year 2019 by Country

A lot of the temperatures that were in the range of 10-15 degrees centigrade have now moved to the 15-20 degrees centigrade and the hotter countries have now gotten even more hot. This indicates that our preliminary analysis was as expected. This can further be corroborated if we plot the average global temperature by month and year.

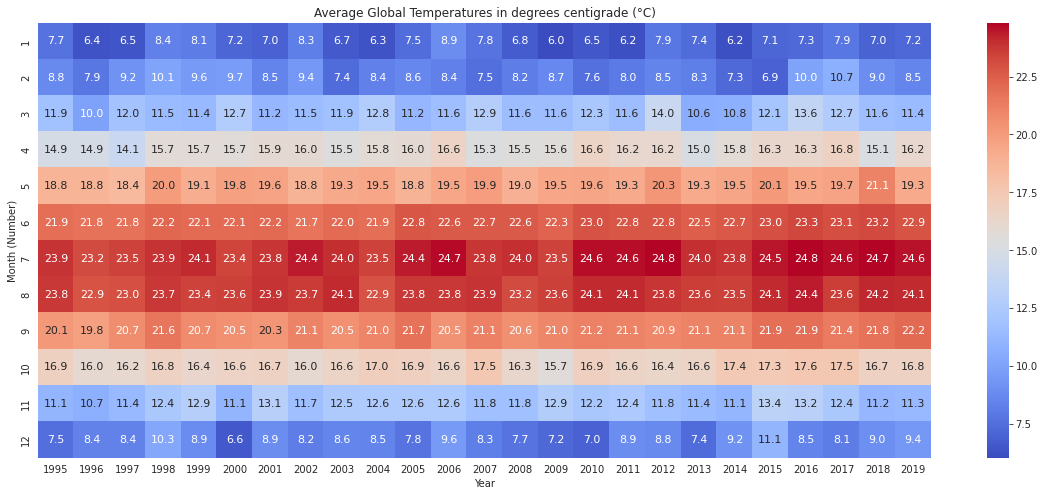


Figure 3.3.3.4: Plot of the Global Average Temperature by Month and Year

As we can see in Figure 3.3.3.4, the global average temperature has a gradual increasing trend in some months. Specifically, in month nine, September, we see that the global average temperature has moved up from 20.1 degrees centigrade to 22.2 degrees centigrade. Each degree increase in the global average temperature leads to the melting of ice caps, which leads to an increase in sea level. The phenomenon of global warming is further corroborated by the data that has been collected.

To further our understanding of the distribution of data by region, we can look at the average temperature across various regions. This will help us observe and learn more about the temperature trends across the globe.

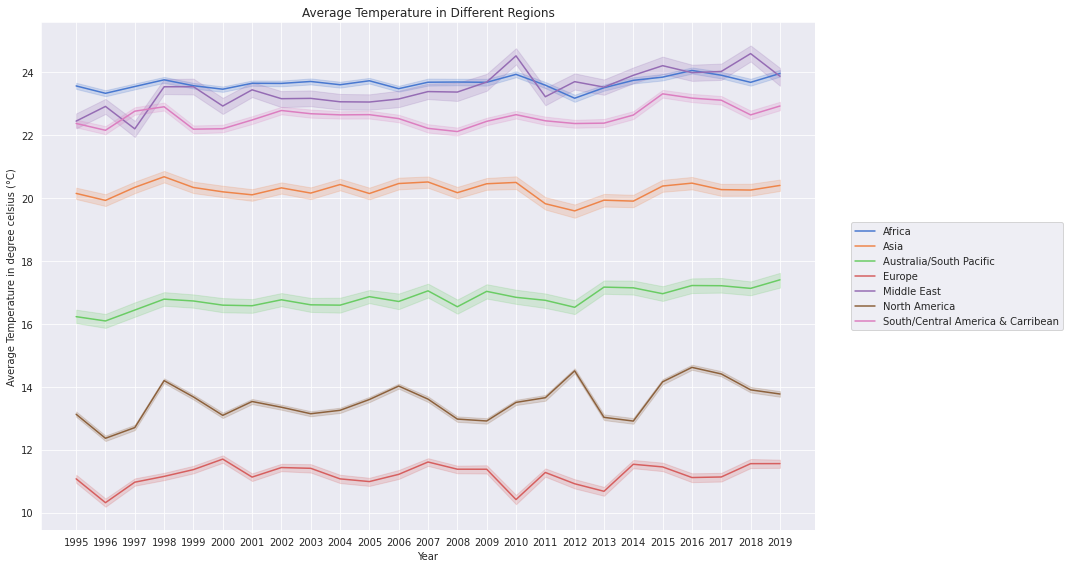


Figure 3.3.3.4: Plot of the Average Temperature in different regions across years

We interpret that the hottest regions are Africa and the Middle East, followed by the South/Central America and Caribbean region. From Figure 3.3.3.4, we also note that the coldest regions, as expected are Europe and North America.

### 3.3.4 Outlier Analysis

In this section, we will look at the distribution of average temperature. We will leverage box plots and plot the distribution of temperatures across 1995 to 2019, by region. Looking at global temperatures, on average, the temperature is expected to be less than 50 °C and more than -40 °C.

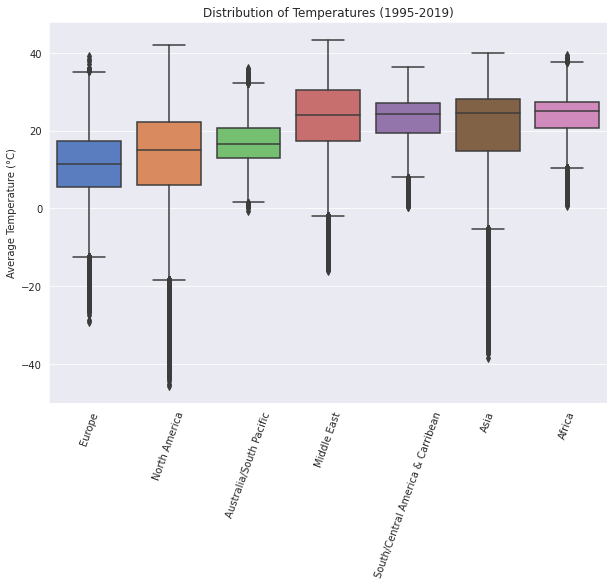


Figure 3.3.4.1: Box plot of the distribution of temperature   
by region across 1995 to 2019

Box plots give us an indication if there are outliers in the data. We will retain all of the points as they are in the acceptable range and these are real-world temperatures. It will not make sense to remove any rows, as we would like to perform a time series analysis. From the plot in Figure 3.3.4.1, we can see that North America and Asia have a wide range of average temperatures. Now, box plots give us an indication of the median temperature, which is shown by the line in the middle of the box. However, box plots do not give us a complete indication of the density or distribution of the points. We can understand more about the density and distribution by looking at the violin plot.

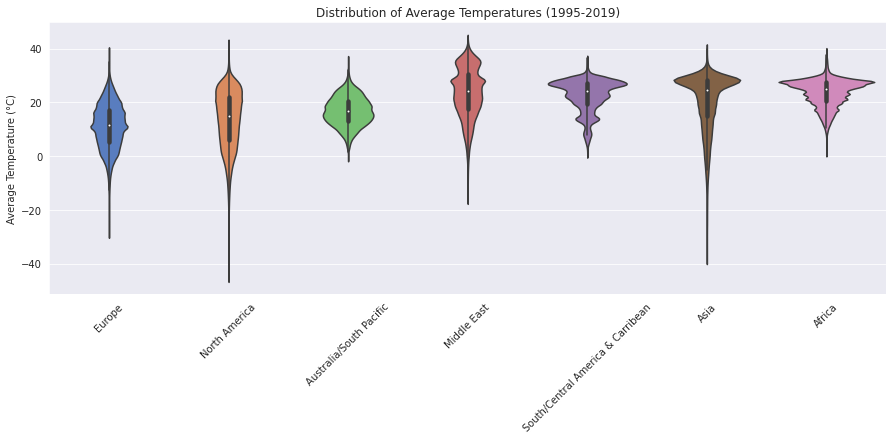


Figure 3.3.4.2: Violin plot of aver

### 3.3.5 Univariate Analysis

### 3.3.6 Relation with Target Variable

### 3.3.7 Distribution of variables with respect to Temperature

### Probability Distribution using KDE

## 3.4 Methods

### 3.4.1 Data Split

### 3.4.2 Encoding

### 3.4.3 Implementation

## 3.5 Model Results

### 3.5.1 Baselines

### 3.5.2 Model Results

## 3.6 Summary

## 

# Conclusion

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